PROCEEDINGS

"Transportation Recording: 2000 and Beyond"

International Symposium on Transportation Recorders

May 3-5, 1999
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TABLE OF CONTENTS

The papers in these proceedings were printed as received by the authors.

A Case for Higher Data Rates

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KEYWORDS

Aviation, Safety, Data-rate, Aircraft-Pilot Coupling.

INTRODUCTION

Flight data recorders required to support aviation accident investigations have benefited from numerous advances in recorder technology. These numerous technology advances for the most part have been directed at increasing the number of recorded parameters, improving the recording media, and improving reliability, maintainability, survivability and recovery characteristics. While these several aspects of the recorders have been improved, there has not been an associated increase in the once-per-second (1.0 Hz.) rate at which the flight data is recorded for accident analysis. This once-per-second rate has persisted in spite of the fact that technology advances could support much higher data rates, as demonstrated by rates of 20 to 100 data points per second (20 to 100 Hz) of current flight test data recordings. The need for a data rate above one data point per second evidently has not been conclusively established for accident analysis.

While the aviation accident rate is rewardingly low, the aviation accident rate has remained stubbornly unchanged for the past two decades in spite of the billions of dollars invested for safety improvement. The following review of the accident data for the most recent ten-year period for which data is available, may provide some insight as to a potential reason for our inability to further improve our aviation accident rate.

During the period from 1988 through 1997[1], the worldwide commercial jet fleet experienced 213 hull loss accidents. For 105 of these accidents, or 49% of the total accidents, the "flight crew" was listed as the primary causal factor. An additional 64 accidents, or 30%, listed "unknown" as the primary causal factor. These statistics indicate that nearly 80% of the hull loss accidents for the most recent ten year period are the results of causal factors for which there is incomplete understanding of exactly what problems need to be solved. Can there be a credible expectation for reducing the accident rate by 80% within ten years[2] when 80% of the causal factors aren't well understood.

The intent of this paper is to demonstrate the need, and argue for the establishment of data rate requirements at least an order of magnitude greater than today's requirements for selected parameters under particular conditions, and to describe the potential benefits that would be derived from the increased data rates.

THE NEED FOR HIGHER DATA RATES

The argument will be made as follows:

- A troubling, and often catastrophic phenomena causing temporary loss of control of the aircraft will be described,

1 Statistical Summary of Commercial Jet Airplane Accidents, Worldwide Operations, 1959 –1997, Boeing Commercial Airplane Group, June 1998
2 White House Commission on Aviation Safety and Security, Vice President Al Gore, Chairman, February 12, 1997

- Recent experiences of this specific control-loss phenomena will be presented,
- A flight test program to expose seven FAA certification pilots to the loss of control phenomena will be described.
- An analysis of the flight test results taken at a data rate of 20, 10, 4, and 1 data points per second to illustrate the degradation of the information content as the data rate is decreased. Associated with the degradation is the shift in the primary causal factor from an aircraft problem (correct answer) to a pilot problem (wrong answer).
- The paper will conclude with a brief projection of the potential benefits of increased flight recorder data rates on aviation accident statistics, and to the aviation safety program.

AIRCRAFT-PILOT COUPLING (APC) – A LOSS OF CONTROL PHENOMENA

Discordant Aircraft-Pilot Coupling is a loss of control phenomena resulting from dynamic distortion of the pilot-aircraft control system. The dynamic distortion will occur in two areas:

- in the information upon which the pilot judges the aircraft's response to his control input (the *feed back* loop)
- in the actual response of the aircraft to the pilot's control inputs (the *feed forward* loop)

The result of a small amount of dynamic distortion (for example, a delay of 0.1-0.2 second between the pilot's control input and the control surface output typical for today's aircraft) may cause a momentary loss of control during an aggressively flown recovery from an upset. The pilot's impression of this APC encounter will be that the incident may have been the result of an external disturbance, or pilot over control. From a hull loss perspective, such instances of momentary loss of control would be catastrophic only if there was contact with the ground or another aircraft, or the structural limits were exceeded. However, passenger discomfort/injury is likely, particularly if passengers are unbelted.

The results of substantial dynamic distortion (that is, a delay of greater than 0.2 of a second between the pilot's control input and the control surface output) can result in such discordant aircraft responses to the pilot's control input that the pilot becomes convinced that the control is broken. Substantial dynamic distortion is the result of the pilot "over driving" the cockpit control beyond the surface actuator (or software) rate limit and/or the control surface deflection (or software) limit. Such "over driving" might be expected during a flight saving recovery to counter a large upset in close proximity to the ground, or an impending mid air collision.

The tendency for pilots to experience the feeling that "the control system is broke" can be further exacerbated during moderate maneuvering by a degradation of the control surface actuator performance. This actuator performance available to the pilot will degrade from of the following:

1) reduced hydraulic pressure from a partial hydraulic system failure,
2) increased friction and flow restrictions caused by the actuator servo valve distortion,
3) depletion of the hydraulic pressure caused by the significant demands of other surfaces/systems.

RECENT APC EXPERIENCES

A partial listing[3] of recent aircraft that have recognized and reported APC events during development flight-testing is provided in the following table:

3 Aviation Safety and Pilot Control, Committee on the Effects of Aircraft-Pilot Coupling on Flight Safety, National Research Council, 1997, Table 1-2

Aircraft	Date	Description
B-777	1995[1]	Several varied events • pitch oscillation at touchdown • 3 Hz structural coupling • Pitch oscillation on take-off
B-2	1994	Approach, landing, aerial refueling
V-22	1994	Several varied events
C-17	1988-94	Several varied events
YF-22	1992[1]	Following aborted landing
JAS-39	1993	Low altitude flight demonstration
JAS-39	1990	During approach

Table 1. Recent APC Events

The above listed aircraft have several common factors:

- All employ a fly-by-wire control system,
- All used design guides derived from past experience to help design an aircraft with harmonious aircraft-pilot interaction,
- All extensively used ground-based flight simulation facilities as a tool to help design an aircraft with harmonious aircraft-pilot interaction, and several utilized in-flight simulation to complement the ground-based efforts,
- During the development process, all were specifically flight tested to discover any lingering APC tendencies,
- Yet every one of these aircraft did, after all of the above precautions, experience one or more APCs in subsequent flight testing,
- The identified design flaws contributing to the APC events, were satisfactorily corrected.

However, one of the more disturbing aspects of APC is that the chances of recognizing APC as a primary causal factor in an accident or incident are exceedingly low[4] without the higher data rates currently only utilized during the development flight testing.

AN APC EXPOSURE/TRAINING INITIATIVE

For two weeks this past December (1988), seven FAA certification test pilots and five flight-test engineers were involved in a concentrated APC training session conducted at the Calspan Flight Research Facility in Buffalo, NY. The training included lectures; ground based simulation, and in-flight simulation on a variable stability Learjet incorporating both a control column and a side stick. On several occasions during the actual flights, APC encounters resulted in loss of control of the aircraft in situations that could well have resulted in a crash. The crash was avoided by the Calspan safety pilot taking control of the aircraft. Control is taken by the safety pilot hitting a paddle switch on his stick, which disengages both the visiting pilot's controls, and the variable stability system.

A typical APC exposure task was a precision landing commenced from an offset approach as depicted in Figure 1:

4 Aviation Safety and Pilot Control, Committee on the Effects of Aircraft-Pilot Coupling on Flight Safety, National Research Council, 1997, Finding 3-2

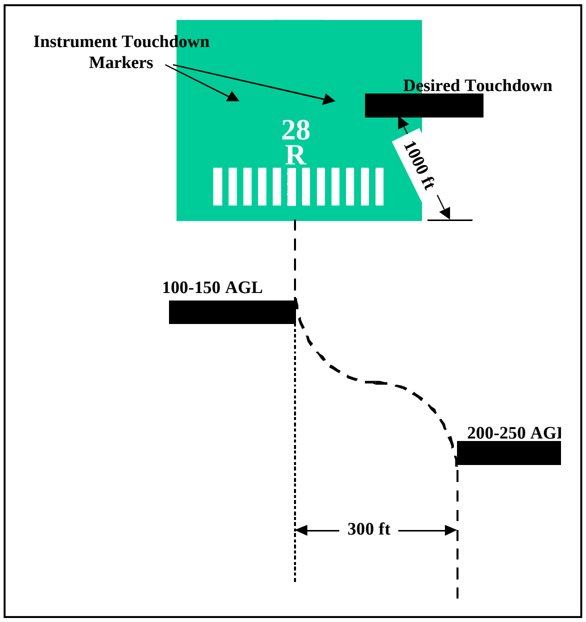

Figure 1. Offset Landing Task

An example data set for an offset approach is presented in Figure 2.

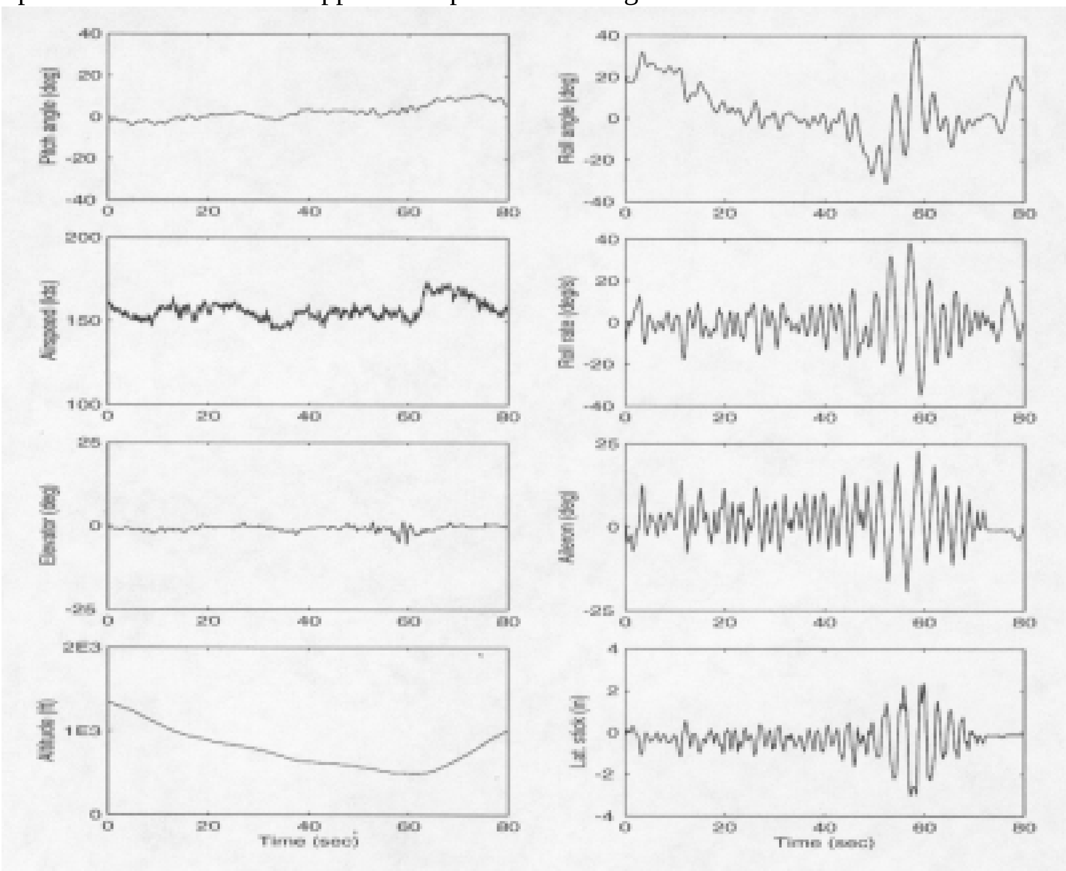

Figure 2. Time Histories of Offset Approach

APC DATA ANALYSIS

Data taken during the APC exposure and training flights are used to illustrate the critical importance of the higher data rates to establish the primary causal factor in accident investigations involving APC. The data are taken from one of the offset approaches for which control was lost. An accident was averted by the safety pilot taking control of the aircraft. Parameters were recorded at a data rate of 20 data points per second, or 20 times the usual data rate available to accident investigators. This 20 data points per second rate is on the low side of most of the data rates used during the development flight testing which recognized the APC experiences in the previous section. Over sixty flight parameters were recorded during the APC exposure. However, only two parameters are needed to address the dominant cause of the more currently recognized APC. Specifically, only an examination is required of the pilot's input at the cockpit controls, and the associated control surface response, which are shown in the Figure 3.

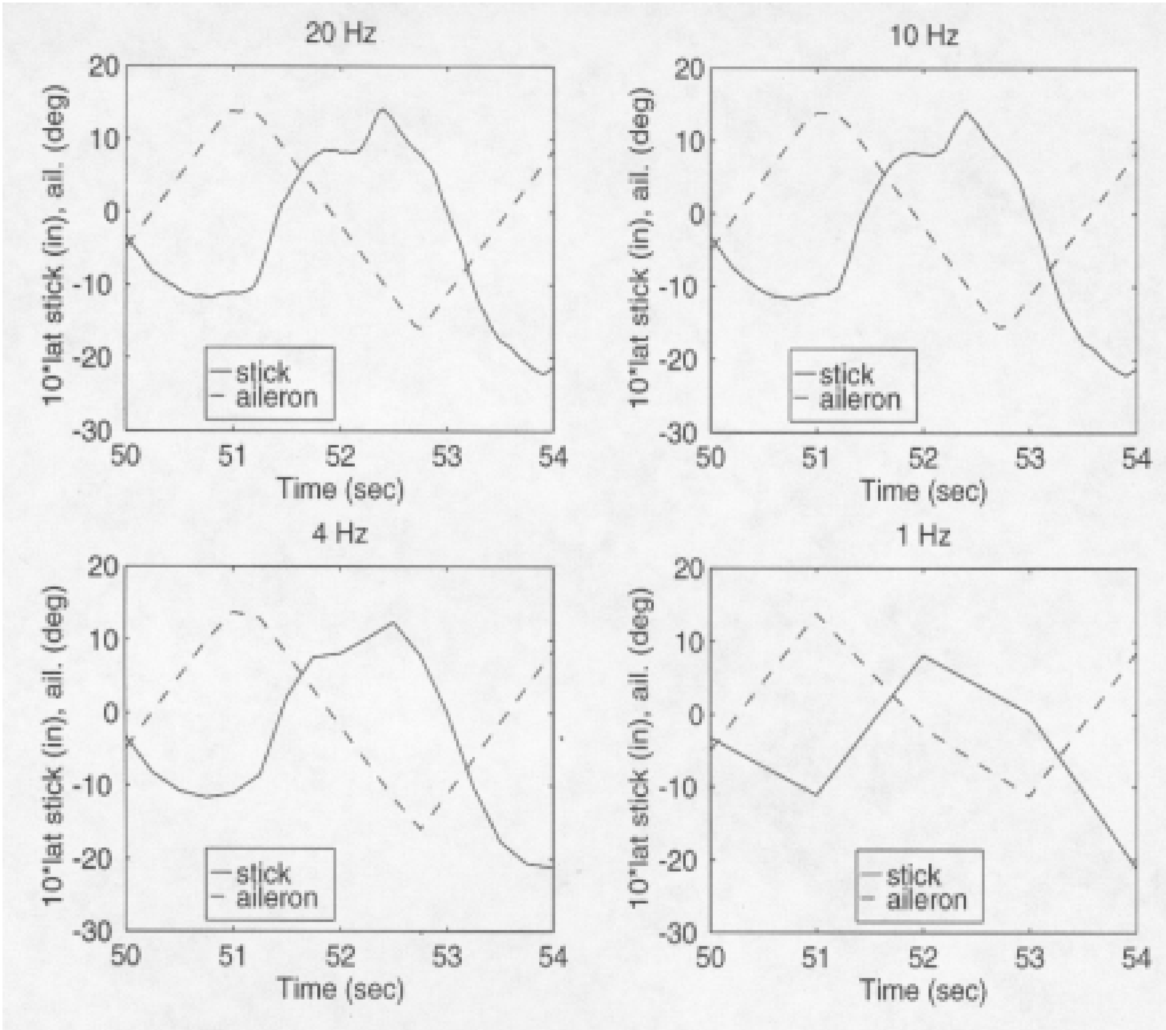

Figure 3. Pilot Input and Surface Output Time Histories

The time delays that can be determined from this Figure 3 flight data as a function of the recording rate are as follows:

Time Delay - milliseconds	Data Rate –Hz.
350	20
300	10
250	4
0	1

Table 2. Time Delays Extracted from Figure 3 Time Histories

The identical data set from the same time history, plotted at data rates of 20, 10, 4 and 1 Hz are shown in Figure 3, with the associated time delays that would be read from those figures listed in Table 2. The ability to consistently discern the magnitude of the time-delay is shown in Figure 3 and the associated Table 2 listing of time delays to substantially degrade with the lower data rates. Note that there is no discernable/measurable time delay at the 1.0 Hz data rate currently exercised on most flight data recorders.

APC DATA SENSITIVITY

In an effort to put this 350 msec time delay in perspective, and to stress the implications of overlooking a 350 msec time delay, a review of the guidance given for the design of military aircraft is warranted. As early as 1980, military specifications stated[5] that *the response of the airplane motion to a pilot-initiated step control force input shall not exhibit a time delay longer than the following*:

TABLE XIV. Allowable airplane response delay

Level	Allowable Delay ~ Seconds
1	0.10
2	0.20
3	0.25

Table 3. From Paragraph 3.5.3 of Military Specification MIL-F-8785C

… where the Levels 1, 2 and 3 reflect "*adequate for mission completion*", "*increased pilot workload/mission degradation*", and "*excessive pilot workload/inadequate mission effectiveness*", respectively.

From the Figure 3 time history recorded at 20 Hz, the time delay between the pilot's input and the associated control surface output would be the 350 msec, as listed in Table 2. . This 350 msec time delay is well in excess of the 0.10 to 0.15 seconds delay that is generally accepted currently[6,7] as the upper limit to prevent a time-delay induced APC. Further, 350 msec is greater than the maximum allowable time delay that the military would tolerate, as indicated by the Level 3 value of 0.25 seconds of Table 3, recognizing that "excessive pilot workload/inadequate mission effectiveness" would be the consequences.

Based on the time histories of Figure 3 and the associated apparent time delays of Table 2, all of the data rates above one Hz. flag the presence of a very significant time delay, i.e., equal to, or larger than, the maximum tolerable Level 3 value of Table 3. Whether this very significant time delay is 250, or 300, or 350 msec is relatively immaterial – what is important is that a large time delay has been identified. But what if the time delay is a smaller value? If the value of the time is to be measured with an accuracy 50 msec, so that investigators can discriminate between an arguably acceptable time delay value of 150 msec and a potentially dangerous value of 200 msec, then the case is made that a 20 Hz rate is required.

POTENTIAL AVIATION SAFETY BENNEFIT

Because APC continues to be unrecognized as a causal factor in operational accidents and incidents, there is little room for credibly projecting a specific reduction of aviation accident rates resulting from providing the capability of determining whether APC is, or is not a causal factor. However, the accident statistics indicating that 50% of the accidents involved "*crew error*" as the causal factor is a large target, as APC could be an unrecognized significant contributor, but the blame is being put on the crew. Likewise, the 30% of the accidents having the primary causal factor "*unknown*" could be harboring a substantial number of APC experiences. Further, the consistent inability of the current complement of analytical tools, design criteria, flight simulation testing, and dedicated flight testing to ferret out adverse

5 Military Specification Flying Qualities of Piloted Aircraft, MIL –F-8785C, 5 N0vember 1980
6 Unified Criteria for Active Control Technology Aircraft Longitudinal Dynamics, Roger Hoh, AGARD AR 335, Paper #4, February 1995
7 Proposed Time Delay Limits for Digital Fly-By-Wire Transports in Precision Landings, David Klyde et al, STI TR-1284-1, May 1993

APC characteristics to such an extent as to preclude a subsequent APC surprise, reinforces the wisdom of identifying a potential APC problem.

CONCLUSIONS

An order of magnitude increase in the data rates utilized for accident investigations is required to establish that APC is, or is not, a primary causal factor. Once APC is recognized as being a causal factor, there are available numerous solutions, as clearly indicated by the many aircraft, such as those listed in Table 1 that have been modified to correct APC difficulties recognized during development. Fixing the pilot is not one of the solutions, but that is the default thinking when a latent design problem goes unrecognized.

ACKNOWLEDGEMENTS

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BIOGRAPHIES

Ralph A'Harrah is the Goal Manager for NASA's Aviation Safety Program at NASA Headquarters in Washington, DC, where he has been a member of technical staff since 1989. The previous 25 years with the Navy, serving in various capacities with the Naval Air Systems Command, the Naval Air Development Center, and the Office of Naval Research. The previous 15 years he served in various research and development roles at North American Aviation, in Columbus, Ohio, following his graduation from the Pennsylvania State University in 1955. Mr. A'Harrah has published 24 technical papers on the subjects of aircraft flying qualities, flight controls, flight simulation and Aircraft-Pilot Coupling; he has served as a technical consultant to the Advisory Group for Aerospace Research and Development (AGARD) of NATO, and to the US Air Force; he has served as Chairman of the Flight Mechanics Panel of AGARD; and is a member of the SAE Guidance and Control Committee.

George Kaseote is the Program Manager of digital flight Data Recorders and Cockpit Voice Recorders for the FAA Aircraft certification Service. He is a test pilot, chair of the Flight Test Technical Committee, member of the Flight Program Oversight Committee, course manager for the FAA Flight Test Pilot/Engineer courses taught by the National Pilot School at Mojave, CA. Prior to joining the FAA in 1990, he was one of three Navy test pilots that conducted the Navy Preliminary Evaluation and two Board of Inspection and Survey trials on the then North American RA-5C (Vigilante) aircraft. He flew that aircraft at twice the speed of sound in 1962, a mere 37 years ago. During his periods of furlough from Pan American World Airways, he was Chief Test Pilot at Lock Haven, PA where he made the fist flight in the PA-41 aircraft, Director of Flight Operations at the Falcon Jet Corporation where he conducted the first flight on the U.S. Coast Guard's HU-25A Falcon aircraft. George has experienced APC events in 4 different airplanes besides those in the Calspan Variable Stability Learjet-25.

The Use Of Deployable Flight Recorders in Dual Combi Recorder Installations

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KEYWORDS

Aviation, Recorders, Deployable, Standards

INTRODUCTION

Flight Data Recorders (FDR's), Cockpit Voice Recorders (CVR's) and Emergency Locator Transmitters (ELT's) have been combined into a single deployable unit and used successfully on military aircraft for decades. Their proven survival strategy, of deploying away from the aircraft and hence the crash site**,** allows for quick location and economical recovery of recorder information, particularly in marine incidents, where the floating recorders can readily be retrieved from the surface of the ocean.

Changes in the needs of accident investigators, and in aircraft use, application, performance monitoring, routing, and avionics have resulted in the current initiatives underway to revise aviation recorder standards. The deliberations of EUROCAE Working Group 50 and the discussions of the group preparing the new AEEC standard of ARINC 767 are airing some radically new concepts in flight recorder requirements and configurations. These include the use of a pair of redundant recorders each storing both Cockpit Voice, Flight Data, and requirements for digital communications and video storage.

In this process of reviewing, revising and adding to airborne recorder standards, there is reason to evaluate the use of deployable recorders on civilian aircraft. An opportunity has arisen for the use of a deployable recorder as the alternate recorder in dual redundant recorder installations. This combination of recorder memory media protection schemes would provide the best of both worlds of fixed and deployable survivability strategies.

As the new EUROCAE specifications pass from embryonic concepts to regulation it is important that matching airworthiness standards levied by the FAA, JAA and other authorities continue to include standards for deployables. Definition and regulation of requirements for deployables, such as those included in the performance specifications being drafted by Working Group 50, would allow the option for the use of a fixed and deployable combined recorder installation on civil aircraft.

DEPLOYABLE RECORDERS AND BEACONS

The deployable recorder is an alternative concept to the survivability design of airborne recorder systems, which would include Flight Data Recorder and Cockpit Voice Recorders (CVR/FDR) technologies. The CVR/FDR must survive highly destructive forces over a broad range of accident scenarios. The conventional "fixed" or crash hardened design concept is an ATR type container constructed to withstand the severest crash scenarios while installed inside the airframe. This construction endures severe impact, fire, and other forces of a crash by enclosing the recorder memory

medium in a protective enclosure. These units are installed toward the rear of the aircraft in order to "ride through" an accident.
The deployable design concept has the recording medium housed within an assembly (the beacon) which deploys and falls away from the aircraft thus avoiding the crash environment. One conventional means of accomplishing beacon deployment is to place the recording medium in an aerodynamic lifting body or airfoil which is affixed to the exterior of the airframe. Crash sensors activate a release mechanism which automatically releases the airfoil during an accident, delivering it safely away from the aircraft impact site. This same concept is also used with some classes of Emergency Locator Transmitters, with the primary objective being the rapid identification of an accident site and quick recovery of survivors. A deployable CVR/FDR recorder typically includes an ELT to provide an alert to Search and Rescue authorities of the crash and to allow homing in to the distress signal frequency and thus allowing the finding of the crash site and the recorder. The high location identification precision of 406 MHZ GPS position encoding equipped units allows identification of the beacon position to within a 25 meter accuracy.

The objective is for each type of recorder to achieve maximum survivability of the recorded information. Survivability of the memory storage media ensures that the information is retained and the consequent analysis of this data allows corrective action be taken to prevent accidents recurring and improve the safety of future aircraft operations.

HOW DEPLOYABLES STARTED

In the early 1960's, concerns were raised in Canada on the means available for the location of downed aircraft in the vast and remote parts of its country. A study by the National Research Council of Canada suggested that some form of detachable and automatically activated ELT system would be desirable. A patent was issued for the concept of an airfoil attached to the skin of an aircraft which, when deployed at impact, entered the airstream and attained high lift allowing it to clear the airframe and then tumble to a much less severe impact away from the accident site.

Figure 1: DFIRS Deployable Airfoil For F/A18

Subsequently deployable systems were developed for a wide variety of fixed and rotary wing aircraft types ranging from small general aviation aircraft to large transports. During the 1970's, for example, the U.S. Air Force operated over 3000 aircraft with deployable systems. Similar systems were also developed and fielded for use on helicopters and were later adopted as part of a CAA mandatory requirement on helicopters operating offshore, typically in North Sea oil operations. In parallel with the deployable ELT development, at that time concerns were being expressed about the survivability and recoverability of existing fixed FDR and CVR systems, since many recorders were either totally destroyed or never recovered after an accident. Consequently, the solution of placing the FDR / CVR recording system inside the deployable airfoil unit was adopted. Technology advancements permitted installation of such a capability on high performance fighters such as the F-104, Tornado and F/A-18.Refer to Figure 1. The introduction of new materials and aerodynamic analysis has allowed deployable systems to become smaller, lighter, and less expensive; but of greatest benefit is increased reliability and survivability of the system.

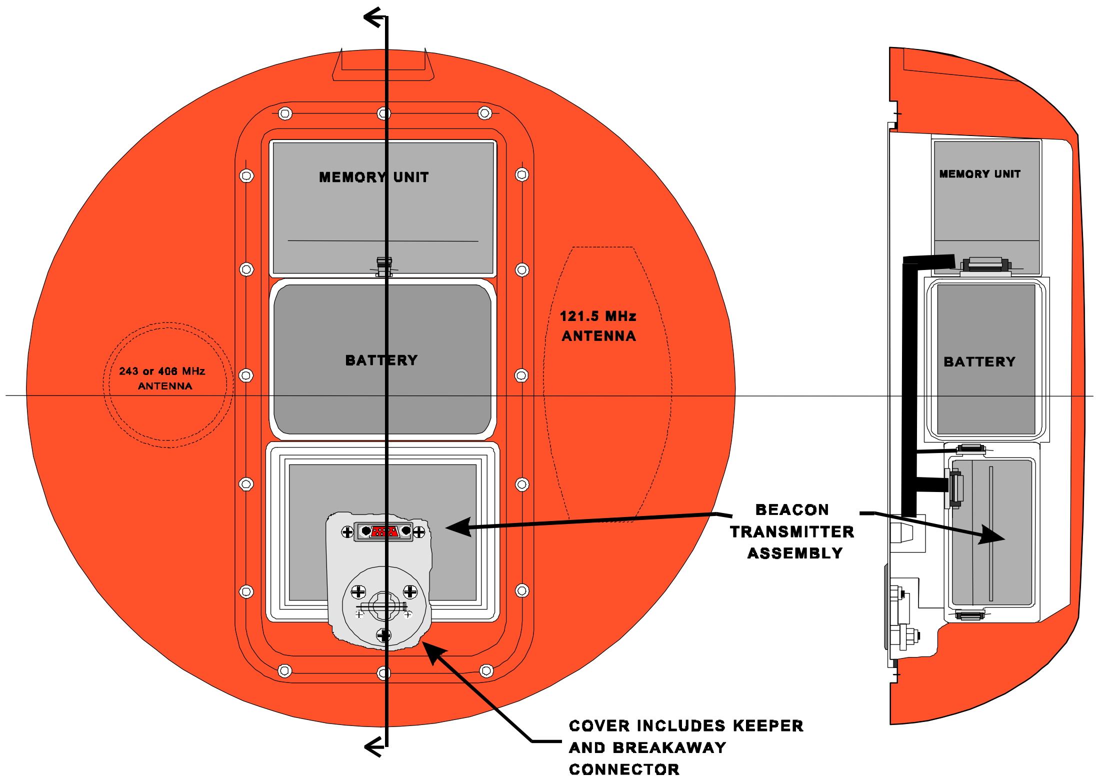


Figure 2: Internal View of Deployable For Use On Helicopters

DEPLOYABLE RECOVERABILITY

The purpose of a combined FDR/CVR/ELT is to provide survivable and recoverable information while at the same time providing immediate notification and location of the accident site for Search and Rescue operations. Location and recovery of a fixed crash hardened system is frequently difficult, time consuming and expensive, particularly in water. Valuable time can be lost when a conventional emergency locator transmitter is either not being carried in the aircraft or fails to operate.

In many deep water accidents, even with an underwater acoustic locator beacon installed, location and recovery is complicated as well as expensive. There are many cases where tremendous effort and resources have been expended over many months to locate aircraft wreckage and recorders. In many instances, nothing was ever recovered.
A deployable CVR/FDR/ELB system addresses and solves all of these concerns. In crash investigations to date using deployables, in greater than 95% of the cases deployable systems have been recovered in pristine condition or with only superficial damage. In situations such as impact at a high angle of

incidence, where the time from initiation of deployment to impact of the airfoil is reduced, the airfoil also includes conventional crash survivability protection means allowing it to be able to withstand high levels of fire and impact. Whatever the scenario, the deployable package is mounted on the exterior of the airframe and actual experience has demonstrated that it remains at the outer edges of the crash site, significantly reducing exposure to the crash environment.

ACTIVATION

Deployment is typically initiated by a sensor system that is activated by impact or immersion in water. Frangible switches can be located in critical areas of the airframe and provide the deploy command upon deformation as the aircraft begins to crush at impact. A hydrostatic pressure switch will initiate the deployment when the aircraft sinks following a soft ditching when no frangible switches have broken. The sensors provide a signal to the release mechanism so enabling deployment. Under normal operation this mechanism secures the deployable unit to the aircraft. The beacon transmitter is automatically activated upon initiation of the deployment sequence.

DEPLOYMENT

The DRS design involves one of the airfoil attachment points being released by a low energy gas pressure cartridge that permits a small spring to begin moving the airfoil away from its mount. The airfoil then uses the energy imparted by the airstream to continue releasing. This allows deployment in a benign manner during normal operation. Upon automatic release, the deployable airfoil unit assumes its own flight characteristics independent of the aircraft. The airfoil immediately begins to decelerate to an impact level well below that of the impacting airframe. With fixed wing aircraft, depending on attitude and airspeed, the airfoil may fly several hundred feet before landing. For helicopters, it will tumble away and land outside, or on the periphery of the impact site. When in water the airfoil will float indefinitely. In all cases its highly reliable transmitter will broadcast a radio distress signal regardless of where it has come to rest.

DEPLOYABLES	**FIXED-ON BOARD**
Radio beacon locator capability	Underwater pinger only - no locator on land
Ease of recovery on land - survives impact away from wreckage	Requires additional time to remove from wreckage
Ease of recovery on water - airfoil floats	High cost of underwater recovery - if located
Weight advantage - lighter	Weight disadvantage

Table 1: Advantages of Deployable over Fixed On-board Recorders

UPCOMING CHANGES IN FLIGHT RECORDER STANDARDS

The current discussion on changes in desired flight recorder standards opens the forum for alternate applications of the deployable recorder concept. The ICAO meeting in Montreal in November 1998 made a number of recommendations on changes to recorder performance that ICAO would require its member countries to adopt over the next decade. These changes, along with others currently in place, will inevitably require aircraft operators to upgrade or replace their existing flight recorder systems. The following table outlines the nature and timing of the changes being planned

Authority	**Change**	**Planned Implementation Date**
ICAO	Recording of Digital Communications	Jan 1 2005
ICAO	Self contained 10 minute backup power supply for CVR Area channel	under review, 2005 estimated
ICAO	Two Hour CVR's standard for new aircraft	Jan 1 2003
ICAO	Video recording capability	under review
ICAO	Magnetic tape recorders to be phased out	2005
NTSB	Use of dual combi recorders with above features (less video) on new aircraft	Jan 1 2003
NTSB	Retrofit of all aircraft to use of dual combis with above features (less video)	Jan 1 2005
EUROCAE	Preparing replacement of ED 55 and 56A with single new MOPs including video and digital message recording	To be determined, approximately 2005
AEEC	Preparing new standard ARINC 767 for dual combined recorder	To be determined, approximately 2005
FAA	Part 121 revision to DFDR systems, 88 parameters	Aug 19 2002 on new aircraft

Table 2: Upcoming Changes to Standards

In this environment of change, which could result in a potential requirement to upgrade or replace thousands of recorders, the various authorities are reviewing every aspect of FDR and CVR requirements to ensure that the ensuing generation of recorders will better meet the needs of investigators. At the same time they recognise the need for the changes to be affordable to aircraft operators.

One observation that can be made is that due to the nature of the process changes are, by in large, reactive to recent incidents, and it is difficult to put in place requirements for anticipated occurrences, however likely, if there is not the precedence of an actual example incident.

THE DUAL COMBINED RECORDERS CONCEPT

The use of two combined "dual combi" recorders including CVR and FDR capability is being recommended by ICAO for use on new aircraft in the "medium term". Combined recorders are currently built to meet the recorder requirements of large helicopters and it is generally acceptable by airworthiness authorities to use two combined recorders on fixed wing aircraft, where one meets the regulatory requirements for a CVR and the other, for FDR. Figure 3 shows a block diagram of a dual combi installation using a common data acquisition unit and two multi-purpose recorder memory modules.

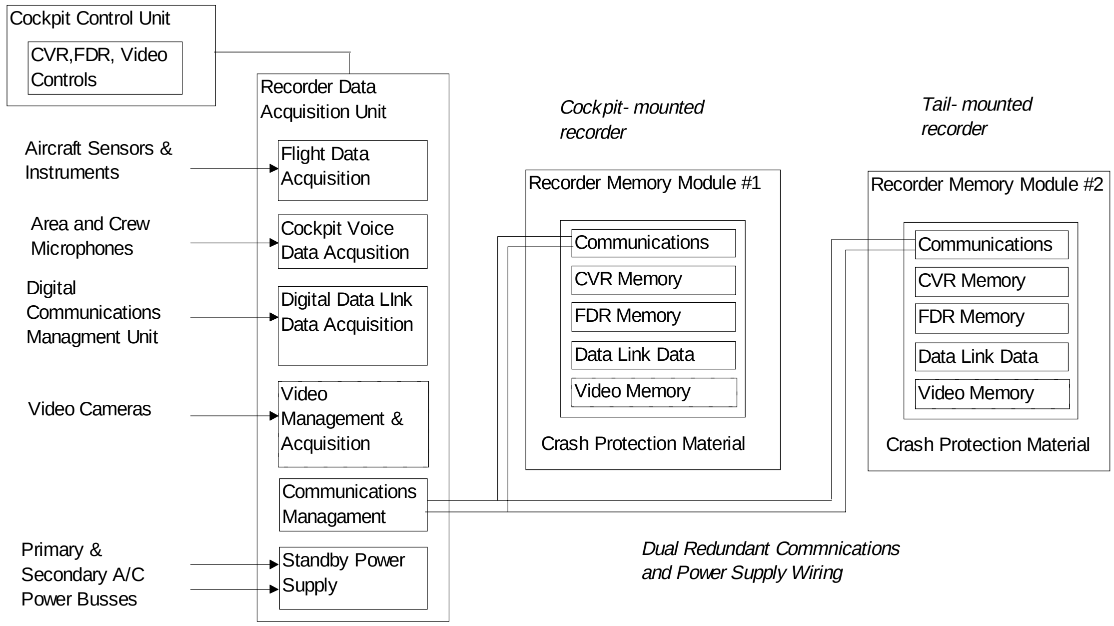


Figure 3: Dual Combined Recorder Block Diagram

EUROCAE WORKING GROUP 50

EUROCAE Working Group 50 is in the course of preparing a new standard to align the requirements of ED-55 with ED 56A. ED-55 is the Minimum Operational Performance Specification for Flight Data Recorders, which is the foundation document for both European and north American Flight Data Recorders. This new document will also replace ED-56A, the Minimum Operational Performance Specification for Cockpit Voice Recorders.

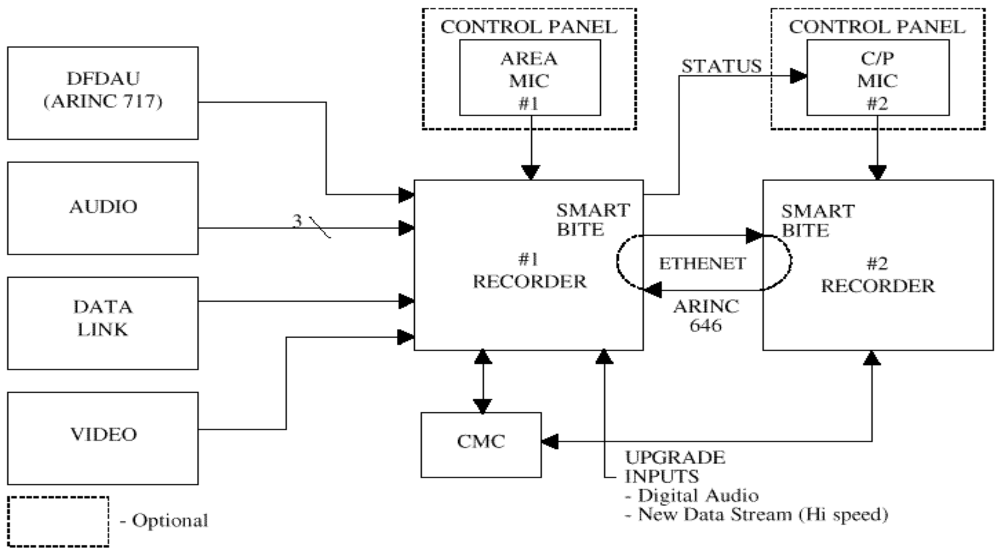
The new document will integrate the two requirements and will add the requirements for cockpit video recording and recording of digital message communications to and from the aircraft. The document will include a section defining the environmental and survivability requirements for the memory medium, which will apply regardless of what type of data is stored in it. It will also include requirements for deployable recorder performance.

The document will also reflect the recommendations of ICAO and FAA in terms of enhanced record times, additional power supplies, and enhanced FDR parameter sets.

THE AIRLINES ELECTRONIC ENGINEERING COMMITTEE DFDR PROJECT PAPER 767

The Airlines Electronic Engineering Committee Digital Flight Data Recorder (DFDR) subcommittee is now working on Project Paper 767, for a Digital Data and Voice Recorder (DDVR). They are now preparing their second draft of this standard, first released in March, 1998. The AEEC have considered it timely to prepare an entirely new standard for Flight Data Recorders, and for the first time in decades are proposing a radically new architecture that is not an enhancement of previous standards and largely reverse compatible to existing installations. Although the AEEC does not set standards for recorder performance or survivability their specification of recorder architecture and interfaces profoundly influences the industry.

The draft ARINC 767 architecture includes two data storage modules where primarily CVR and FDR data is stored, but potentially also video and data linking information. Figure 3 shows one concept proposed by the sub-committee for the ARINC 767 recorder architecture.



Proposed Data and Voice Recorder Architecture

Figure 4: Draft ARINC 767 Recorder Architecture

INTEGRATED DEPLOYABLE AND FIXED COMBINED RECORDER SYSTEMS

It is planned that dual combined recorder systems will achieve enhanced survivability by locating one recorder in the cockpit area and the other towards the rear of the aircraft. The rational for this being based on observations at crash sites where it has been rarely seen that both sections of the aircraft receive the brunt of a crash impact.

The integrated deployable and fixed recorder concept would have the tail recorder provided with the ability to deploy from the aircraft under certain ejection criteria, the primary one being the immersion of the recorder in water below a certain depth. This release capability would facilitate the prompt recovery of the recorder in the event of an over water crash event. The standards for the fixed and deployable components of the system should be compatible to optimize the probability of recovery of recorder information from one of the two systems under any conceivable crash scenario**.**

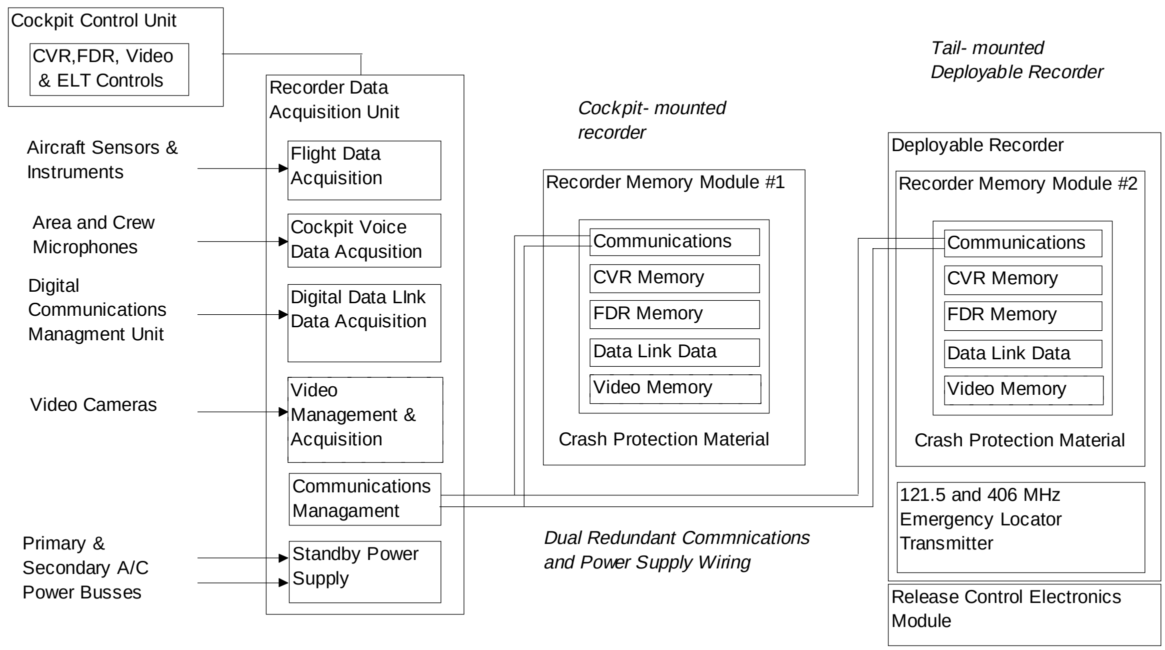


Figure 5: Integrated Deployable and Fixed Airborne Recorder System

NEW REASONS FOR DEPLOYABLE APPLICATIONS

The following provides examples of why the use of deployable recorders need to be considered in light of new developments in air travel and accident investigation.

THE NEED FOR PROMPT ACCESS TO RECORDER DATA

A number of recent major air tragedies in North America have resulted in the loss of aircraft in ocean or swamps, and recorder recovery has taken from days to months:

Incident	Nature of crash
ValuJet Flight 592	Swamp impact
TWA flight 800	Midair explosion over the ocean
Swissair flight 111	High speed impact with ocean
Air india	Midair explosion over the ocean
Korean Airlines	Shot down into ocean
Dominican Republic	Impact into ocean

Table 3: Recent Ocean Incident Recorder Recovery Times

The slow recovery of recorder information, in some instances, has resulted in a lot of pressure being placed on authorities while awaiting recorder retrieval. In turn demand for corrective measures has arisen, some typical concerns being:

What if the event had been a terrorist incident?

> The nature of terrorism is that it tends to be repeated, and is vital that any possibility of its occurrence be confirmed promptly and appropriate measures be taken. For some time after the TWA event there was intense speculation as to its cause. The prompt recovery of recorder data, which would have been more likely with a deployable in a maritime incident, could have made a significant difference to the investigation. Had the cause of the accident really been terrorism prompt recovery of the recorder could have confirmed this and allowed authorities to take preventative measures.

If it takes several days to recover a recorder, is there a possibility of one being utterly lost?

> One can imagine cases such as a midair breakup over deep ocean where the exact location of the aircraft is difficult to track and ensuing debris is dispersed over a wide expanse of ocean several miles deep. Recovery of recorders could be quite difficult, especially if the bottom was muddy. If the search extended beyond the 30 day lifetime of the ultrasonic locator beacon the the recorders might never be found. There comes a point where sifting the mud of several square miles of deep ocean floor is simply impossible. Other similar scenarios can be imagined, where a floating recorder with a built in locator beacon is much preferable to a lost one.

INCREASED AIR TRAFFIC INCIDENTS AND INVESTIGATION COSTS

A major aircraft manufacturer predicts that air accidents will reach the rate of one a week in the near future simply as an extrapolation of increases in air traffic. Although it is also the goal of airworthiness authorities to proportionally improve statistical air safety, it will remain to be seen if this is achieved.

These additional incidents will put a higher work load on air accident investigation authorities. Already, due to limited budgets, investigators regularly choose not to investigate some minor events. To date it is rare that compromises are been made between full investigation and none at all. However the ready access of a floating recorder may allow the adoption of a compromise policy where, in the case of certain types of well understood accident, the recorder is recovered but the wreckage is not. The availability of a floating recorder may then save the authority , and in turn taxpayers, the multi million dollar bill for recovering equipment off the ocean floor.

This latter approach is currently favoured by some military authorities, where in the case of a fighter aircraft pilot ejecting from his aircraft for known reasons, the ready availability of the recorder data can provide a formal record of an incident and economically provide closure to it.

FREE FLIGHT

The concept of Free Flight, where aircraft no longer adhere to prescribed routes but choose the most direct or economical route between two points, probably to be introduced in the middle of the next decade, will result in increased air traffic over the poles and other inhospitable areas of the globe where finding the location of an air incident may be much more difficult. There will be an equally significant need for ensuring the timely identification of the crash location to enable the provision of speedy medical aid to help survivors.

The nature of a deployable recorder is that it includes a built in Emergency Locator Transmitter which has, due to the higher crash survivability requirements of the recorder, much better protection than normal and consequently is better assured to operate in adverse conditions.

As previously mentioned, the survival record of non-deployable emergency locator transmitters is disappointing. NASA and NTSB data shows an overall effectiveness of only 20%-25% for these systems, largly due to damage during crashes. Fixed emergency locator transmitters can suffer significant transmitter attenuation (up to 20 dB), and antenna pattern nulls due to unpredictable crash debris. In contrast, the deployed beacon airfoil containing the emergency locator transmitter travels away from the immediate crash site, providing better homing and more reliable signal for SARSAT and SAR reception. Accordingly, with accidents occurring in more severe environments there is greater reason to both increase the ease of obtaining the accident information, but more importantly provide better assurance of rescue to the survivors through the deployable ELT. Air Accident Investegators have the mandate to investigate crashes, but airworthiness authorities have the larger mandate to ensure the best package of safety measures is provided to the public.

SETTING THE STANDARD FOR THE FIXED AND DEPLOYABLE COMBINED RECORDER SYSTEM

The inclusion of requirements for deployables in the WG 50 MOPS sets a standard that needs to be reviewed by international airworthiness authorities, particularly with the respect to deployable use on large helicopters and dual combi fixed wing applications. Understanding the implications of these standards, and obtaining international agreement on them, will ease the way towards their formal incorporation in airworthiness regulations.

It is likely that a deployable recorder used in a dual combi installation would need to meet the full functional and environmental requirements of a fixed recorder. However some deployable specific issues need to be addressed in any regulation, reflecting the nature of the system as a combined CVR, FDR and ELT, such as:

-The need for additional ELT endurance in a combined system
-The replacement of the ULB function with that of the ELB
-The conditions for release of the deployable
-The need for the deployable to capture the last milliseconds of flight
-Deployable crash survivability requirements

Until recently, international Minimum Operational Performance Standards (MOPS) and Type Standard Orders (TSO’s) included specific requirement for deployable recorders. Unfortunately the recent update of TSOC124 to 124a dropped its applicability to deployables by including the requirements of ED 56A, which again excluded deployables. The following table summarizes the applicability to deployables of recent regulation:

Organization	Standard	Addresses	Applicability to Deployables
FAA	TSO C91a	121.5/243 ELT's	Included
	TSO C123	CVR	Included
	TSO C123a	CVR	Not Addressed
	TSO C124	FDR	Included
	TSO C124a	FDR	Included (intent requires confirmation)
	TSO C126	121.5/406 ELT's	Included
EUROCAE	ED 55	FDR	Included
	ED 56	CVR	Included
	ED56A	CVR	Specifically not addressed
	ED 62	121.5/243/406 ELT's	Included
	WG 50	FDR/CVR	Included
RTCA	DO-183	121.5/243 ELT's	Included
	DO-204	121.5/406 ELT's	Included
TCA	SCA 96-03	CVR, FDR, ELT	Included

Table 4: Applicability of Current Recorder Standards to Deployable Systems

CONCLUSION

The deployable recorder is a proven flight safety system. The adoption of a dual combined recorder system as the standard for commercial transport aircraft provides for a wider application for deployable recorders as the alternate recorder in these combined systems. This combination of technologies if correctly adopted could provide unsurpassed survivability of recorder information along with prompt access to it.

The draft MOPS to be produced by WG 50 does include the requirements for deployable recorder systems, and for reasons of improved recorder recovery and passenger safety it is important that international parties such as the NTSB, FAA and CAA review these requirements, and include provision for deployables in upcoming FAA TSO's and European JARs.

REFERENCES

National Transportation Safety Board Safety Recommendation, March 9, 1999

ICAO Flight Recorder Panel (FLIRECP) Second Meeting " Reports on Agenda Items" November, 1998

EUROCAE Working Group 50 "Meeting Agenda And Minutes" February 2, 1999

AEEC LETTER 98-204/DFDR-29 "Report on The Digital Flight Data Recorder (DFDR) Subcommittee Meeting Held December 1-3, in Kissimme Florida", December 30, 1998

NASA Contractor Report 4330 "Current Emergency Locator Transmitter (ELT) Deficiencies and Potential Improvements Utilizing TSO-C91a ELTs", Contracts NASW-4228 and NASW-4518, October 1990.

BIOGRAPHY

Rob Austin is the Senior Systems Engineer at DRS Technologies Canada, and was instrumental in the development of an integrated deployable combined CVR/FDR/ELT system for use on civil helicopters and military fixed wing aircraft. He has worked closely with Transport Canada airworthiness (TCA), the UK Civil Aviation Authority (CAA), the UK Air Accident Investigation Branch (AAIB), and the Canadian Transportation Safety Board (TSB) in the development and implementation of deployable recorder standards.

3D Animation of Recorded Flight Data

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KEYWORDS

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Flight Data Monitoring (FDM)
Animation
Flight Path Reconstruction

INTRODUCTION

Three-dimensional animation technology has been used for many years for accident investigation purposes. With the advent of faster, lower cost personal computers this technology is now available to multiple individuals at airlines as a cost-effective enhancement for Flight Data Monitoring (FDM) and Flight Operational Quality Assurance (FOQA) programs. Aircraft animations with synchronized cockpit instrumentation are an effective means of presenting results, and drawing cause-effect relationships from recorded flight data.

The animation of an event encompasses the aircraft's flight profile, cockpit instrumentation, terrain and scenario data. With an increasing number of parameters being recorded on aircraft, a method of relaying the large amounts of available information in a meaningful manner is needed. 3D animations are one such method. Furthermore, 3D animation capabilities are now accessible to multiple end-users from their desktop PC.

TECHNICAL CONSIDERATIONS

The primary consideration in producing an animation of an event is ensuring that the playback is accurate. The animation must account for the sensor type, signal source, valid range, accuracy and resolution of the recorded data. Furthermore, the raw data must be processed to remove any bad data; otherwise the animated sequence will be erroneous. The examples contained herein are taken from the Software Kinetics Ltd 'Flight Animator'.

FRAMES OF REFERENCE

The data sources pertaining to the aircraft dynamics, motions of aircraft parts, flight path and terrain are relative to specific frames of reference. Several types of transformations including scaling, translation and rotation may be applied to the objects in a known frame of reference.

The principal frames of reference utilized in an animation system are the following orthogonal, right-handed Cartesian frames:

- Geographic Frame

  The position and orientation of the aircraft centre of mass is described relative to a set of axes, which are fixed to the Earth. The instantaneous motion relative to the fixed axes can be used to generate the XYZ coordinates and orientation information depicting the aircraft's flight path.

  The geographic frame of reference is:

  - X (East);
  - Y (North); and
  - Z (Up).

  Figure 1a) depicts the geographic frame of reference.

- Body Frame

  The body frame of reference is fixed to an object. Assuming exact symmetry of the aircraft, one convention for defining the aircraft body axes is:

  - X is along the longitudinal reference line of the aircraft, pointing forward. A positive rotation about the X-axis corresponds to right wing down.
  - Y is along the lateral reference line of the aircraft, pointing along the right wing. A positive rotation about the Y-axis corresponds to nose pitch up.
  - Z is orthogonal to X and Y, pointing downward. A positive rotation about the Z-axis corresponds to a positive counter-clockwise rotation in yaw.

  Figure 1b) illustrates the body frame of reference for an aircraft.

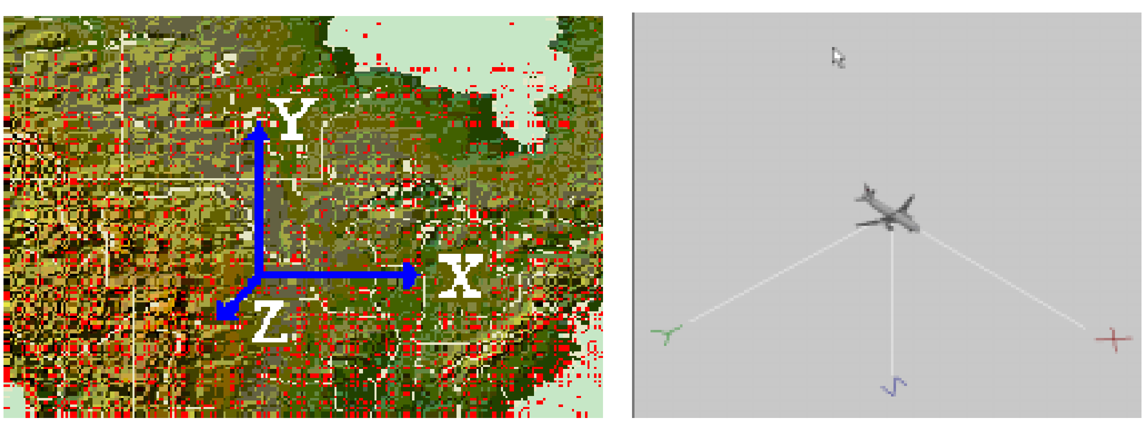

Figure 1: a) Geographic frame of reference [1] b) Body frame of reference [1]

Aircraft models may be defined hierarchically, whereby they consist of multiple child parts attached to parent parts. Body frames of reference are associated with each part, thereby allowing parameter data inputs to drive individual parts, such as the control surfaces. Also, parts may be attached to other parts in such a way that movement of one part will automatically cause movement of all its attached parts. For example, all the child parts relative to an aircraft's landing gear may be driven by the gear position data.

Depending on the availability of data, it is possible to animate multiple objects in a scene such as multiple aircraft, ground vehicles and markers in the scenery.

FLIGHT PATH RECONSTRUCTION

Flight path reconstruction consists of utilizing recorded flight data to derive the aircraft's instantaneous position and orientation relative to an orthogonal, right-handed Cartesian frame of reference that is fixed to the Earth.

Several algorithms exist for calculating an aircraft's flight path, which require different sets of input parameters. The total set of parameters includes airspeed, pressure altitude, radio altitude, ground speed, drift angle, roll attitude, pitch attitude, heading (true or magnetic), glideslope deviation, localizer deviation, magnetic variation, wind speed, wind direction, temperature and station pressure.

There are two categories of flight path reconstruction algorithms, those that employ Dead Reckoning techniques and those that employ absolute-referencing techniques.

Dead Reckoning involves the calculation of incremental distances traveled relative to a previously known position in the path. Thus, Dead Reckoning algorithms must be initialized before a continuous flight path can be calculated. For each time interval in the data set the incremental distances traveled along the three-dimensional frame of reference are computed. The distances traveled relative to the previous position in the path are then utilized to compute the current position. This is repeated until the complete, continuous flight path has been generated.

In absolute-referencing, the flight path of an aircraft is determined through conversion of latitude and longitude to XY absolute grid coordinates. Geodetic latitude and longitude outputs supplied by the on-board navigation system and recorded in-flight are the input data sources. The two-dimensional horizontal terrain coordinates can be obtained through conversion of the latitude and longitude information to the Universal Transverse Mercator (UTM) reference system. The UTM grid reference system is derived from an ellipsoidal model of the Earth appropriate to the intended application. Although, each XY path coordinate is calculated independently from the previous position in the path, it is only an absolute coordinate reference if the data source for the latitude/longitude information is also an absolute position solution. Global Positioning System (GPS) navigation systems are one such example.

Latitude/Longitude information from Dead Reckoning systems, such as inertial navigation systems, may also be used to reconstruct an aircraft's flight path. However, the user should be aware of the different error characteristics for the different types of navigation systems. Dead Reckoning solutions are subject to increasing errors as a result of the integration of bias offsets and scaling errors over time [2].

The Z-coordinate is derived from radio and pressure altitude information.

The process of choosing an algorithm for reconstructing an aircraft's flight path must take into consideration the accuracy, sampling rate and resolution of the recorded parameter data, as well as, the input data source [3].

External data sources such as a known touchdown point on the runway may be used to make fine adjustments to the aircraft's calculated flight path. Thus, the optimum flight path is obtained through correlation of data from:

- Multiple flight path reconstruction techniques;
- Radar systems;
- Cockpit voice recorder and air traffic control transcripts;
- Ground observations; and
- Pilot reports.

Refer to Figure 2 for an illustration of an aircraft's flight path.

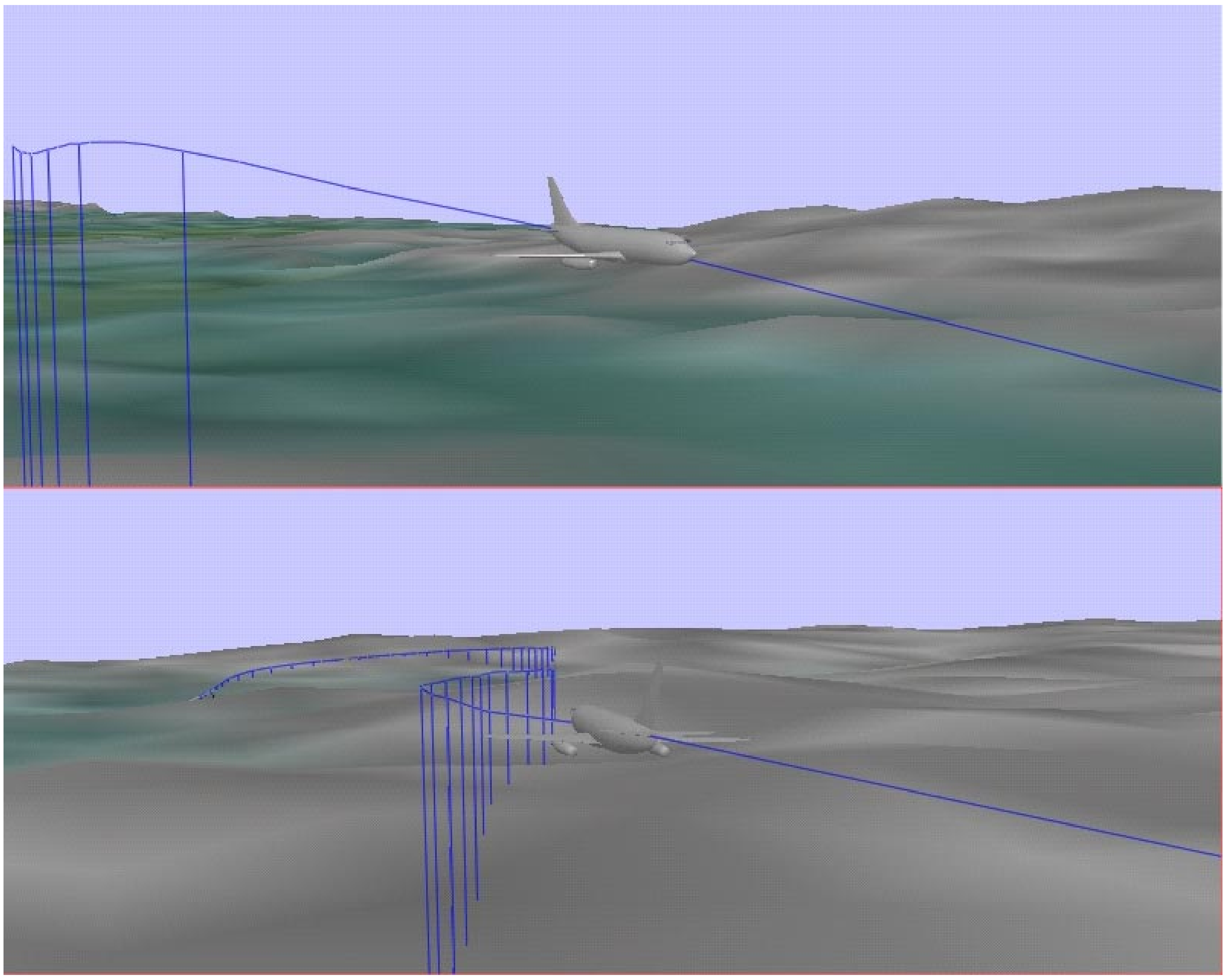

Figure 2: Aircraft flight path [1]

TIME-BASED SUBTITLING
Cockpit voice recorder transcript, air traffic control transcript or other time-based text transcripts may be overlayed with the animation.

INSTRUMENTATION
The graphical display of data-driven instrumentation is a means of relaying the recorded flight data in a manner similar to what the pilot may have observed in the cockpit. Some examples of cockpit instrumentation include: control stick, control wheel, tachometer, altimeter, horizontal situation indicator

(HSI), airspeed indicator, Electronic Flight Instrument System (EFIS) Primary Flight Display (PFD) and Electronic Centralized Aircraft Monitor (ECAM). Figure 3 is a snapshot of an aircraft animation with an instrument panel.

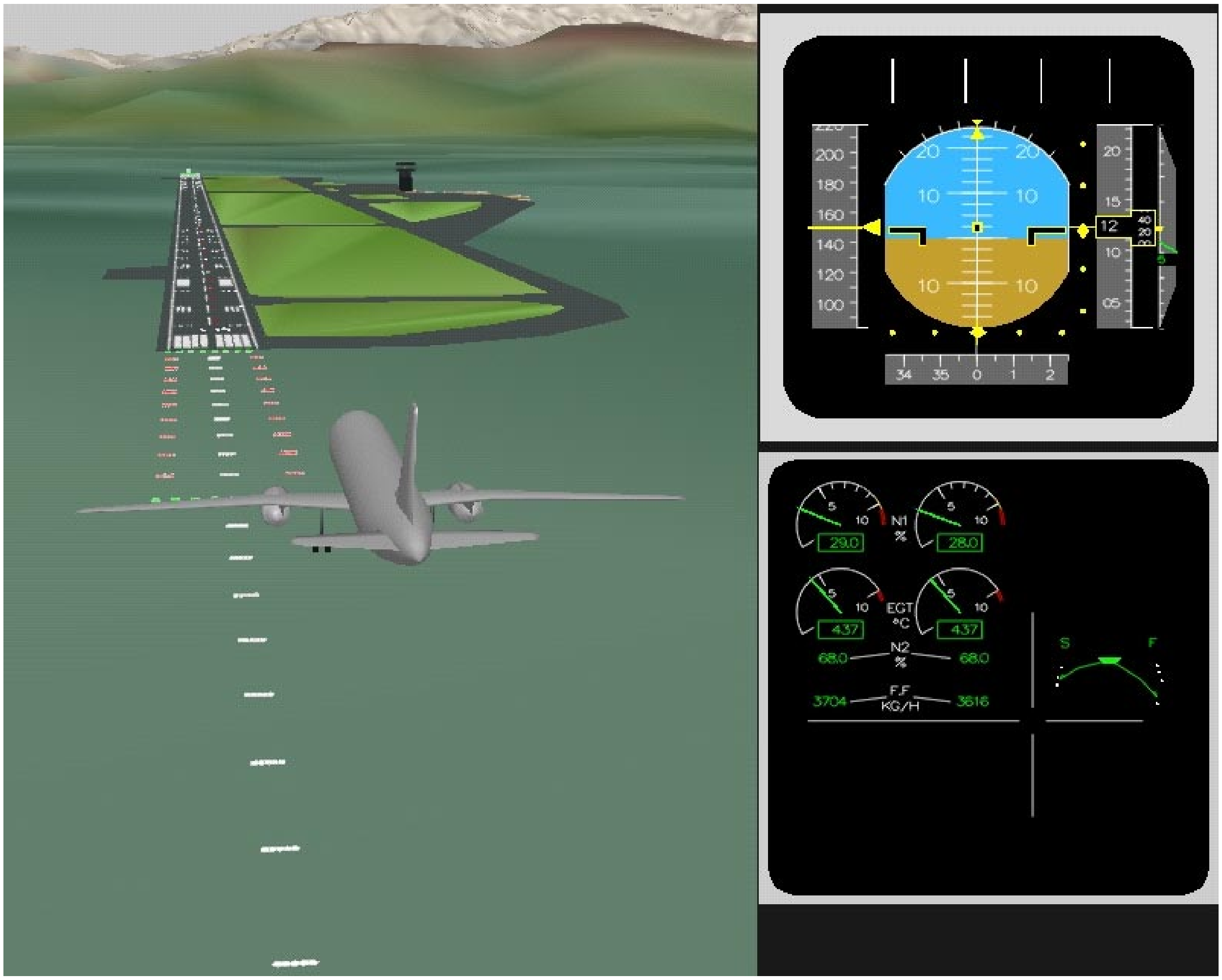

Figure 3: Aircraft animation snapshot with instrument panel and terrain elevation data [1]

DATA INTERPOLATION AND SMOOTHING

Bspline smoothing, cubic spline and linear interpolation are examples of numerical methods, which may be applied to individual parameters to derive intermediate values between recorded samples.

SCENERY AND ENVIRONMENTAL FACTORS

To further augment understanding of a particular event, environmental factors such as visibility, cloud layers and daylight illumination may be depicted. Terrain elevation data, runways, towers, navigation aids, ground vehicles and buildings are other examples of cultural features, which may be rendered. External references such as digital maps, weather reports and detailed approach plates are required to ensure the information is represented correctly.

Figures 3 and 4 are illustrations of terrain elevation data and a final approach relative to the glideslope.

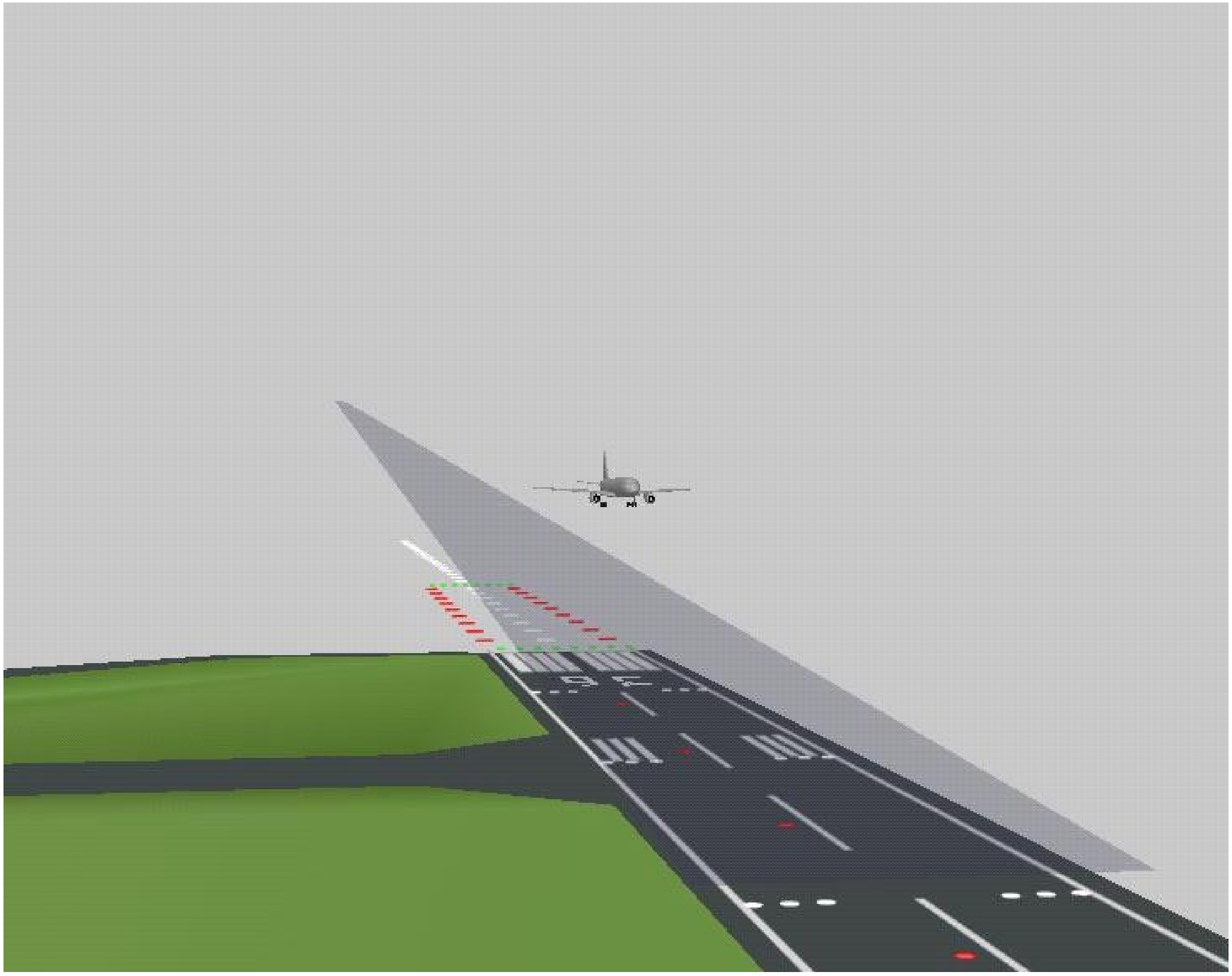

Figure 4: Representation of the glideslope [1]

REAL-TIME PLAYBACK

Despite the computation-intensive algorithms for the graphics and spatial reference frames, the software design must ensure time accuracy during real-time playback of an animation.

INTERACTIVE CONTROL

Some key system characteristics include camera view control (chase, chase ground, cockpit and fixed ground), time control (playback speed and direction) and camera position control (radial, horizontal and vertical distances). These assist the analyst with the interpretation of a flight segment. Unlike videotape, which was more commonly used in the past, direct access to desktop animation systems allows the end-user to interact with the system. Figure 6 illustrated four different view perspectives.

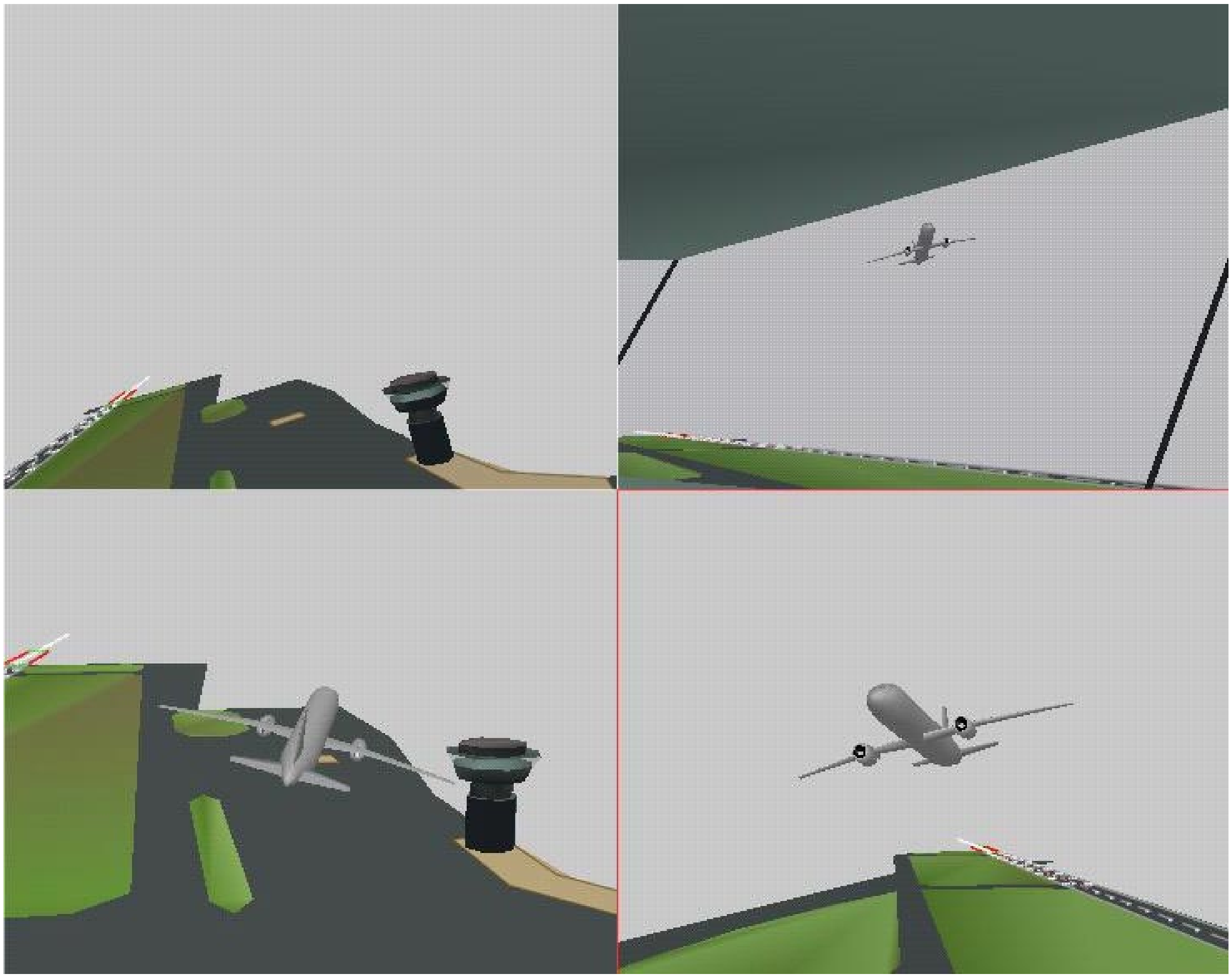
Figure 4: View perspectives (cockpit, fixed ground, trailing chase and forward chase) [1]

BENEFITS

There are numerous, wide-ranging benefits of 3D animations. These include:

- Crew self-assessment;
- Flight training;
- Airline safety improvement;
- Human factors study; and
- Operational procedures review.

One example scenario would be a pilot self-debriefing session following a particular flight.

CAUTIONS

Misuse of animation systems may result in misleading results and events being falsely interpreted. For example:

- incorrect use of numerical methods may skew the data;
- representation of subjective information such as weather phenomena should be clearly indicated;

- instrument displays reflect the status of recorded data, which may not necessarily represent the actual instrument accuracy and functionality; and
- conclusions regarding what the pilot actually saw should not be drawn from the recorded data.

CONCLUSIONS

3D Animation is a compelling, useful method for visualizing recorded flight data. It is an effective means of conveying the results of analyses to various end-users in a manner that is easily understood. The tremendous benefits of 3D animation are contingent on the fidelity and accuracy of the animation.

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REFERENCES

1. Software Kinetics Ltd., 'Flight Animator' copyright 1996-1999.
2. Siouris, G., Aerospace Avionics Systems, A Modern Synthesis, Academic Press Inc., San Diego, California, USA, 1993.
3. Software Kinetics Ltd., Flight Data Monitoring System Design Document, Document No. 9500-05-054, Version 01, June 1997.

BIOGRAPHIES

Ms. Carole Bolduc is a Professional Engineer at Software Kinetics Ltd. She is currently the Project Engineer on the Flight Data Monitoring project. She has participated in projects relating to Flight Data Monitoring, flight data recorders, aircraft certification and navigation systems. She obtained her Bachelor of Aerospace Engineering Degree from Carleton University in June 1993 and her Master's Degree in Aerospace Engineering from Carleton University in June 1995.

Mr. Wayne Jackson has managed research projects at TDC since February 1993 in Flight Data Monitoring, crash survivability, flight recorders, air traffic control, cockpit voice recorder (CVR) explosion analysis and wake vortex prediction. He has 29 years of experience in air navigation software development, research and project management. He is a Professional Engineer with degrees in Mechanical Engineering from the University of Western Ontario and Computer Science from the University of Waterloo.

The Next Generation FOQA Programs

by

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KEYWORDS

Aviation
Use of in-flight recorded data for Flight Operational Quality Assurance
Flight Guidance
Cockpit Workload

INTRODUCTION

The reason why the aircraft accident rate has stayed fairly flat since the mid-70' has caused many to speculate as to why. First of all, - is it at an acceptable level? or is "Zero Accidents" an attainable goal to strive for. We must always as an industry strive for "Zero Accidents".

The increase in traffic density over the next ten to fifteen years is bound to have an effect, not only on the rate, but the number of accidents. The numbers we are looking at are unacceptable.

What has kept the accident rate flat since the mid-70' is better flight training programs with the introduction of LOFT and Cockpit Resource Management programs. Introduction of GPWS and TCAS. The value that these programs have added to further reduce accidents has been exhausted as indicated by the persistent flat accident rate.

One of the yet un-exploited tools is Flight Operational Quality Assurance or FOQA.

The goal of FOQA programs is to provide airline managers with information that will enable them to better understand risks to flight operation and how to manage risk.

HISTORY

Airlines in Europe (SAS, KLM, Swissair, BA and others) has done Flight Analysis since the

Mid 1970'. The first programs included reading data off the metal foil recorders, raw data from the early Flight Data Recorders containing from 5 to 30 parameters. The first QAR (Quick Access Recorders) which was really called a DAR (Digital Airborne Recorder) containing 200-300 parameters.

Why did the Europeans embark on, in those days, cumbersome data extraction? Foil recorder reading engraving through a microscope and process DAR tapes on mainframe computers only to get a limited benefit. The answer is very simple. <u>They needed information.</u>

INFORMATION
As always the driver is an accident. In the mid 70' there was no CNN to show the horrors of an accident. The ones who suffered were the families of the victims. The airline and the manufactures of airframe and engines had their own problems. The airlines realized that they needed an insight in the day-to-day operation. Terms like <u>quality</u> emerged. They need to <u>"see it before you see it on CNN".</u>

The more information you have the better decisions you are able to make. Or we may even go as far as saying the more intelligence you have the better you are able to understand a problem and be proactive. Intelligence in a military sense is gathering of information. Comparing information, double-checking, looking for patterns and deviation (from peacetime) norm. Isn't that exactly what we want to do? Look for patterns, look for deviation from an established norm and finally do <u>Risk Analysis.</u>

FOQA programs use in-flight recorded data to determine the flight path of an aircraft from takeoff to landing. But, the real value of FOQA is turning the in-flight recorded data into meaningful and useful information. Information that evaluate and audit the quality of; flight training programs, standard operating procedures, quantifying risk, quality of management, ATC flight guidance, cockpit workload, etc.

Recovering of all in-flight recorded data is of the utmost importance. The devil is in the details. An exceedance detected is of no value unless you are able to determine what caused the exceedance. An engine event/exceedance is good information. The engine can be put on the alert list. But what you really want to know is the causal factor. What lead up to the event in the first place?

It is all in the in-flight recorded raw data.

Again, what is it that we really want to know? Is it just exceedance of a value under certain conditions. We will probably still look at exceedances as a source of information, but in a different light. First, it is not of interest to us during an approach when a limit is exceeded, but rather at what height above touchdown was the aircraft out of the "Gray" area again. We would also want to know what the pre-coursers were to the approach exceedance e.g. high approach speed and/or rate of descent. Pre-coursers could be ATC guidance of the flight or it could be an un-flyable approach procedure or it could be the environment inside the cockpit – a cockpit resource management (CRM) issue. Or high tailwind aloft could have caused a high-speed approach. By identifying pre-coursers and causal factors we have then come a long way, and it is all in the in-flight recorded data.

What we really want to know is the environment inside the cockpit. The human factors. Let's pause for a moment.

This is a big one.

We must assume that the pilots are well trained and that the pilots want to perform to the standards that they have been trained to. But the pilots can only guide the aircraft to the standards they have been trained to or as good as the performance of the autoflight system is and the information available.

Autoflight system altitude capture is a good example of poorly designed systems on some aircraft types. Who got blamed for altitude excursions – the pilots of course. It was not until the causal factors were uncovered in the in-flight recorded raw determined that it was a combination of design and software that caused the altitude busts. The system was not flyable or performing to specifications.

This paper discusses how in-flight recorded data may be used to determine cockpit environment and the cockpit workload for the crew. What inside and outside factors are influencing the cockpit workload and how can those factors be determined so that change to flight guidance can be made.

Safe flight guidance is a complex issue. It depends on ATC management, weather, complex takeoff or approach procedures due to terrain or noise abatement, the flight guidance system avionics and warning systems. What it boils down to is safe guidance of an aircraft with minimal risk.

By processing of in-flight recorded data that can provide information of the cockpit environment, adequate changes can be made to minimize risk and prevent accidents.

Human factor research is continuing with major advances being made in system safety and reliability. Accidents are caused less by failures of the machine and more by the performance failures of man. Is it possible to measure cockpit environment and workload?

Let's give it a try.

AlliedSignal FOQA II™

AlliedSignal FOQA II™ is a next generation Flight Operational Quality Assurance program designed to provide useful and meaningful information to airline managers. FOQA II is an end to end hands-off fully automated software program designed to provide useful information to airline managers in flight operation, flight safety, flight training and engineering. Focus in the design has been to allow maximum time for the operators to do analysis and minimal time to operate the system. FOQA II is intended to be accessible on an airlines' network for optimum utilization of information by end-users. The system is expandable and designed to store all in-flight recorded data. This allows airlines to re-process the data under different search criteria. FOQA II consists of two main components: The Raw Data Processing System (RDPS) and the Decision Support System (DSS).

The Raw Data Processing is mainly a background program that takes care of all processing requirements.

The Decision Support System is a uniquely designed relational database system that allows for extraction of information such as "what-if" and queries of a large number of events stored in the system. FOQA II uses high fidelity visualization and simulation whenever feasible, to display a situation or an analysis. Visualization is 3-dimentional. The Visualization and Simulation can be used to display and replay AlliedSignal Enhanced Ground Proximity Warning events using a photo realistic terrain database.

The database Risk Management System also assesses risk to flight operation on a daily basis and determines probability of reoccurrence of detected events. FOQA II determines Pre-Cursors, Atypicality and Risk Analysis (PAR).

AlliedSignal PAR™
(Pre-Cursors, Atypicality and Risk Analysis)

This advanced type of analysis is in the development phase.

Pre-Courser
The purpose of Pre-Cursors to Event Determination is to be able to make change to procedures, training or ATC environment. As an example what are the pre-coursers to an unstable approach to LAX RW 25R. "See it before you see it on CNN".

Atypicality
The purpose of detecting atypical flights or flights that deviation from an established baseline norm is to identify flights that could end up as being a high risk approach. This technique will allow detection of flights that are deviating from normal operation, but not necessarily triggering pre-defined exceedance events. The baseline will be dynamically updated as part of the raw data processing. The base line norm can be used to evaluate procedures. Comparison of the actual baseline to standard operating procedures, e.g. at what point is the landing gear in the down and locked position. This can be done for all flights or one aircraft type, or approaches to a specific airport runway.

Risk Analysis
Risk Analysis is a process that includes Risk Assessment and Risk Management. Risk Assessment is identifying hazards to a flight that may lead to an accident or at some point during flight will cause an unwanted situation that may lead to an accident. Risk is characterized in qualitative or quantitative terms. This includes the probability of an occurrence.
Risk management is the process within risk analysis that includes identifying, evaluating and implementing alternatives for mitigating risk.

FOQA II Risk Index
Airline managers must on a daily basis be kept abreast of the risk to the passengers and the fleet of aircraft being operated. FOQA II will provide the tools to do so by creating a Risk Index for each airport and runway based on flights flown over a period of time.

AlliedSignal CWI™ (Cockpit Workload Index)

This program is in the development phase.

The AlliedSignal CWI™ creates an index for each approach flown to an airport and runway. Assessing flight guidance of the aircraft and crew actions in the cockpit needed to operate the aircraft. Each critical milestone is weighted based on criticality and time detected before actual touchdown on the runway the aircraft was set up to land on. By comparing CWI from different flights, it may be determined why cockpit workload is high under certain conditions.

How is this done? We need all the in-flight recorded raw data to determine what environment that the pilots have in the cockpit. The process could begin at 10,000' or FL100. That is where most airlines define the cockpit as sterile until parked at the gate. This is where the workload increases and risk is increased also. The CWI will be a compilation of certain milestones during the descent, approach and land phase. The milestones could be by actions by the pilots in connection with the guidance of the aircraft or could be maneuvering of the aircraft in accordance with instructions given to the autoflight system. Checklist items will also be determined as milestones. Are some checklist items performed late and shortly before touchdown? If the items are performed late this could be an indication of high workload or that something was not quite normal during the approach.

Milestones (routine event snapshots) typical examples:

- Abnormal switch position for phase of flight
- Late descent compared to distance/time to touchdown
- Late ILS localizer and/or glide slope capture or late turn onto final
- Large heading change below a specific height
- Low energy and high speed
- Late landing configuration of the aircraft
- Weather, turbulence, icing
- Abnormal configuration or any aircraft system fault configuration
- Abnormal high power setting for flight condition
- Unstable heading
- Checklist items late completion
- Missed approach and pull-up

The CWI will be available for analysis on a daily basis for each flight. The CWI will identify runways that have a high index value for further investigation. The analyst might look for contributing factors such as weather, time of day or traffic congestion. Or compare flights of similar high CWI and identify similarities.

CONCLUSIONS

Information gathering for the purpose of doing airline risk management is a daunting task. Information is gathered to prevent certain events from happen.

The aviation industry is battling our friend Murphy. Recent technology advances allow us to more fully evaluate the man machine interface – the Human Factor.

High workload in a cockpit constitutes a high risk and high probability of an accident. When, due to high workload, the normal and trained interaction between the captain and co-pilot is degraded the risk of an accident can become unacceptably high. By analyzing flight guidance, determination may be made, why under certain conditions cockpit workload is high, determination of casual factors can be made and action through training, procedures and system design can be taken to prevent future accidents.

Can we afford not to, I think not!

Smiths Industries Flight Data/Cockpit Voice Recorders

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aviation, record, monitor, HUMS

INTRODUCTION

This paper is intended to provide an avionics manufacturer's industry perspective of modern recording and diagnostic monitoring systems for aircraft applications. Smiths Industries Voice And Data Recorder (VADR®) product line combines reliable, rugged, entirely solid-state technology with proven data recording expertise available in a variety of packages. The VADR® product family consists of Cockpit Voice Recorders (CVRs), Flight Data Recorders (FDRs), combined function (CVR & FDR) recorders, and Integrated Data Acquisition And Recorder System (IDARS) and Health and Usage Monitoring Systems (HUMS) equipment. All models are Authorized to Federal Aviation Administration (FAA) TSO-C123a and TSO-C124a performance requirements, and also meet the functional and performance standards of European Organization for Civil Aviation Electronics (EUROCAE) ED-55 and ED-56A.

The company's flight data recorders are fitted to over 6,700 military aircraft and became the US Air Force and US Navy standard for all aircraft in 1988. The US Army, US Coast Guard, Federal Aviation Administration, and many civil and allied nations' military fleets also make extensive use of Smiths Industries recorder products and systems.

Compact, light weight, and affordable, the VADR® is applicable to virtually any aircraft, offering a unique advantage to those aircraft previously constrained by the weight and bulk of traditional data recording systems. The VADR® single box solution measures 3.4"H x 4.25"W x 7.5"D (8.6cm x 10.8cm x 19.0cm) and weighs 6.5 to 9.3 pounds (2.9 to 4.2 kilograms), depending upon configuration.

WHAT IS NEW IN FDR/CVR TECHNOLOGY

BACKGROUND OVERVIEW

Aircraft monitoring systems have been around since almost the beginning of aviation. In an industry so constantly striving for perfection and improved performance, developers and operators have always tried to increase aircraft performance understanding, enhance operations and reduce costs. Data acquisition and recording systems have come a long way since the first mechanical foil recorders. Aircraft monitoring requirements have also grown apace. Aircraft mishap recording has grown primarily from civil regulatory requirements. Regulations are in place now which will increase parameter-recording requirements over four fold. Concurrently, with the development of increasingly complex, higher performance vehicles, the need for more information and increased reliability has grown. Aircraft operators and manufacturers have evolved a variety of specialized monitoring equipment to support system, performance and component life tracking needs. Increased operations tempo, greatly increased complexity of newer aircraft and requirements for more expeditious support activities has led to a need for dramatic improvements in aircraft monitoring system capabilities. With the advent and growth of solid state electronics capabilities and concurrent software systems, dramatic improvements in data acquisition, recording and processing of aircraft data is possible today. Today recorders are required to support multiple requirements and multiple functions as illustrated in Figure 1.

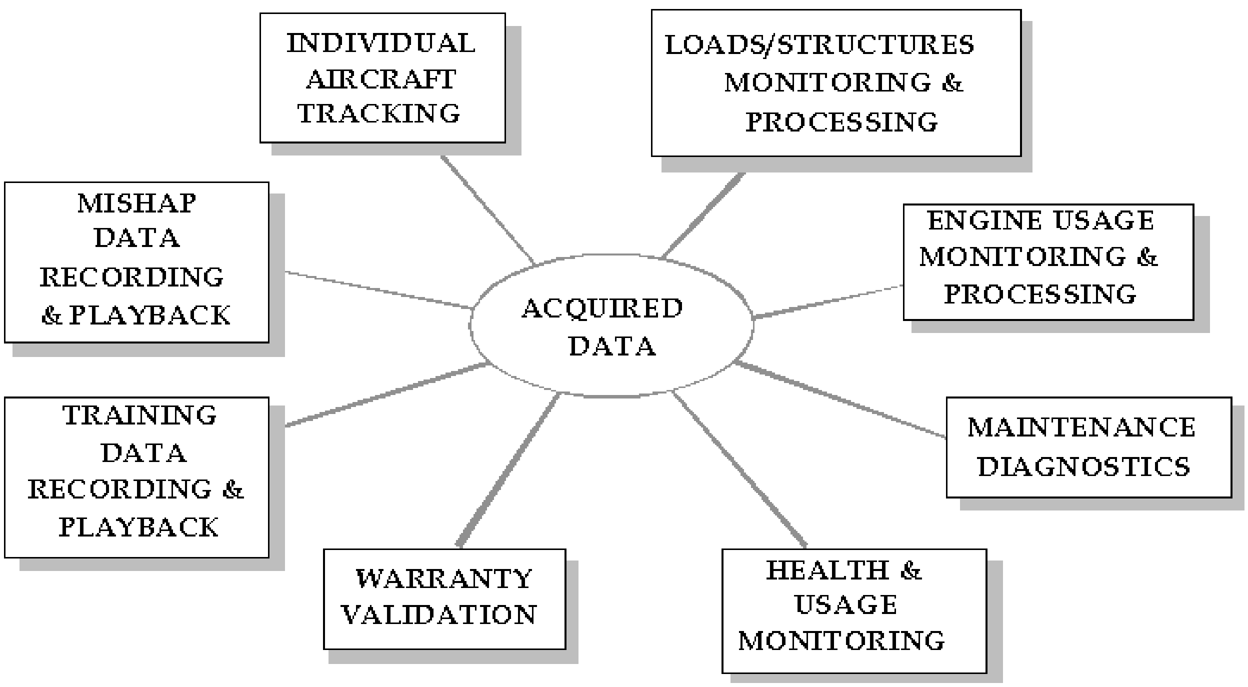

Figure 1: Modern Aircraft Monitoring System Functions & Relationships.

EVOLUTION OF AIRBORNE RECORDER SYSTEMS
Development of recording systems applied to aircraft has its origins in the audio recording and playback equipment produced during the early decades of the twentieth century. Recordings for musical entertainment and of the spoken word for radio and archival uses drove technology toward magnetic wire, tape and metallic foil media. The increase in civil passenger air travel during the 1930’s, 1940’s, and 1950’s demanded that information be preserved should a crash occur.

The first mandate for flight data recorder installations in the United States was issued by the Civil Aeronautics Board (the predecessor of today’s Federal Aviation Administration) in the late 1950’s. Crew voice recording was mandated in the early 1960’s, and throughout the next two decades the number of data parameters and time duration of both cockpit voice and flight data recorded was increased. After several incidents from which recorders did not survive crash impact, fire, and water immersion, standards for the crash survivability were upgraded and put in force during the 1990’s.

Despite the evolution in recorder function and performance standards, the basic system architecture concept remained much the same during the span of more than fifty years. Recorder systems were comprised of three pieces of equipment: Cockpit Voice Recorder (CVR), Flight Data Recorder (FDR), and Flight Data Acquisition Unit (FDAU). Each avionics box required its own basic circuitry, power supply, and chassis, mounting hardware, connectors and wiring. The size, weight, and power inherent to such a system architecture made it difficult at best—and often impossible—to apply recording systems to military tactical and smaller civil aircraft, despite the need. Industry responded to the need by applying new technology solutions to implement multi-function recording devices in new, innovative packaging.

SMITHS INDUSTRIES RECORDER SYSTEMS EXPERIENCE

Smiths Industries Aircraft Monitoring Systems
It is now well over 30 years since the first Smiths Industries aircraft monitoring system was developed. That system, for engine health monitoring in the Hawker Siddeley Trident airliners, was housed in a half ATR box and sampled just 13 parameters – temperatures, pressures, vibration and speeds – translated them into digital format and recorded the data on an on-board tape recorder. On landing, the tape was taken to a ground-based facility for processing and analysis.

Simple the system may have been by today's standards, but the foundations had been laid for the future. It had been appreciated that if the actual behavior of the engines could be recorded and analyzed, much could be determined about the stress and strains being experienced in flight. This could be used to interpret the wear on components, the 'amount of life used' and used to calculate remaining 'safe life' of the component. In essence, manufacturers were beginning to develop a concept of "on condition maintenance" being actively pursued to this day.

Smiths Industries Flight Data Recorders and Cockpit Voice Recorders
Smiths Industries has been building military crash protected memory (CPM) flight data recorders for almost 20 years. Initiated by the US Department of Defense in the late '70s, SI initially won a contract to provide modern, solid-state data acquisition and recording equipment for the US Air Force F-16 under the Crash Survivable Flight Data Recorder (CSFDR) Program. This was shortly extended and enhanced under the US Air Force Standard Flight Data Recorder (SFDR) and US Navy Standard Flight Incident Recorder (SFIR) Programs eventually to over 44 aircraft types in over 20 countries around the world. Solid-state CPMs have evolved from the initial 56Kbyte memories of the mid '80s to 72Mbyte production units today with even larger units in development. Acquisition and recording has grown from the early 13-parameter units to applications today monitoring hundreds of parameters.

The Future of Aircraft Monitoring Systems
Today, commercial flight data recorders flying in many of the world's fleets record only a small, limited set of parameters on a variety of recording media technologies. Data availability and usage is quite restricted. However, electronics technology has made dramatic improvements in capabilities, ruggedness, signal interfacing and processing capability. Single use systems have been multiplying for applications such as engine monitoring and structures recording. This is just scratching the surface. Today's aircraft monitoring systems do more than just acquire and record aircraft signals. Typically, the information is monitored for accuracy and results calculated and recorded in real time to support rapid feedback, reduced data volume and immediate output to other systems. Today's systems have grown much more capable, supporting multiple functions within a common chassis. This not only reduces acquisition, integration and support costs, but also allows for the sharing and correlation of data between functions. For example, flight parameters such as g force acceleration and angle of attack across the air intake will affect engine performance and can be related to engine temperatures and performance. On an increasing number of aircraft flight parameters can be directly correlated with airframe fatigue stresses and fatigue life,

eliminating the need for costly dedicated strain gauges. SI has developed special algorithms supporting this trend under a concept called Fatigue Usage Monitoring System (FUMS).
The future of aircraft monitoring is further functional integration, expanded signal monitoring, greater recorded resolution and data fidelity and increased reliance for improved maintenance management, focused maintenance diagnostics, reduced life cycle support cost and aircraft service life extension. The Smiths Industries Integrated Data Acquisition and Recording System (IDARS) exemplifies this trend

EVOLUTION OF SMITHS INDUSTRIES' CONCEPTS
The multi-function nature of Smiths Industries compact, rugged airborne recorder systems expanded the range of feasible applications. More and more civil and military fleet operators were finding that the availability of small and reliable yet affordable recorder systems could satisfy safety-related mandates as well as the need for accurate information to support improved aircraft maintenance logistics practices. The US and their Allied Military services pioneered efforts such as the Aircraft Structural Integrity Program (ASIP) and Comprehensive Engine Monitoring System (CEMS) to gather flight data for analysis and refinement of aviation fleet logistics management.

While the need for expanded collection of aircraft flight data remained strong, the desire for recording of aircrew and radio traffic audio was not well satisfied, especially in military applications. Smiths Industries was asked to develop a recording system that would add audio recording capability to the other functions of the data recording process. What evolved and introduced to the market in 1995 was the unique Voice And Data Recorder (VADR®). The VADR® is a very small combined data and audio recorder, which matched the CVR and FDR functions of conventional systems but in a compact, low weight, and entirely solid state design (Figure 2).

Figure 2: Compact, Rugged and Reliable: SI's Voice And Data Recorder (VADR®).

The VADR® was an instant success, but fell short of meeting the demand for acquisition of a large number of individual directly connected analog data signals. The conventional approach was to apply a FDAU or newer Digital FDAU (DFDAU) to gather signals and format them for transfer to a data recorder, but this meant undesired growth in system size, weight, complexity, and cost. It was determined, instead to approach the need with a system solution., that the VADR® concept should expanded to include greater signal interface capacity for a large number of analog and discrete inputs and yet retain the single box architecture (Figure 3). The concept of the Integrated Data Acquisition and Recording System—the IDARS—was born, and the initial platform applications to date include:

- USAF/USN T-6A (JPATS)
- USAF UH-1N
- USAF B-1B
- USAF U-2S
- USAF KC-135
- Brazil AL-X (Super Tucano)
- Eurocopter EC.135, BO.105 & BK.117
- UK Chinook HUMS
- UK Sea King HUMS
- UK Puma HUMS
- UK Lynx HUMS
- NATO Flying Training Canada (NFTC) program

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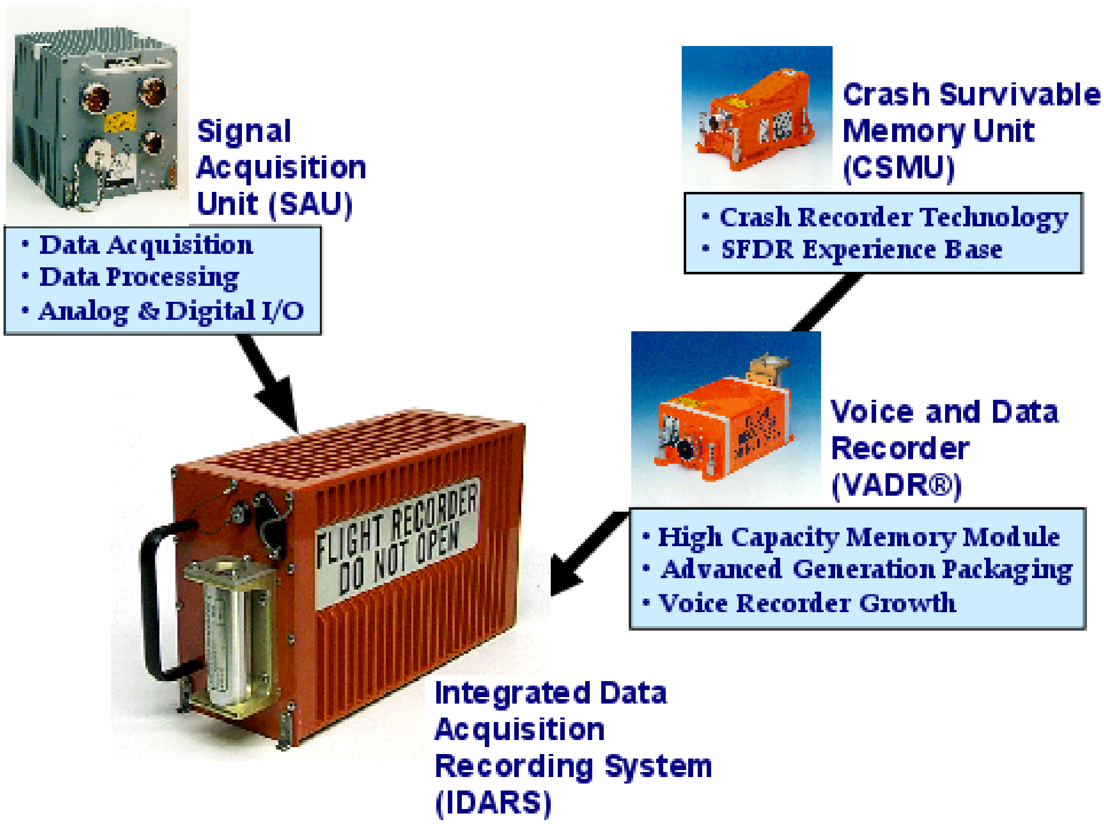

Figure 3: Smiths Industries IDARS Evolution

INTEGRATED DATA ACQUISITION AND RECORDING

GROWING DATA ACQUISITION PERFORMANCE NEEDS

Newer aircraft applications and the need to extend the life of existing aircraft has led to the need for more and better data on aircraft usage. At the same time, aircraft upgrades have led to a premium on available avionics space on aircraft. Cost is always important. The Integrated Data Acquisition and Recorder System (IDARS) is designed to meet these needs. In a single box, the IDARS (Figure 4) includes circuitry for extensive direct analog interface, acquisition and processing, data storage in mass memory, crash-protected memory and removable memory.

Figure 4: SI's Single Box Solution—Integrated Data Acquisition And Recorder System (IDARS).

IDARS CAPABILITIES
The IDARS acquires and processes all aircraft sensor data, stores relevant data on the integral Crash Protected Memory (CPM) and/or the external Data Transfer System, and displays relevant exceedances, alerts and data on the Cockpit Control Unit (CCU). The IDARS consists of a chassis assembly and a set of plug-in electronic Circuit Card Assemblies (CCAs). The IDARS accommodates up to five CCAs with all data communications and power distribution handles through the rigid multiple layer motherboard. Conditioned power is supplied to all CCAs with the exception of the CVFDR subsystem, which has a separate power-supply, for electrical isolation. The CCAs are partitioned into the following subsystems:

- Flight Data Acquisition Unit (FDAU)
- Cockpit Voice and Flight Data Recorder (CVFDR)

Flight Data Acquisition Unit (FDAU)
The IDARS FDAU provides monitoring and acquisition of flight data and sensors including analog, strain gauge, frequencies, low level AC/DC voltages, MIL-STD-1553, ARINC-429, RS-422, discrete signals, etc. It also provides outputs for various status and Built-In-Test (BIT) data and outputs for use by other system components for crew alerts and data display. Table 1 indicates input/output capabilities of the IDARS FDAU.

Signal Type	Available
AC/DC and Synchro Inputs	80
Variable Frequency input	8
Input Discretes	96
Output Discretes	8
Phase Reference Inputs	6
Low-Level Differential DC	14
RS-422 / RS-485	6
MIL-STD-1553	2
ARINC-429 Inputs	8
ARINC-429 Outputs	3

Table 1: DAPU/IDARS Input / Output Capacity

The IDARS FDAU is the primary analog/discrete/digital data acquisition, processing, compression and storage management component of the DAPU. It is capable of:

- Capturing data parameters
- Sampling data parameters
- Analyzing relevant conditions and changes
- Calculating resultant parameters
- Compressing data and managing data storage
- Performing the flight data acquisition functions for the CPM

The FDAU processes all parameters that are required by appropriate regulatory agencies for incident/mishap investigations. These parameters are buffered at the sampled frequency with no compression and sent to the CVFDR subsystem via an RS-422 communications channel for recording in the CPM.

Cockpit Voice Recorder and Flight Data Recorder (CVFDR) Subsystem

The IDARS CVFDR provides data collection and incident/mishap recording of audio data, aircraft flight and system parameters to support post incident analysis. The IDARS CVFDR subsystem consists of:

- Voice Processing Unit (VPU) CCA
- Crash Protected Memory (CPM)
- Acoustic Beacon

The CVFDR meets the operational requirements of EUROCAE ED-55 and ED-56A and FAA TSO-C123a and TSO-C124a. The flight data rates, interface and storage capabilities meet the standard of Aeronautical Radio, Inc. (ARINC) 573/717/747 and ED-55. These data rates meet or exceed those required for normal maintenance functions. The formatted data to the CPM is via a dedicated serial interface. BIT data is available through a separate RS-422 interface. In compliance with regulatory requirements, the VPU is functionally and electrically isolated from the other DAPU subsystems with the exception of an RS-422 serial interface.

The acoustic beacon is a mechanically integrated, water (fresh or salt) activated, device. It is compliant with EUROCAE ED-55, as well as applicable FAA Technical Standard Orders and ARINC standards.

GROWTH BEYOND DATA ACQUISITION AND RECORDING

GROWING PERFORMANCE TO MORE ADVANCED DATA USE

Today, the need for accurate, detailed aircraft and aircraft subsystem performance recording and analysis is well established. The requirement for operational readiness rates is higher than ever before. Maintenance costs, which are a significant factor in life cycle costs, have also risen dramatically. Modern aircraft monitoring equipment coupled with comprehensive ground support and analysis systems can offer improved aircraft availability and a greater safety margin.

CURRENT MULTIFUNCTION MONITORING

Engine monitoring is done on nearly every engine produced or in service today and has directly led to increased performance and lower maintenance costs. For example, an engine that had lower temperatures and less vibration than another could be expected to be serviceable longer, and therefore its maintenance cycle could be extended. Similarly, an aircraft experiencing lower flight stresses and less turbulence during flight could be expected to use less of it's structural fatigue life. The advent of accurate data recording allowed this tracking to become a reality. A very dramatic example illustrating the variation in seemly similar flight is the experience of the Red Arrow flight team in the UK. There it was found by employing structural recorders that the wingman typically experienced aircraft structural stresses double, triple or even higher over that of the flight lead.

THE FUTURE: COMPREHENSIVE HEALTH AND USAGE MONITORING

The integration of airborne monitoring and diagnostic systems with multifunction ground data analysis and support systems provides an evolving capability for very accurately tracking aircraft usage, system / sub-system life and supporting fleet management and maintenance. These systems improve airworthiness, improve reliability, and reduce aircraft cost of ownership by detecting and diagnosing potential and actual failures, monitoring usage, automating test procedures and providing advance warning of potential equipment failures and collecting valuable data for routine maintenance.

Smiths Industries' HUMS Overview

The Smiths Industries HUMS extends IDARS into a proactive maintenance and diagnostic system. It monitors nearly 200 parameters vital to aircraft operation – continuously acquiring, processing and storing data. Data is distributed for storage and retrieval in internal mass memory, in removable storage (a Data Transfer Module or DTM) for routine maintenance, and with cockpit voice data in a crash-protected memory (CPM) to support incident analysis like the IDARS. HUMS upgrades IDARS to include the addition of special purpose circuit cards to support HUMS vibration monitoring and other growth maintenance functions. Sensors around the airframe provide input on engine and gearbox vibration, rotor track and balance, avionics and overall aircraft performance. Essential health data is provided to the flight crew, while more detailed information is stored for later use by ground support technicians. Fatigue life usage can also be calculated in real time. SI can offer total system integration, production of major elements of hardware and software, installation design, aircraft installation and logistics support in the field.

Data Acquisition and Processing Unit (DAPU)

The DAPU acquires and processes all aircraft sensor data, stores relevant data on the integral Crash Protected Memory (CPM) and/or the external Data Transfer System, and displays relevant exceedances, alerts and data on the Cockpit Control Unit (CCU). The DAPU consists of a chassis assembly and a set of plug-in electronic Circuit Card Assemblies (CCAs). The DAPU accommodates up to five CCAs with all data communications and power distribution handles through the rigid multiple layer motherboard. Conditioned power is supplied to all CCAs with the exception of the CVFDR subsystem, which has a separate power-supply, for electrical isolation. The CCAs are partitioned into the following subsystems:

- Flight Data Acquisition Unit (FDAU)
- Cockpit Voice and Flight Data Recorder (CVFDR)
- Vibration Monitoring System (VMS)

Flight Data Acquisition Unit (FDAU)

The Flight Data Acquisition Unit (FDAU) functions as described in the IDARS section above.

Cockpit Voice and Flight Data Recorder (CVFDR)

The Cockpit Voice and Flight Data Recorder (CVFDR) functions as described in the IDARS section above.

Vibration Monitoring System (VMS)

The VMS functions include comprehensive rotor, drive train, gearbox, engine and structures health monitoring, diagnostic data acquisition and maintenance processing. Key capabilities include:

- Automatic or manual collection of vibration and optical tracker data from a series of flight regimes
- Collection of spectra from a series of flights for trend monitoring
- Capturing random spectra at the user's request for later analysis of intermittent events
- Communication of vibration alarm (exceedance) conditions
- Collection of spectra for health monitoring
- Calculation of rotor and blade maintenance adjustments based on track and vibration data

The VMS is a high performance data acquisition and processing subsystem hosted on one or two double-sided Vibration Acquisition Unit (VAU) CCA. The DAPU chassis supports up to two VAU CCAs. When configured with two CCAs, 48 vibration channels, 20 speed sensor channels, and 4 blade trackers can be accommodated, as listed in Table 2:

Signal Type	Available
High Band Vibration Channels	48
Speed Sensor Channels	20
Blade Tracker Channels	4

Table 2: VMS Input / Output Capacity

The digital signal processor (DSP) based design provides measurement and processing capability to allow most faults to be diagnosed on-board the aircraft. As with the APU, programmability if sampling rates, gains and input characteristics is a key feature of the card. The VAU DSPs eliminate the need for specialized analog acquisition circuitry and phase lock loop acquisition methods. Growth capability for incorporation of neural network technologies via software upload has been designed in.

BENEFITS OF RECORDING, CONDITION MONITORING, AND DIAGNOSTIC SYSTEMS

The reality is that aircraft are being kept in service for longer and longer and their mission requirements are continuously being revised. As a fleet ages, maintenance costs continue to grow. Concurrently, the pressure to increase maintenance productivity, reduce maintenance man-hours and improve aircraft readiness continues to strain the current force structure. Better understanding of aircraft actual usage, more accurate and timely information on needed aircraft maintenance actions and improved tracking of component usage is critical to realizing gains in aircraft readiness. Comprehensive aircraft monitoring is the key to this achievement.

A comprehensive aircraft monitoring system with associated sensors can support significant gains in reduced maintenance man-hours and increased aircraft and component life extension. Typically supported functions include:

- Mishap/Incident Recording, Playback and Analysis
- Training
  - Aircrew Tactical Training
  - Maintenance Training
- Warranty Recording
- Aircraft Usage Monitoring,
  - Individual Aircraft Tracking (IAT)
- Airframe Structures Monitoring
  - Loads/Structures Monitoring
  - Aircraft Structural Integrity Program (ASIP)
- Engine Health and Usage Monitoring
  - Low Cycle Fatigue
  - Engine Structural Integrity Program (ENSIP)
- Transmission Health Monitoring
- Rotor Monitoring

Each of these functions may be inter-related and many aircraft parameters are used for multiple functions. Therefore a comprehensive aircraft monitoring system is both necessary and cost effective. Use of accurate aircraft usage data can lead to more accurate tracking of aircraft structural life usage and an extension of calculated remaining life. Similarly, engine usage tracking can lead to earlier identification of incipient engine health problems, but more significantly to more accurate tracking of actual engine life usage and eventual conversion to an on condition maintenance program and engine overhaul cycle.

CONCLUSIONS

Modern technology has a lot to offer the operating organizations. Better, more comprehensive monitoring of aircraft components, systems and performance coupled with enhanced means of transferring and analyzing the recorded data can provide big payback. An adaptable, integrated, low cost solution is critical to affordably realizing this benefit. The VADR® and IDARS are leading the market for this capability with:

- **Light Weight**
- **Small Size**
- **Reduced Power**
- **Integrated Single ‘Box’ Solution**

ACKNOWLEDGEMENTS

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REFERENCES

4. Specification LA1268, Voice And Data Recorder (VADR®), Smiths Industries Aerospace.
5. Technical Standard Order TSO-C123a, Flight Data Recorder, Federal Aviation Administration.
6. Technical Standard Order TSO-C124a, Cockpit Voice Recorder, Federal Aviation Administration.
7. Specification ED-55, Flight Data Recorder, European Organization for Civil Aviation Electronics.
8. Specification ED-56A, Cockpit Voice Recorder, European Organization for Civil Aviation Electronics.

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MARINE VOYAGE DATA RECORDERS

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KEYWORDS

Marine, IMO, IEC, ISM, Port-State, VDR

INTRODUCTION

"Data recorders" in some form have been around for quite some time in the marine industry. They include, but are not limited to, log books, navigation charts, bell or engine order logs, course recorders, hull stress meters, propulsion and auxiliary engine computer logs, vessel traffic service (VTS) systems, Rescue Coordination Center (RCC) radio transmission tapes, and the Automatic Identification System[1] (AIS). A marine voyage data recorder (VDR) centralizes the various measurements taken on board a vessel in one "protective" place from which data can be retrieved at a later date for analysis. Many companies have already taken the initiative of installing VDRs not only to obtain data in the event of an accident or incident, but also to assist in managing their fleets.

In an October 10, 1998, article, *Boxing Clever,* Lloyds List writes,

> Ironically, of all the technical requirements that are designed to prevent accidents (although most are designed to minimize their consequences), the provision of 'black boxes' is something that only comes into its own after the incident. Not that there is no commercial reason (value) for their adoption on ferries. Voyage event recorders can monitor whatever is required, from the way a ship is handled, to the performance of the machinery, and its forensic employment must be considered almost incidental. They have proved themselves in operation in a number of areas, from the optimization of fuel economy measures to the defense of the owner in the event of an incident. And although it can be argued that they scarcely affect safety directly, the lessons they produce certainly do.

[1]AIS gathers vessel movement information and assembles it into an AIS-compliant data sentence. Incoming vessel information, including GPS/DGPS, heading, course over the ground, and speed, is displayed on a device, such as a personal computer or laptop. A vessel provides its identification (official number), position, course, heading, speed, and receives information on other vessels, port data, and hazards in area.

This paper will review the history of VDRs, specifically their promotion by the NTSB, the International Maritime Organization's (IMO's) actions and its pending carriage requirements, the International Safety Management (ISM) code requirements, IEC performance standards, the position of the classifications societies on VDRs, the VDR and Port State control, VDRs in international investigations, and operational management requirements of the ship owner.

MAIN SECTION

MARINE DATA RECORDERS - A HISTORY:

Promotion by the NTSB

The National Transportation Safety Board (NTSB) has promoted the use of event recorders on ships since the 1970s. Drawing on its extensive experience with aviation and surface vehicle data recorders, the Safety Board has worked with the U.S. Coast Guard, other agencies, and marine industry companies in rulemaking efforts and development of technical standards for VDRs. The NTSB supports the use of these systems not only as accident investigation tools, but also as management tools. The following is a brief summary of marine accidents investigated by the NTSB in which it identified the need for VDRs and issued safety recommendations related to developing or requiring the systems.

The NTSB identified the potential use of VDRs in accident reconstruction in its investigation of the collision between the SS *C.V. Sea Witch* and the SS *Esso Brussels* and resulting fire in New York Harbor on June 2, 1973.[2] Based on its findings in the accident, the NTSB made the following safety recommendation to the Coast Guard:

> Require the installation of an automatic recording device to preserve vital navigational information aboard oceangoing tankships and containerships. (M-76-8)

Following its investigation of the collision of the U.S. tankship SS *Marine Floridian* with the Benjamin Harrison Memorial Bridge in 1977,[3] the NTSB made the following safety recommendation to the Coast Guard:

> Conduct a formal study in coordination with the Federal Maritime Administration and the shipping industry to determine a standard array of operational and audio data that should be recorded automatically with a view to establishing a requirement for the installation and operation of suitable equipment in U.S. vessels over 1,600 gross tons built after 1965, and to submitting an initiative to the Intergovernmental Maritime Consultative Organization (IMCO)[4] for the adoption of a similar international requirement. (M-78-2)

As a result of its 1981 special study, *Major Marine Collisions and Effects of Preventive Recommendations*,[5] the NTSB made the following safety recommendation to the Coast Guard:

> Expedite the study to require the installation of automatic recording devices to preserve vital navigational information aboard applicable ships. (M-81-84)

[2] Marine Accident Report - SS *C.V.* Sea Witch – SS Esso Brussels *Collision and Fire, New York Harbor, June 2, 1973* (NTSB/MAR-75/06).
[3] Marine Accident Report - *US. Tankship* SS Marine Floridian *Collision with Benjamin Harrison Memorial Bridge, Hopewell, Virginia, February 24, 1977* (NTSB/MAR-78/01).
[4] Now known as the International Maritime Organization (IMO).
[5] MSS-81-1

The NTSB ultimately classified the three recommendations cited above "Closed—Unacceptable Action," based on responses contained in a May 1982 letter from the Coast Guard, which stated:

> The Coast Guard generally supports the concept of shipboard voyage recorders as an aid in casualty analysis. Recently, the U.S. Maritime Administration canceled their voyage recorder project and IMCO removed voyage recorders from their work schedule. In view of this and the severe funding limitations within the Department of Transportation, the Coast Guard does not plan to actively pursue a voyage recorder project at this time.

In 1995, the NTSB again identified the need for VDRs during its investigation of the collision between the Netherlands Antilles passenger *ship Noordam* and the Maltese bulk carrier *Mount Ymitos*.[6] Based on its findings, the NTSB made the following safety recommendations to the Coast Guard:

> Require all vessels over 1,600 gross tons operating in U.S. waters to be equipped with voyage event recorders. (M-95-5)
>
> Propose to the IMO that it require all vessels over 500 gross tons to be equipped with voyage event recorders. (M-95-6)

Based on comments in a December 1, 1995, Coast Guard letter concerning VDRs, the NTSB replied that because the Coast Guard was not taking the "unilateral action as requested," Safety Recommendation M-95-5 had been classified "Closed—Unacceptable Action" on February 6, 1996. The Coast Guard sent a follow-on letter dated September 23, 1996, concerning Safety Recommendation M-95-6, in which it stated:

> We concur with the intent of this recommendation. We will work with the international maritime community and at the IMO to develop specifications for voyage event recorders. The carriage of a 'black box' is currently being discussed. However, there is presently insufficient support among member governments at IMO to establish international requirements for voyage event recorders, and to unilaterally establish requirements for vessels in U.S. waters would be detrimental to our efforts at IMO. We will keep the Board advised of our progress on this issue.
>
> On March 20, 1997, the NTSB wrote:
>
> Because the Coast Guard will work with the international maritime community and at the IMO to develop specifications for voyage event recorders and their carriage as requested, Safety Recommendation M-95-6 has been classified "Open—Acceptable Response." The Safety Board [NTSB] would appreciate periodic updates on the progress of this issue.

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[6] Marine Accident Report - *Collision of the Netherlands Antilles Passenger Ship Noordam and the Maltese Bulk Carrier* Mount Ymitos *in the Gulf of Mexico, November 6, 1993* (NTSB/MAR-95/01)

The Noordam accident also resulted in the NTSB asking the marine industry to promote the use of VDRs. The NTSB made the following safety recommendation to the International Council of Cruise Lines (ICCL):[7]

> Propose to members that all passenger vessels over 1,600 gross tons operating from U.S. ports be equipped with voyage event recorders. (M-95-8)

Upon receiving notification from the ILLC that it supported the NTSB's position on VDRs and that it had distributed copies of the safety recommendations to its constituency for their information and consideration, the NTSB classified Safety Recommendation M-95-8 "Closed—Acceptable Action" on December 12, 1995.

The NTSB made the following recommendation to Holland America Line Westours, Inc., as a result of the Noordam accident:

> Review the management oversight program and implement measures to ensure that company watchstanding policies are followed on all ships. (M-95-10)

In an August 8, 1995, letter, Holland America advised the NTSB that, along with other management and oversight measures, it was evaluating a VDR system that had been installed on its passenger vessel *Statendam*, and that, if the system was satisfactory, Holland America would install such a system on all its other vessels. In response to Holland America's action, the NTSB classified Safety Recommendation M-95-10 "Closed—Acceptable Action" on October 17, 1995.

Actions by the IMO

In 1996, in response to proposals by the United States and the United Kingdom, the IMO's Navigation Subcommittee (NAV) requested that the International Electro-technical Commission (IEC) develop an international technical testing standard for VDRs based on IMO recommendations. On March 19-21, 1997, the IEC working group (TC-80/WG-11) began work on the performance standard recommended by the IMO's NAV 43; the group issued its draft standard on March 19, 1999.

At the Design and Engineering Subcommittee (DE), the United States encouraged the IEC and the International Safety Organization (ISO) to cooperate in developing VDR standards. This should be re-emphasized because aspects of VDRs, such as carriage requirements and protection of the equipment, may extend beyond the purely electrical issues of VDRs.

IMO Resolution A.861(20), *Standards for Shipborne VDRs*

IMO resolution A.861(20) recommends VDR performance standards that, much like the standards for aircraft data recorders, are based on maintaining a record of data for accident analysis. Resolution A.861(20) observes that an IMO resolution adopted in May 1994[8] had

[7] The ICCL is a major cruise ship operator association that represents some 19 cruise lines. Each year, its overnight cruise vessel operators carry more than 4 million U.S. passengers on 87 ships.
[8] IMO Resolution 12.

concluded that fitting ships, particularly passenger vessels, with VDRs is desirable to assist in investigations into casualties and had called on the IMO Maritime Safety Committee to develop standards for VDRs. Observing that SOLAS may make VDR carriage mandatory, IMO resolution A.861(20) invites governments to encourage shipowners and ship operators to install VDRs on their vessels as soon as possible. The resolution discusses including VDR carriage requirements in the revision of SOLAS chapter V (Safety of Navigation), which is expected to become effective in 2002.

The performance standards proposed in IMO resolution A.861(20) apply to either float-free or fixed models of VDRs and include the general provision that the purpose of a VDR is to maintain a storage, in a secure and retrievable form, of information concerning the vessel's position, movement, physical status, and command and control for the period leading up to and following an incident. The information would be for use by the Administration and the ship-owner during any subsequent investigation into the causes of an incident.

The proposed performance standards require that the VDR continuously maintain sequential records of preselected data items relating to equipment status and output and of the ship's command and control. The VDR must be installed in a brightly colored protective capsule that is fitted with a device to aid in locating it. The VDR must operate automatically and record data for at least 12 hours. If the ship owner so wishes, the recorded information may be downloaded so long as the download does not interfere with the data recording function. This feature makes the installation and use of the VDR quite appealing to a ship owner as a management tool.

The complete VDR system, as defined by IMO resolution A.861(20)/4.1, must include all items required to interface with data input sources, all items necessary to process and encode data, the recording medium in its capsule, the power supply, and the dedicated reserve power source. The VDR, at a minimum, will record:

> Date, time, ship's position, speed, heading, bridge audio, communications audio (radio), radar data, post-display data, echo sounder, main alarms, rudder order and response, hull openings (doors) status, watertight and fire door status, accelerations, hull stresses, wind speed, and wind direction.

IMO Carriage Requirements

The 44th session of the IMO Sub-Committee on Safety of Navigation, held in July 1998, considered VDR carriage requirements and made proposals, which appear as draft regulation 22 to SOLAS Chapter V. The proposed options include a provision limiting the new requirement for VDRs to Ro-Ro[9] passenger ships on international voyages. Other options, which were submitted by the United Kingdom and supported by the European community, the United States, Canada, Australia, and New Zealand, require that all new vessels built by a certain date have a VDR and that all existing vessels install a VDR during a phase-in period, which will be at a later date. The United States proposed a requirement that VDRs be tested annually for operability by an

[9] Roll-on roll-off vessels (Ro-Ro) that are designed with large bow or stem ramps (or both) to allow trailers or cars to be driven rather than lifted on and off the vessel.

independent inspection authority, much like the requirement for annual liferaft examinations. The United States observed that, with the proper equipment, the VDR test could be conducted on the vessel, and upon satisfactory completion of the exam, a certificate could be issued, which would show Port State authorities that the vessel is in conformance with regulation.

Some countries opposed the VDR requirement for "all" vessels. Japan and others stated that the carriage requirement should apply only to vessels on "international voyages;" Panama maintained that the VDR should only be required on "self-propelled" vessels. The IMO Sub-Committee hopefully will conclude its work on VDRs (and Chapter V) at its 45th session, and will require VDR carriage for all vessels over 3,000 gross tons, with a specified phase-in period for existing vessels.

IEC Performance Standards

In 1998, technical experts from around the world, including equipment manufacturing representatives and government accident investigators such as NTSB representatives, met at the British Standards Institute (BSI) in London to develop VDR functional performance requirements based on the generic performance standards approved by IMO in November 1997 (IMO Resolution A.861.) The IEC TC-80, WG-11 is tasked with developing these functional performance requirements, which, when published, will be known as IEC 61996 *Shipbourne Voyage Data Recorder (VDR), Performance Requirements, Methods of Test and Required Test Results*. The "enquiry for vote" was submitted to the IEC members for review and solicitation of comments on March 19, 1999. The closing date for voting is August 31, 1999.

Classification Societies and the VDR

In recent discussions with representatives of the International Association of Classification Societies (IACS) and Lloyds Register of Shipping (Lloyds), this author asked about the position of the classification societies on the issue of VDRs. On February 2, 1999, Mr. James D. Bell, IACS Permanent Secretary, stated:

> So far, there are no IACS policies or resolutions on VDRs at this stage. Of course, if/when something definitive does emerge it will be a statutory requirement rather than class associated and we will be involved as authorized agents for the Administrations. This does not mean that our members have not individually been involved in national and regional developments of such equipment.

In response to a July 13, 1998, email, a Lloyds representative responded to questions regarding discounts or preferences being offered to shipowners who have VDRs installed, stating:

> There is no truth to this [rumor] that Lloyds or other societies were offering any discounts if a VDR is fitted. A class society will make a small charge for the approval of the installation and subsequent periodic surveys. The benefit comes from the shipowner being able to demonstrate that he is applying due diligence through a notation in the register book which specifies his ship has a VDR installed.

Lloyds subsequently issued *Provisional Rules for the Classification of Ship Event Analysis Systems* in 1998.

ISM Code Certification[10]

According to the chairman of the IACS, the greatest contribution to improved maritime safety can only come from higher conformance by the world fleet to recognized IMO Conventions and international safety standards. The *International Management Code for the Safe Operation of Ships and for Pollution Prevention* (ISM Code), adopted by the IMO in November 1993, is therefore a vital instrument to bring the improvements expected by the international community.

In a recent article, *Safe Today Is No Guarantee For Tomorrow,*[11] Det Norske Veritas's (DNV) Dr. Tor-Christian Mathiesen writes, "We are facing greater expectations of safe operation and pollution prevention. The answer is not the introduction of more rules and regulations. The challenge is to ensure compliance with all the rules and regulations that we have today." Tor-Christian Mathiesen believes that shipping's most important development in the past 10-12 years has been the focus on the human element. He states, "The human element is involved in all accidents. If you analyze accidents you will find the human element somewhere in the chain of events leading to them. Man is accountable for 100 percent of all accidents, not the 80 percent frequently quoted."

Dr. Mathiesen considers the ISM Code the most important modern safety instrument to the shipping industry, stating, "I am sure that the ISM Code has been on the agenda of the Board of all shipping companies operating internationally….if we succeed with proper implementation of the ISM Code, which we have to, we will see the development of a safety culture in shipping."

The IMO developed the ISM Code because it recognized that effective company management was paramount to ensuring marine safety guidelines and environmental protection. The ISM Code became a requirement for all vessels, except bulk carriers, in July 1998. As its full title implies, the objective of the ISM Code is to encourage companies to develop and maintain a safety-management system, which accomplishes the following general measures:

- Provides for safe practices in ship operation and safe working environment;
- Establishes safeguards against all identified risks; and
- Improves the safety management skills of shoreside and shipboard personnel.

The ISM Code provides specific guidelines to companies for developing an effective safety-management system. For example, the ISM Code indicates that a company's safety-management system should include the following functional requirements:

- A safety and environmental protection policy;

[10] DNV FORUM ISSUE No. 3,1996, article.
[11] DNV FORUM ISSUE No. 1, 1998, *Dr Tor-Christian Mathiesen, Chairman of The Council of IACS:*

- Instructions and procedures for ensuring safe vessel operation and environmental protection in compliance with relevant international and domestic law;
- Defined levels of authority and lines of communication between and among shipboard and shoreside personnel;
- Procedures for reporting accidents and non-conformities;
- Emergency preparedness and response procedures; and,
- Internal audit and management review procedures.

The ISM Code recommends that companies designate a shoreside person (or persons) having direct access to the highest level of management to be authorized and responsible for monitoring the safety and pollution aspects of each ship in the company's fleet and to make sure that adequate resources and shore-based support are applied "as needed." In addition, the ISM Code states that the company should clearly define and document the following areas of responsibility for each ship's master:

- Implementing the safety and environmental-protection policy of the company;
- Motivating the crew in the observation of that policy;
- Issuing appropriate orders and instructions in a clear and simple manner;
- Verifying that specified requirements, such as marine regulations, operational directives, and so forth, are observed; and
- Reviewing the safety-management system and reporting its deficiencies to shore-based management.

Under procedures established by the IMO, companies that demonstrate compliance with the ISM Code will be issued a *Document of Compliance*. Vessels owned and/or operated by these companies will be issued a *Safety Management Certificate* to be displayed on board the vessel. While the development of the ISM Code was developed primarily for deep-draft ships engaged in international commerce, the provisions of the Code are general and may be applied to all sectors of the maritime industry, including inland and coastal barge and towing operations. An example of an inland program is the American Waterway Operators' *Responsible Carrier Program*.

The central objectives of the ISM Code are improved and consistent compliance through stronger enforcement of international rules and regulations. The ISM Code is widely regarded as the most important single development in maritime safety for many years. Introduced in two stages, the ISM Code will ultimately apply to 90 percent of the world's fleet, with 8,000 shipowning and operating companies. Phase One required the auditing of some 18,700 ships before 1 July 1998. Phase 2 will require another 20,700 ships to be audited before 1 July 2002.

Dr. Mathiesen observes, “A most important part of the [ISM] Code is the requirement to record incidents, analyze, and try to identify the basic cause in order to prevent recurrences.” He describes Phase One of the ISM Code as “an important step” towards an industry safety culture. “By safety culture,” he explains, “I mean a culture of saying, “I can always improve,” which will enhance safety and pollution prevention.

Companies Employing VDRs to fulfill “ISM Responsibilities”

A survey by this author found that a number of operators view VDR systems as valuable tools to achieve the objectives of the ISM Code. P & O Lines, which is considered a pioneer in the development and use of VDRs, has been using VDR systems for years to fulfill its ISM responsibility to provide management oversight of its fleet. A P & O subsidiary, Three Quays International (Broadgate), reports that it has 120 VDR units throughout its fleets of Ro-Ro ferries, bulkers, tankships, and other vessels. VDR systems have been voluntarily installed on BP tankships, Conoco tankships, Chevron tankships, and Holland America Line passenger ships. In addition, the U.S. Navy has an experimental project with a system called “Smart Ship,” which, among other functions, records radar data. Reportedly this system is being tested on the USS *Harry S. Truman* and the USS *Yorktown*.

Companies are finding that, in addition to the obvious ISM and postaccident value of VDR information, they can realize a payback in their fleet operations by using the data to monitor the various systems on board. In an 1998 article written for DNV FORUM ISSUE No. 2, *Performance Monitoring Enhances Operational Efficiency*, Stuart Brewer endorses the benefits of maintaining vital machinery data in order to review main engine performance data and to make adjustments as needed. Mr. Brewer’s article states:

[12] DNV FORUM ISSUE No. 1, 1998, *Dr Tor-Christian Mathiesen, Chairman of The Council of IACS:*

> There are several benefits in maintaining performance (records) of the main engine. As an example: modern two-stroke slow-speed engines are fitted with variable injection timing equipment (VIT). Correct functioning of the VIT is essential for good engine performance and by monitoring performance as laid down in the DNV program we can detect maladjustment's and make the necessary corrections. A correctly adjusted engine ensures better fuel economy, more operating hours per cylinder, and better overall engine condition and economy. It also results in cleaner exhaust gases and reduced harmful emissions. …we see performance monitoring as a means to optimize the engine's condition and its maintenance intervals.

Based on the results from its "New Machinery Project" and in line with the procedures from its pilot test ship program, the DNV is planning to launch a new, voluntary class notation.

When the DNV was asked if it saw any use for such a new notation, a representative replied that such a notation would be much like a "stamp for good housekeeping," conveying to the market that from this ship you could expect reliable performance, good fuel economy and fewer unexpected costs in machinery maintenance.

In its first review of maritime safety, [13] the European Transport Safety Council (ETSC) estimates that 140 fatalities occur annually in European sea transport and observes that the safety culture and safety regulations must be improved. The ETSC review identifies priority measures for accident reduction. Among these measures are a systems approach to safety and the need for better statistical information, specifically an European Union (EU) database and VDRs, and an independent maritime accident investigation agency. Other needs or changes that the ETSC review identifies include the following: a common education and training framework, international medical/psychological standards, a legal maximum blood alcohol level, fatigue reduction measures, on-board facilities, improved communications technologies, safety guidelines in and near ports, bulk carrier and ro-ro ferry design, survival capability of high speed craft, and passenger ferry survivability.

1 VDRs in Port State Control – Compliance

In a 1997 article[14] for *IMO News*, the senior deputy director of the IMO's Maritime Safety Division states:

> Port State control - the inspection of foreign flag vessels visiting national ports - has been described as the last safety net in marine safety. In an ideal world, Port State control would not exist, but when shipowners, classification societies, insurers or Flag administrations have in one way or another failed to do their job, Port State control comes onto the scene. Port State control is recognized as being a step in the right direction towards the eradication of substandard ships, when it

[13] Copies are available from the ETSC, Rue du Cornet 34, B-1040 Brussels, Belgium.

[14] *Port State control: An Update*, Fernando Plaza, Senior Deputy Director, Maritime Safety Division, IMO, IMO NEWS, Number 4, 1997.

> is carried out in accordance with IMO Assembly resolutions and recommendations.

It is only natural that government agencies and their delegated inspectors[15] employ the information gathered by the VDR in conducting the various Port State requirements, which includes enforcing the ISM Code and ensuring that a vessel is in compliance with U.S. navigation safety regulations (33 CFR 164) and applicable pollution prevention regulations (IMO/MARPOL[16], and 33 CFR 151 to 159). The Coast Guard guidance in NVIC 4-98, states:

> The objectives of SOLAS IX and the ISM Code are to ensure safety at sea, to prevent the occurrence of human injury or loss of life, and avoid environmental and property damage. Specifically, the ISM Code seeks to address the issues of human error and human omissions. To accomplish its objectives, the ISM Code requires owners of ships, or other organizations such as the managers, or bareboat charterers, who have assumed responsibility for ship operations, to implement Safety Management Systems for their companies and ships.

2 VDRs in International Investigations

On November 27, 1997, the IMO adopted IMO Resolution A.849(20), *Code for the Investigation of Marine Casualties and Accidents*, which the U.S. Coast Guard endorsed and disseminated in *Navigation and Vessel Inspection Circular Number: 5-98*. In issuing NVIC 5-98, the Coast Guard summarized the IMO action as follows:

> The international community has increasingly become aware of the benefits of cooperating in casualty investigations given the international nature of shipping and the fact that Flag-State interests often overlap port-state interests. As a result, a series of IMO resolutions have addressed international cooperation in increasing depth, and many valuable cooperative investigations have resulted in the past 10 years. Drawing on the experience of these cooperative investigations, and recognizing the opportunity to improve safety through information sharing, the IMO member states developed a Code for the investigation of marine casualties and incidents. The Code provides a standard international approach to investigations and enhances the existing cooperative frameworks.

The Code includes an appendix, *Guidelines to assist investigators in the implementation of the Code*, which provides the following guidance on VDRs:

> Where information from a VDR is available, in the event that the State conducting the investigation into a casualty or serious incident does not have appropriate facilities for readout of the VDR, it should seek and use the facilities of another State, giving consideration to the following:

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[15] Through its Streamline Inspection Program with small passenger vessels and its Alternate Compliance Program (see 46 CFR 8, *Vessel Inspection Alternatives*), the U.S. Coast Guard now authorizes the American Bureau of Shipping to perform inspections and certification on behalf of the Coast Guard.

[16] International Convention for the Prevention of Pollution from Ships 1973, MARPOL

.1 the capabilities of the readout facility;

.2 the timeliness of the availability of the facility; and

.3 the location of the readout facility.

CONCLUSIONS

VDR Safety Issues

The installation of VDRs is an important safety issue for all marine operators, especially for operators of passenger vessels. Automatic data recording devices provide crucial factual information for accident investigation and play a key role in identifying and addressing causal factors. While it can be argued that the VDR may not be a first line safety tool, such as a life jacket or fire extinguisher, it certainly has great value in ensuring that a vessel is operated safely, that its gear is performing as intended, and that the crews are performing as required by regulation, company policy, and the general rules of "good seamanship."

VDR as a Management Tool

The VDR provides the vessel operator and owner with information that can be used to better manage the vessels operation, thus providing key information that can be used to improve traffic routing, manage hull stress conditions, and better manage fuel consumption. The VDR also provides the owner/operator with a comprehensive record of what occurred in an event, thereby assisting in the event of some tort action. The management benefits derived from installing a VDR system would quickly offset the cost of its installation.

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3 Author's Bio

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Mr. Brown is a 1975 graduate of the Massachusetts Maritime Academy, earning a BS in Marine Transportation. He earned an MS in Management from Lesley College in 1986. He has sailed on various classes of merchant vessels and holds a U.S. Coast Guard license: Master 1600 G.T., Oceans; Master 4000 G.T., Inland, Third Mate Any Gross Tons, Oceans. He received a direct commission in the U.S. Coast Guard in 1977, and has served in various marine safety assignments. Now a Commander, U.S. Coast Guard Reserve, he is presently augmenting the

Chief, Vessel Compliance Division at Coast Guard Headquarters. He joined the NTSB is 1991 as a Marine Transportation Safety Specialist. Mr. Brown participated with the U.S. delegation to IMO's NAV-44 and is presently a member of the IEC TC-80, WG-11 working on the development of the VDR performance standard.

An Autonomous Data Recorder for Field Testing

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Inter-modal, Data Recorder, Autonomous

INTRODUCTION

Progress in the development of miniature sensors, microprocessors, compact nonvolatile “flash” memory, and battery technology allows the design of sophisticated miniature autonomous data recorders for a wide variety of inter-modal transportation applications.

In some cases, requirements for data recorders are well known or already specified by law. However, in new applications for data recorders, it is not always apparent what parameters need to be measured, nor with what frequency or precision. It may be useful in early field tests to collect more data than might be justified in an operational system, to allow assessment of what data is actually most useful. Since early field tests often involve retrofit into existing vehicles, it is also useful for a field-test recorder to have its own sensors, to simplify installation. This can also enable “fleet surveys” in which a few recorders are moved from one vehicle to another. Small autonomous data recorders are also useful for gathering data during vehicle testing. In some cases they may find use supplementing conventional data recorders, because they can be distributed throughout a large vehicle with little or no wiring.

Tether Applications has designed a Small Intelligent Datalogger (SID) with a variety of unusual features, including multiple on-board sensors, on-board alarm clocks for low-duty-cycle operation, and several serial-interface networking options. Its original purpose was as the core of some very small, low-cost, low-power spacecraft, but it also appears relevant for a variety of applications requiring small autonomous data recorders. It appears particularly well suited to early field-testing, where programming, installation, data recovery, and data analysis are likely to cost far more than purchase of the recorders themselves.

MAIN SECTION

Numerous applications exist for miniature autonomous field data recorders. SID appears most suited to applications where:

1. Developing data recorder specifications for new applications requires gathering field data to assess which parameters are needed, and at what frequency, precision, and overwrite-interval.
2. Running wires throughout the vehicle or connecting to existing sensors or electrical systems is time-consuming, unsafe, or not allowed, but field data must be collected. An example is adding new sensors during a vehicle test program. Using a small autonomous datalogger with its own sensors and batteries could reduce vehicle down-time. This may significantly speed up the test schedule.
3. A backup data collection system is desirable in some operational vehicles that already have data recorders. One case is collecting data after failure of primary vehicle power. A small low-powered battery-powered system could supplement the primary data recorder with pressure, temperature, acceleration, and other data. A related issue is that a recorder that can process data onboard to provide useful short and long-term summaries for maintenance (eg, fatigue life indicators; changes in resonant frequencies, etc.) may supplement existing mandated data recorders.

DESIGN PHILOSOPHY

Our hardware design philosophy was to include all features we need for an initial list of applications, plus as many other features useful to related applications as we could accommodate without driving the system size, cost, or power requirements. Since "one-size fits all" solutions often fit nothing well, we designed the board for easy expansion via stacking boards, rather than trying to fit everything interesting on the board itself. The board can be assembled with all or a subset of its nominal sensor suite.

The board uses commercial off the shelf parts and is assembled using standard techniques. It includes board-wide latchup detection and protection. This is not needed for terrestrial applications, but may be useful in high-altitude aircraft. To improve reliability in high-vibration environments, electrical interfaces to other boards or devices use short ribbon cables that are soldered in place, instead of connectors. In cases where connectors are needed, they can be installed on ribbon cables or stacking interface boards.

Most components are surface-mount type, for reduced board size, higher reliability, and greater thermal robustness. (Surface-mount assembly puts the chips and board through a thermal torture-test much worse than it will generally see in service, except in a vehicle fire.) But the oscillator crystals use through-hole cylindrical packages and compliant potting, for better shock and vibration tolerance than available with existing surface-mount crystals. The board should handle shocks and accelerations >1000 gees. Vibration limits will vary with resonances in the supports but should be quite high. Components larger than 0805 (0.080"x0.050") are leaded, to increase robustness against board flexing and thermal cycling. For good heatsinking even at high altitudes or in a vacuum, heat-dissipating chips like the regulators are near corner mounting holes, and internal copper layers are used as "thermal ground planes" in those areas.

SID is designed around a highly integrated Hitachi SH7045F 32-bit RISC microcontroller. Hitachi SH microcontrollers are used as embedded controllers in numerous applications ranging from digital cameras to heavy off-road trucks. The SH7045F includes 256 Kbytes of non-volatile "flash" program memory, 4 Kbytes of SRAM, an 8-channel 10-bit A/D converter, and a variety of other intelligent peripherals. The board has another 1Mbyte of SRAM and 8 Mbytes of serial flash memory for data storage. An 11-wire programming interface allows users to make in-circuit upgrades of the software in the flash program memory. Stacking expansion boards can add up to 4 Gbytes of additional flash memory if needed.

SID is 10x55x85 mm and weighs <50 grams without batteries or external packaging. This is light enough that in some cases, SID might be installed by being taped into place, using a tape like 3M VHB foam tape. SID consumes ~70 mA at 5.5V to 10V when running at 7MHz, with all sensors on. This allows a standard 46-gram 9V alkaline "transistor battery" to power the board for 6-8 hours of "on time." Hitachi specifies the CPU only over the -20^{o}C to 75^{o}C temperature range, but prototype boards have worked properly even at -80^{o}C, and we are using it at less than half its rated maximum speed.

SID has 3 independent alarm clocks. They allow SID to turn itself on and off on an arbitrary schedule, to see if the host vehicle is in use. This can greatly extend main battery life in low-duty-cycle vehicles such as general aviation aircraft. SID can turn on, initialize, and check its sensors within 20 ms, so even frequent status checks can be compatible with long battery life. SID can also can be awakened by an external active-low signal or by battery installation, and SID can determine what triggered its wakeup.

Perhaps SID's most unusual feature is its two independent 512-byte blocks of dual-port battery-backed SRAM that can be powered, addressed, and accessed (read or write) by an external "1-wire" network even when SID is off. Each board also has 2 independent 1-wire network controllers. As a result, one board can read, write, and pass 512-byte messages between a large number of other boards on each of two networks, whether those boards are on or off at the time. We call this network concept "DreamNet."

ON-BOARD SENSORS

The on-board sensors measure temperature, ambient pressure, 3-axis acceleration, and 2-axis angular rates. (The board is scarred for the 3rd rate axis, but the chip is not yet available, so we provide connections for an off-board sensor.) The acceleration sensors are typically used in automobile airbag controllers, and the angular rate sensors are used for image stabilization in video cameras. Their drift is far too large to use for guidance (~1deg/sec after correction for temperature effects), but adequate for detection of turns, skids, and vehicle roll. The onboard sensor characteristics are listed below in Table 1. Analog sensor outputs are digitized by the SH7045F with 10-bit resolution, typically at 100 Hz. The digitized data can be scaled, offset, and compensated for thermal effects, using calibration data specific to each sensor on each board.

On-board Sensor	**Range**	**Comments**
Digital Temperature Sensor	-55 to 125°C	Allows compensation for temperature-induced sensor errors.
Ambient Pressure Sensor	0-15 psia	Portless sensor (ie, senses air pressure where board is)
X and Y axis accelerometer	±50 g	Software can also select a ±5 g range in real time
Z axis digital accelerometer	±50 g	Sensors also available in other ranges (±5 to ±100 g)
X and Y axis rate gyro	± 180 deg/s	Large thermal drift, mostly correctable.
Z axis rate gyro	TBD	Now off-board; may be available on board by end of 1999

Table 1: On board sensors

INTERFACES TO OFF-BOARD SENSORS

Besides the above on-board sensors, SID provides interfaces for various off-board sensors. The most interesting one for vehicle data recorder applications may be a "frame-grabbing" imaging interface to a new CMOS imaging chip from Photobit. This interface allows SID to "grab" up to 5 video-quality frames at rates up to 30 Hz. After that, SRAM will be nearly full and images must be overwritten, compressed, and/or saved to flash memory. One way to use this imaging interface is to continuously grab images at ~2 per second, and save the 5 most recent images (and some later ones) if a crash occurs.

External Sensor	**Number**	**Range**	**Comments**
Thermocouples or photodiodes	16	Variable	Set scaling resistor and software for type used.
Digital temperature sensors	64	-55 to 125°C	2 sets of up to 32 "party-line-wired" sensors.
Event-detectors	4	N/A	Uses 4 photopairs to detect door status, etc.
CMOS imaging camera	1	Variable	Photobit PB159 CMOS 384x512 imaging chip.
Z axis rate gyro	1	±180 deg/sec	Sensor must be mounted normal to board.

Table 2: Interfaces to off-board sensors

OTHER EXTERNAL INTERFACES

Besides the on-board sensors and interfaces to off-board sensors, SID has various uncommitted resources that may be useful in various applications. They are listed below. All are brought out to ribbon-cable interfaces around the edge of the board. Some are arranged to ease specific applications. For example, the ribbon cable interfaces for two of the serial ports also have unregulated power-switches associated with them, so SID can switch on other serial-interface devices such as telemetry transmitters or GPS receivers.

External Interface	**Number**	**Comments**
Bi-directional 0-5V serial ports	4	Muxed; up to 230 kb/s asynch or 860 kb/s synch, if f=7MHz
Interrupts	8	Active low inputs, with 4.7K pullup resistors to 5V
0 to 5V analog input lines	4	10-bit A/D; can each be read at up to ~10 kHz or muxed 8 ways
Timer I/O pins	8	Event-timing; pattern generating, etc.
Other I/O port pins	8	Can be written to or read under DMA control if desired
Other available pins	24	Two 8-bit VHC output latches plus 8 other misc. I/O functions
40V, 1A power switches	6	Power supply is separate but ground is common with board
Other lower-power switches	8	To switch power to expansion boards, DreamNet networks, etc.

Table 3: Other external interfaces

EXPANSION BOARDS

SID allows easy expansion using stacking boards connected by short 10-wire ribbon cables, with mechanical support and heatsinking at the corners. A 55x55x4 mm add-on memory board can add 256 Mbytes of flash memory to the 8 Mbytes on SID itself, and up to 16 such boards can be used if necessary. The 4 unused analog lines can be expanded to 32 muxed channels (with signal conditioning) on a similar board, and an imaging mux board allows the board to select and grab frames from any of 8 cameras. The flash and imaging boards should not add much to average power consumption, because they can operate in standby mode most of the time. But they will increase peak consumption, requiring some attention to battery impedance. (This can be a serious constraint at low temperature, especially near the end of battery life.) Other special-purpose expansion boards can be designed as needed, to use various combinations of the uncommitted resources listed in Table 3. For example, the 0-5V serial ports can be converted to RS232 or RS422; IR or CAN interfaces can be added; and suitable connectors can be added as needed. One other interesting expansion option is a solar cell array. A 55x85 mm array of cells in full direct sunlight can provide roughly enough power to run SID. If connected to rechargeable batteries and mounted under an untinted windshield, such an array may provide enough power for some modest-duty-cycle applications like general-aviation aircraft.

Board	**Comments**
32 channel analog expansion	Uses 4 free A/D channels + 4 octal muxes + signal conditioning
Flash memory expansion	Up to 16 boards can be added, each with sixteen 16Megabyte chips.
Imaging multiplexer	This allows SID to select and grab frames from any of 8 cameras.
Solar cell array	55x85 mm array may be enough to recharge batteries in some cases.

Table 4: Typical expansion boards

PROGRAMMING

Early in our development effort we realized that in many low-volume applications, programming will be the dominant life-cycle cost. So we focused on making the board reflect the structure and capabilities of the CPU, to minimize the need for customizing or extending the software development tools made for the SH CPU itself. The SH family was designed for efficient execution of C code. Hitachi, GNU, and Green Hills provide C and C++ compilers. Stenkil Engineering’s “MakeApp” program is useful for configuring the many intelligent peripherals on the SH7045F. Much of the code development and testing can be done on Hitachi's SH7045EDK Evaluation/Development Kit. That kit includes an interface board and software that allow any PC to reprogram the SH7045F's flash program memory through a serial port. SID uses the same interface board and software for in-circuit program updates, with a special adapter cable. If desired, we can develop application-specific programs for users or assist them in their programming efforts.

CURRENT STATUS

We have built and tested prototypes of the 3 major parts of the board (the sensor section, the digital core, and the power management section). We have laid out 90% of the components and traces for the final board, and expect to have the layout completed and printed circuit boards fabricated before the end of April. Assembled prototypes should be available in May, along with simple programs now being developed on the SH7045EDK. Price for one board with a sample datalogging program will be ~$3K.

CONCLUSIONS

Many applications exist that can benefit from small autonomous data recorders. This new data recorder provides a combination of on board sensors and external interfaces that make it suitable for use in a wide variety of applications, particularly development-intensive applications like early field testing.

ACKNOWLEDGEMENTS

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REFERENCES

Hitachi SH7040 Series Hardware Manual, Version 3.0.
MakeApp for the SH7040 family, available from www.stenkil.com (demo version is free)
Dallas Semiconductor DS2404 Econoram Time Chip datasheet, February 1998.
Photobit PB-159 DX CMOS Active Pixel Digital Image Sensors datasheet, Ver. 3.0, August 1998.

BIOGRAPHIES

Joseph Carroll has worked as a consultant on microcomputer design for remote datalogging and applications of tethers in space since 1981. He founded Tether Applications in 1989 to commercialize a concept he developed at Energy Science Labs under NASA SBIR funding. Tether Applications was the prime hardware contractor to NASA Marshall Space Center on the SEDS-1 and SEDS-2, (Small Expendable-tether Deployment System) flight experiments. SEDS-1 demonstrated controlled deorbit without rockets, using a 20 km tether; SEDS-2 demonstrated passive stabilization of a pair of spacecraft. Tether Applications has also provided tether deployer hardware to Johnson Space Center, the Naval Research Lab, and the European Space Agency. Mr. Carroll has a BA from Catholic University of America (1969). He was awarded a NASA Public Service Medal in 1994 for his work on the SEDS 1 and 2 projects.

Michael Fennell has worked on materials and electronics development projects since 1983. From 1995 to 1996 at Volution Inc. he contributed to the development of a multi-sensor fume, smoke, and fire detector for Navy ships. He was a consultant for Tether Applications for several years, and has been an employee for a year. He has a BA (1983) from Swarthmore College and an MS (1988) from the University of California, San Diego.

Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Crash Recorders to Emergency Medical Services Providers

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KEYWORDS

Highway, Crash, Treatment, Urgency

INTRODUCTION

In 1997, the National Transportation Safety Board (NTSB) made three particular recommendations that are helping to build an "Automatic Lifesaving System for a Safer America". The NTSB is to be commended for its recommendations on crash recorders (H-97-18 and H-97-21), for holding this Symposium, and for its recommendation (H-96-13) to increase funding for motor vehicle safety efforts at the State level.

To the National Highway Traffic Safety Administration (NHTSA):

- *H-97-18 "Develop and implement, in conjunction with the domestic and international automobile manufacturers, a plan to gather better information on crash pulses and other crash parameters in actual crashes, utilizing current or augmented crash sensing and recording devices." [1]*

To the Domestic and International Automobile Manufacturers:

- *H-97-21 "Develop and implement, in conjunction with the National Highway Traffic Safety Administration, a plan to gather better information on crash pulses and other crash parameters in actual crashes, utilizing current or augmented crash sensing and recording devices." [2]*

To the Governors and Legislative Leaders of the 50 States and U.S. Territories, and to the mayor and Chairman of the Council of the District of Columbia:

- *H-96-13 "Emphasize the importance of transporting children in the back seat of passenger vehicles through educational materials disseminated by the State. Consider setting aside one-tenth of 1 percent from all motor vehicle insurance premiums for policies written to establish a highway safety fund to be used for this* ***and other safety efforts****. (Urgent)" [3]*

The first two are on the NTSB's list of "Most Wanted Transportation Safety Improvements." The third recommendation, when fully implemented will generate about $100 million per year for State highway safety efforts. These funds can be used to organize a nationally compatible Automatic Lifesaving System in each State.

This paper addresses the building of a national Automatic Life-Saving System based on these pioneering NTSB recommendations to realize the full potential of new technologies as soon as possible. The work described herein is the result of efforts of a multidisciplinary team of trauma surgeons, emergency physicians, crashworthiness engineers and statisticians. The team examined the safety potential of communicating crash recorder data via wireless telecommunications with Automatic Crash Notification (ACN) technology to improve emergency transport and treatment of crash victims.

The research team developed ***URGENCY*** software for automatic and instant conversion of crash recorder data into a crash severity rating that calculates the probability of the presence of serious injuries in any given crash. ***URGENCY*** software version 1.0, now in the public domain, can improve triage, transport, and treatment decision-making for highway crash victims.

FINDINGS: The Problem

By the year 2005, the U.S. Department of Transportation projects that the annual number of crash deaths will rise to 51,000 people killed per year – despite its current safety programs [4]. Historically in motor vehicle crashes, more than 3 million Americans have been killed, and 300 million injured. That is more than 3 times the number of Americans killed, and 200 times the number wounded in all wars since 1776.

Currently about 42,000 Americans die from crash injuries each year. Nearly 20,000 people die each year before receiving hospital care. Many of the remaining 22,000 people die after reaching hospital too late to be saved. That represents the mortality part of the problem. The morbidity part of the problem involves an estimated 250,000 Americans suffering seriously life-threatening injuries in crashes each year [5,6,7].

The economic costs of crash injuries incurred each year amount to an estimated $100 billion in current dollars. Including compensation values for intangibles such as pain & suffering, the comprehensive costs of crash injuries incurred each year amount to about $350 billion [7]. The human costs to individuals and families of the deaths, injuries, and disabilities incurred in crashes, each year, are unmeasured tragic losses.

Each year, on the 4 million miles of roads in the U.S., 5 million Americans are injured in 17 million crashes involving 27 million vehicles. Among those 27 million crash-involved vehicles, approximately 250,000 Americans suffer seriously life-threatening injuries -- at unpredictable times and places [7]. Thus, the focus of this research was "How to identify, rapidly and automatically, those vehicles in which the 250,000 people are seriously injured and need time-critical emergency care?"

Currently, of the 42,000 crash deaths each year, nearly 20,000 victims die at the scene. At the scene, about 13,500 people die from injuries in rural crashes and about 6,500 in urban crashes. Of the 22,000 crash deaths that are taken to hospital, many die because they arrive too late to be saved. Thousands of crash deaths occur each year in which the victim did **not** arrive at a hospital – much less at a trauma center -- within the "Golden Hour."

The Safety Improvement Solution: Time, Technology, and Urgency Information
Time Available to Prevent Deaths and Disabilities:
Emergency medical care experience has shown that for many serious injuries, time is critical. As described by RD Stewart:

> "Trauma is a time-dependent disease. 'The Golden Hour' of trauma care is a concept that emphasizes this time dependency. That is in polytrauma (*typically serious crash victims suffer multiple injuries*) patients, the first hour of care is crucial, and the patient must come under restorative care during that first hour…. Pre-hospital immediate care seeks to apply supportive measures, and it must do so quickly, within what has been called the 'Golden Ten Minutes.'" [8]

The goal in trauma care is to get seriously injured patients to a trauma center for diagnosis, critical care and surgical treatment within the "Golden Hour" [8, 9,10,11]. To get the seriously injured patient into the operating room of a trauma center with an experienced team of appropriately specialized trauma surgeons within the "Golden Hour" requires a highly efficient and effective trauma care system.

The time/life race of the "Golden Hour" to deliver patients to definitive care consists of the following elements:

(1) Time between crash occurrence and EMS Notification,
(2) Travel time to the crash scene by EMS,
(3) On-scene EMS rescue time,
(4) Transport time to a hospital or trauma center,
(5) Emergency Department resuscitation time.

Now, increasingly, there are new opportunities in each category to act more rapidly and effectively to transport patients to definitive care within the "Golden Hour."

The need and the opportunities are especially important on rural roads where more than 24,000 fatalities occur in crashes each year. Data collected by the National Highway Traffic Safety Administration (NHTSA) show that only 24 percent of crashes occur on rural roads, but nearly 59 percent of the crash deaths occur on rural roads. "Delay in delivering emergency medical services is one of the factors contributing to the disproportionately high fatality rate for rural crash victims." according to NHTSA [12].

In urban areas there are about 17,000 fatalities each year. In both urban and rural areas, a substantial number of fatal crashes occur at night or early morning. About 16,000 (43%) fatal crashes occur each year between the hours of 9:00pm and 9:00am, times when crash discovery, notification and emergency response are more likely to be slower. Table 1 lists the ***average*** time intervals experienced in fatal crashes in the U.S. in 1997 [13]. Entry number 5 for the Emergency Department Resuscitation time interval is not based on data, but is an assumed value of 15 minutes for the purpose of relating pre-hospital times to the "Golden Hour" for the delivery of definitive care to save seriously injured patients.

Table 1. Average Elapsed Times in Fatal Crashes in 1997 (Minutes)

Time Intervals	***Urban***	***% Unknown***	***Rural***	***% Unknown***
1. Crash to EMS Notification	4	48	7	35
2. EMS Notification to Scene	6	49	11	34
3. Scene Arrival to Hospital	26	72	36	67
4. Crash to Hospital Arrival	35	72	52	68
5. ED Resuscitation (No Data)	*15*	*100*	*15*	*100*
Totals	50		**67**	

Note: Average times consist of shorter and longer times and vary greatly by State.

1. Elapsed Time from Crash to EMS Notification:

More than 10 minutes elapse before EMS is even notified (much less able to deliver pre-hospital emergency care within the Golden Ten Minutes) in thousands of fatal crashes each year. In 1997, there were 21,809 fatal crashes with both times recorded, or 59% of the total 37,280 fatal crashes. Among the crashes with recorded times, EMS Notification exceeded 10 minutes in 2,707 (19.4%) of the rural fatal crashes, and in 497 (6.3%) of the urban fatal crashes. Reported fatal crashes with long elapsed notification times amounted to 3,204. Among the 15,471 fatal crashes with unreported times, there probably were many more long elapsed EMS Notification times that would raise the total.

Since 1992, there has been a steady reduction in the national ***average*** of both rural and urban fatal crash notification times -- down about 30%. This improvement has been coincident with, and apparently significantly caused by, the increasing use of wireless telephones by "Good Samaritans." (Note, however, that comparable improvements have **not** been observed in the subsequent critical time intervals discussed below.[5])

In the future, ACN will reduce many of the longer times dramatically. With ACN, ***all*** crash notification times, not just ***average*** notification times, will be reduced to about ***one minute***. Reductions in rural ***average*** crash notification times from 9 minutes to 1 minute after the crash have been estimated to potentially save 3,000 lives per year [14].

2. Elapsed Time from EMS Notification to EMS Arrival at the Scene:

In the future, ACN, ***URGENCY***, crash location information, and navigation equipment on board rescue vehicles increasingly will be able to shorten this time interval.

3. ***Elapsed Time from EMS Arrival at Scene to EMS Arrival at Hospital:***

In the future, ACN + ***URGENCY*** technology will help dispatchers, instantly and automatically, decide to send extrication equipment in severe crashes, thereby, saving additional precious minutes in this time interval.

4. ***Elapsed Pre-hospital Times – Time of Crash to Hospital Arrival:***

Nationwide, data (where both times are reported) show that in about 2,300 fatal crashes each year, this time from crash to hospital (not necessarily Trauma Center) arrival, **exceeds 60 minutes**. The actual number is much greater considering the large number of crashes where times were unknown.

In the future, ACN + ***URGENCY*** information and navigation technologies will make it possible to greatly increase the number of people in potentially fatal crashes who get to hospital well within 60 minutes.

5. ***Emergency Department Resuscitation Times:***

Current medical references allocate **15 minutes** to Emergency Department (ED) resuscitation times for tests, diagnoses, decision making on treatment strategies, and required pre-operating room procedures before surgical care [11]. Table 1 adds the needed 15 minutes for ED resuscitation to the ***average*** reported times [13]. The result is that on rural roads with the average of 52 minutes that it takes to get a seriously injured patient to a hospital (often not a trauma center) in the average fatal crash, the "Golden Hour" is lost. Thus, the "Golden Hour" is exceeded in many thousands of fatal crashes each year. And currently, too many time/life races are lost.

In the future, ***URGENCY*** information on injury probabilities that are transmitted ahead to the hospital at the time of crash probably will include pre-existing medical conditions, blood types, reactions to medications, etc., that will help reduce time currently lost in this time interval.

Lost "Golden Hours" and Lost Lives - During 1996 and 1997, for example, the reported ***average*** elapsed time from crash to arrival at a hospital (without time measured for ED resuscitation) in rural fatal crashes exceeded 60 minutes in eight States. The States in alphabetical order were: Arizona, Louisiana, Michigan, Montana, Nevada, North Dakota, Texas, and Wyoming [13].

In 1997, there were 37,280 fatal crashes in the U.S. Data from 'time of crash' to 'time of hospital arrival' is available for 11,075 (or only 30%) of these fatal crashes. Among the 11,075 fatal crashes with both times reported, there were 2,336 fatal crashes where the elapsed time to hospital arrival was reported to have exceeded 60 minutes. Thus, **21%** of all fatal crashes with both times recorded exceeded 60 minutes [13]. If times were reported in all cases, not just cases with recorded times, the number of all fatal crashes exceeding 60 minutes would be much higher. Table 2 provides data on the number of fatal crashes reported with time of hospital arrival exceeding the "Golden Hour" increasing over the period 1993 through 1997.

Table 2. Fatal Crashes
Reported Elapsed Times from Crash to Hospital Arrival
Between 61 - 120 Minutes (Number & Percent Reported)

Elapsed Times	1993 Urban	1993 Rural	1994 Urban	1994 Rural	1995 Urban	1995 Rural	1996 Urban	1996 Rural	1997 Urban	1997 Rural
>60min	301	1,817	346	1,934	314	1,897	323	1,995	319	2,017
Reported	7.4%	29.2%	7.7%	30.9%	7.5%	30.8%	7.4%	30%	7.5%	29.6%

New Technologies:

As described in ***AirMed*** [15], the technologies are now increasingly available to make dramatic improvements in public safety through faster and smarter emergency medical care:

- Wireless telecommunications technologies now enable people to make calls for emergency help without having to search for a land-line telephone, thereby, saving precious minutes from crash notification times.
- Wireless location technologies and Global Positioning System (GPS) technologies can enable calls to be instantly located by emergency responders – thereby taking the "search" time out of "search and rescue".
- Air bag crash sensor technologies on board vehicles now enable objective and instant measures of the severity of crashes. These crash severity sensor measurements can be automatically communicated to EMS providers, via cellular telephone, as a simple numerical probability of the presence of a serious injury. This will save the time currently lost while waiting for the first responder to travel to the scene for visual evaluation of the seriousness of the crash before dispatch of appropriate EMS care such as helicopter rescue.

Automatic Crash Notification (ACN) technologies using crash sensors, GPS, and wireless telephones are now being installed on production cars. Automobile manufacturers including GM, Ford, BMW, and Nissan are offering first generation versions of ACN technology (that report when an air bag deploys) in 1999 model year vehicles in the U.S. The U.S. Department of Transportation (DOT) currently is installing a more advanced version of ACN technology in 1,000 vehicles in the Buffalo, New York area. This ACN system, built by Calspan, measures crash forces in all types of crashes (not just air bag deployment crashes) and automatically transmits ***URGENCY*** injury severity probabilities.

The DOT contract with the Calspan Corp. of Buffalo, N. Y., is testing this advanced ACN technology that provides for an automatic, crash-activated, call for help using an on-board cellular telephone to transmit voice and data. The call electronically communicates information on the location of the crash and the severity of the crash (for all major crash modes: frontal, side, rear impacts, and rollover). It also transmits data on vehicle pre-crash speed, direction of travel, and vehicle identification information including many attributes such as vehicle type. The equipment is being installed by the Cellular One Company in a fleet of 1,000 vehicles in the Buffalo area. The Erie County Medical Center is participating in the evaluation of this system. ***URGENCY*** software is in use with the Calspan system currently, and in the future can be used on all motor vehicles.

Urgency Information:

In March of 1997, for the first time, the research team developed ***URGENCY*** version 1.0 computer software to improve computer-assisted dispatch of rescue resources using crash recorder data. The goal was to develop a system that instantly, and automatically, identifies the approximately 250,000 crash vehicles with serious injuries from among the 27 million vehicles in crashes each year.

The ***URGENCY*** triage algorithm was developed by the team to predict injury severity probabilities based on vehicle, occupant, and crash parameters. All parameters, for which data was available, were evaluated in terms of their power to predict the probability of serious injury. Through an extensive series of logistic regression analyses of national crash data files, the team related crash forces (measurable in crash severity recorders) to serious injury probabilities. Probabilities were developed for all major crash modes: frontal, side impacts, rear impacts, and rollovers – both individually and in combination to cover complex crashes. Injury probabilities were calculated for vehicle and crash severity parameters of Crash Force (Crash Delta Velocity), Principal Direction of Crash Force, Rollover (number of quarter turns), Vehicle Weight, and Safety Belt Use.

Injury probabilities were also developed for the powerfully predictive occupant and crash parameters of Age, Gender, Entrapment, and Ejection -- data that may be obtained by EMS dispatchers via hands-off, two-way cellular communications with the vehicle occupants and bystanders. The Age parameter, for example, predicts that the probability of a serious injury for a 50-year-old in a crash of a given Delta V is nearly double the probability of serious injury for a 25-year-old [16].

With ***URGENCY*** software, upon vehicle impact, crash sensor measurements are instantly, and automatically, translated into a single figure rating of urgency from 0 to 100% probability of a serious injury being present in the crash.

Figures 1 and 2 show an ***URGENCY*** bar chart that a dispatcher would see on the computer screen and a map location of the crash site. For example, Figure 1 shows an ***URGENCY*** reading of 89% probability of the presence of at least one serious injury of AIS 3, or greater, severity. In this example, this 89% ***URGENCY*** rating would be triggered in a side impact crash of 38 mph Delta V, involving a rollover with a female occupant (age and gender can be programmed into the vehicle algorithm as the principal driver).

Future versions of ***URGENCY*** will include other sensor data such as pre-crash speed and braking deceleration, crash pulse, air bag time and level of deployment, seat belt forces, door openings, presence or absence of fire, and number, size and seating positions of occupants. In addition, medical records can be used in upgraded ***URGENCY*** computations. Medical records also can be instantly sent electronically to the Emergency Department containing data on blood type, drug reactions, current medication, etc., so that this information arrives before the patient arrives, and further expedites and improves emergency treatment decision-making. [A free copy of ***URGENCY*** Software 1.0 is available on request from HRChampion@aol.com]

To gain the benefits of this exciting and far-reaching capability, continued research is needed to relate these new variables to injury probabilities. Further development of the ***URGENCY*** algorithm based on interdisciplinary research is vital. Investigation and documentation of crashes with recorders needs to be accelerated. The injuries to occupants need to be correlated with data from the recorders. The cooperation of trauma physicians, crash investigators, biomedical engineers, trauma care providers, and vehicle safety engineers is essential to the rapid and accurate development of this breakthrough safety technology.

Taken Where - Trauma Center, Nearest Hospital, or Morgue?

During the past ten years, nearly 400,000 Americans died from crash injuries. Nearly 50 percent were ***not taken*** to a hospital for treatment [5]. In too many cases, especially in rural areas, people die without having obtained definitive care at a trauma center within the "Golden Hour." Definitive care includes thorough, timely, and accurate diagnoses, intensive critical care, and trauma teams with surgeons specialized in brain injuries, internal organ injuries, and orthopedic injuries.

Currently, each year, 20,000 people die at the scene. The problem is greater in rural areas. Although in rural and urban areas the number of crash deaths of people taken to a hospital for treatment are about equal at 10,500 per year, the number ***not taken*** in rural areas (13,500) is about twice the number in urban areas (6,500). [Historical data by State are available upon request from HRC.]

Notification times and response times will improve with ACN and ***URGENCY*** technologies. Helicopter and other emergency response vehicles will be able to reach the scene faster using on-board navigation systems that will use the ACN crash location coordinates. Rescuers also increasingly will have on-board navigation guidance to the scene via the "fastest route." And with instant ***URGENCY*** information on the probability of serious crash injury, we will be able to do a better job saving lives and preventing disabilities by taking people to the right place the first time, rather than to the wrong place [17, 18].

URGENCY software will enable us to advance beyond current rescue practices – especially regarding helicopter dispatch. In general, under current practices, when a crash occurs – however serious it may be – someone in authority (police, fire or EMS) first, must travel over land to the scene, second make a determination that the seriousness requires a helicopter response, and third send a radio request for air medical assistance. And if, and when, the request is granted, only then does the process of helicopter deployment begin. In the future, computer assisted dispatch protocols will be developed that will expedite this process – with lifesaving results.

The Benefits

Several projections of benefits estimate that thousands of lives could be saved each year. The U.S. DOT cites a study projecting that benefits of an ACN system would result in a 12% reduction in rural crash deaths and save an estimated 3,000 lives each year when all rural crash notification times are reduced to 1 minute [14]. The Europeans project a 15% increase in survival rates from in-vehicle "automatic emergency call" systems [19]. The Japanese aim to cut in half their current emergency response times [19]. In addition to lives saved, it is reasonable to expect significant reductions in disabilities and human misery through the faster and more intelligent delivery of emergency medical care for non-fatal, but serious, injury crashes.

Perhaps the most significant benefits of ACN + ***URGENCY*** will result from the data generated on crashes, injuries, treatments and outcomes. This data will form the scientific basis for continuous improvements in vehicles, roadways, driver behavior and emergency care. Programs in crash injury prevention and treatment will have a new scientific resource for advances in the protection of the motoring public.

The Race To Produce Automatic Lifesaving Systems

Currently in the race to produce a national Automatic Lifesaving System, Japan is ahead of the U.S. and the rest of the world. Toyota, Nissan, and other auto manufacturers plan a national ACN program in Japan in cooperation with the National Police Agency, the Fire Defense Agency, and telecommunications companies. Daimler-Benz also announced plans to start a similar emergency call service in Japan on September 1, 1998. E Call Japan was set up jointly by Daimler-Benz, Nippon Telegraph and Telephone Corp., Tokio Marine and Fire Insurance Co. and others. The auto manufacturers expect that these ACN services will halve the current average emergency response time of 30 minutes in Japan [19].

In America, a group of physicians, nurses, law enforcement groups, and others have joined with wireless communications companies to create the ComCARE (Communications for Coordinated Assistance and Response to Emergencies) Alliance. The ComCARE Alliance supports legislation to accelerate ACN development and deployment.

Now that basic research has been done, there remains an urgent need for a national program in America, under medical direction, to involve the nation's emergency medical infrastructure. Leadership, time, people, and money are needed to deliver the lifesaving benefits that are now possible with deployment of these technologies. Systems will have to be improved at all trauma centers/systems to apply this technology. This will involve systems integration of hardware and software, development of new protocols, and training to deliver the benefits of improved triage, transport and treatment to people in need of urgent care.

To create an Automatic Lifesaving System nationwide we need to expand the research, development, testing and evaluation (RDT&E) program of the 1,000 cars in Erie County, N. Y. One problem is that this fleet is too small to experience enough serious injury crashes. Statistically we can expect less than one serious injury crash during the one-year test. This operational test needs to be expanded to increase both the number of vehicles and the length of the test period -- and to be conducted at a larger number of trauma centers geographically located across the nation – at least one in each of the 50 States. The Automatic Lifesaving System must be nationally compatible so that a motorist from one State can be similarly protected as the car travels across State lines.

Congress has already funded DOT research on crashes at trauma centers in 9 States (AL, CA, DC, FL, MD, MI, NJ, NY, and WA). This research needs to be expanded to each of the remaining States.

Congress authorized $2 million, per year, for the next 6 years to perform research at a new Calspan research center at the State University of NY at Buffalo. RDT&E programs in each of the 50 States are needed for trauma care systems to upgrade the necessary emergency medical infrastructure in each state to deliver the full lifesaving potential of these technologies to the American people. A proposal of $100 million per year in research may seem costly, but in fact, it is far more costly to ***not*** conduct such a program. The savings become clear when the proposal is compared with the more than $150 million in new economic costs ($600 million in comprehensive costs) incurred by the 115 crash deaths and 500 serious injuries that occur on U. S. roads - ***every day.*** This research will lead to the saving of many lives each day. In fact, one-percent improvement, i.e., saving just one life each day, will save the nation far more than the cost of the program.

The U.S. Department of Transportation (DOT) is currently spending less than 0.01 percent of the $38 billion per year DOT budget on Automatic Crash Notification. Yet motor vehicle crashes account for more than 90 percent of the nation's transportation safety problem.

Building A Safer America

To build a safer America, we must create a system by which the emergency medical community continuously improves its ability to deliver care. ACN technology provides an opportunity and a mechanism for the continuous improvement of emergency medical care. ACN can generate the data for quality improvement programs at all levels of prevention and treatment.

With a medically directed national program of research, development, testing and evaluation we can improve the nation's emergency medical infrastructure to use these technologies to deliver definitive care. As we do so, we will create a research mechanism for continuous improvement of emergency medical care in its broadest sense. The benefits of ACN technology to the public will be much broader and greater than just improving care for crash victims. For example, when cars are so equipped, citizens (for themselves or as Good Samaritans) will be able to make emergency calls for such incidents as heart attacks, strokes, injuries due to falls and other causes—even crimes.

The ability to make instantaneous wireless calls for emergency help (with automatic location) has been strongly identified in market research, both by the auto industry and the cellular industry, as products and services the public is willing to pay for as consumers. One market research study found that 48% of car buyers said that Automatic Dial 911 Safety equipment is "important" or "very important" in their purchase decisions [20]. More recently, a Louis Harris poll for Advocates for Auto and Highway Safety found 68% would like to have such safety equipment in their car [21].

GM recently offered its ($1,300 MSRP) OnStar equipment free with "installation at no extra charge on every new Buick" model under the advertisement headline: "You can't put a price tag on security. So we didn't." However, GM does require a one-year pre-paid OnStar subscription and cellular service. [22]. And GM's OnStar currently only provides crash notification to a private OnStar call center, that then calls for public "911" rescue service. And OnStar currently is limited to only those crashes in which an air bag deploys (primarily frontal crashes, not rollovers, side, and rear impacts).

The cost of the more advanced ACN safety equipment provided by Calspan that covers all crash modes, according to Calspan and the government is estimated "at between $200 and $300" [23]. Moreover, the cost of electronics equipment is dropping fast as the technologies and competition develop and production volume increases.

The public clearly wants, and the technology is now available for, an intelligent transportation system that delivers help wherever and whenever Americans are in danger—in time to save lives.

CONCLUSIONS AND RECOMMENDATIONS

The research team concluded that significant improvements in emergency care could be achieved by using new technologies. The lifesaving and disability-reducing benefits of faster, and more informed, emergency responses are expected to be substantial. Instant, and automatic, communications of information on crash occurrence, location, and injury probability via wireless communications to EMS could save thousands of lives each year [14, 19]. To realize the lifesaving and disability reducing benefits of this technology requires a nationally coordinated program to develop a nationally compatible system of major trauma care for crash victims. Nationally coordinated multidisciplinary research, development, testing, and evaluation on a state-by-state basis is needed.

The recommendations of the NTSB already are moving the nation to a safer highway environment. Further attention by the NTSB is needed to develop and deploy the nation's Automatic Lifesaving System as soon as possible to reduce the losses in lives and livelihoods of thousands each year. As the NTSB considers both the immediate and intermediate-term uses of crash recorder data for the continuous improvement of safety on U.S. roads, its recommendations will move the nation closer to becoming a safer America.

Hopefully the NTSB will consider issuing additional recommendations to governmental agencies at the federal and State levels, as well as to private sector organizations to build the Automatic Lifesaving System.

- Federal and State agencies, i.e. GSA and State Police Departments, could purchase Calspan-type crash recorders for their vehicles to begin the R. D. T. & E. process of saving lives and encouraging deployment of this technology as was done with air bag technology in the 1980's. In the 1980's air bag demonstration fleets purchased by GSA and insurance companies saved the lives of employees and provided market incentives for air bag technology development. Today, Calspan-type ACN crash recorders can be installed on new vehicles (or retrofitted on existing fleets) for less than $300 per car. A fleet of 50,000 cars could cost about $15 million. Such a fleet size is needed to achieve statistically significant results.

  Such a national operational test program could be conducted with University-based Trauma Centers doing crash injury investigation work in each of the 50 States. This could be part of an expanded NHTSA Crash Injury Research and Engineering Network (CIREN) currently in operation at 7 Trauma Centers. The results of crash investigations in each State will provide valuable information to the various agencies of State and local governments on how to improve both the technology and the safety systems in their State.

  Indeed, the NTSB could be connected to the existing CIREN centers, and ultimately to an expanded 50-State CIREN, so that it can electronically obtain all cases as they are entered into the CIREN system. This would give NTSB an expanded real-time data collection tool in serious injury highway crashes. Thus, the NTSB could economically become more scientifically involved in medical and engineering investigations of a larger number of serious injury motor vehicle crashes each year. Such an increase would result in a level of NTSB involvement more commensurate with the magnitude of the safety problems posed to the nation by motor vehicle crashes than is possible with current NTSB resources.

- Governors need to direct the resources of their State highway and police departments, State University Medical Centers, Trauma Centers, EMS, and highway safety offices to develop the wireless safety communications and the emergency transport and treatment infrastructures into statewide systems that are nationally compatible. The Federal government has an important role to fulfill in improving emergency transportation in all modes, especially helicopter rescue, when so many avoidable tragedies are time-critical. This role includes coordinating nationally compatible emergency communications standards and crash recorder data standards.

- Until such time that all vehicles are equipped with ACN + ***URGENCY*** systems integrated into a national Automatic Lifesaving System, we need to do a better job of locating crashes as soon as possible using existing wireless location technology. The FCC has ruled that wireless 911 calls shall have location information imbedded in the calls by the year 2001. Unfortunately, and fatally for many Americans, that rule is not being implemented on schedule. The wireless industry currently transmits nearly 100,000 emergency 911 calls each day – without location information imbedded in the call [24]. This is creating a major problem for emergency responders who don't know where the caller is located. Leadership is needed to move the nation to rapidly apply existing wireless location technologies. We must do better building the wireless infrastructure for the existing 70 million wireless phone users. They often could be helped with embedded location signals when they are endangered on our roads. They also could be more effective in their efforts as "Good Samaritans" to save their fellow Americans.

- Crash recorder data could be used in a national program for continuous improvements in the prevention and treatment of crash injuries. The systematic capture and organization of crash recorder data will enable citizens, governments (at all levels) and the auto, insurance, and health care industries to contribute to the building of a safer America on a solid scientific foundation of objective data. The technological availability of crash recorder data now provides the nation with the opportunity to improve upon the triage guidelines currently in use worldwide based upon work done a decade ago [25]. For one example of additional benefits with systematized crash recorder data, state highway departments could obtain a wealth of information, including location, on all serious injury crashes for continuous system improvements.

- As recommended recently by the National Academy of Sciences, in its Report Reducing the Burden of Injury, the need is clear for a federal re-commitment to Trauma Center/System Development in each of the 50 States to save people suffering from serious, time-critical, injuries. Whether the time-critical injuries are the result of crashes or other causes, the timely delivery of emergency care will help save lives and livelihoods. In addition, an advanced trauma care system will also result in saving the lives of people suffering from time-critical illnesses such as strokes and heart attacks and needing rapid and safe emergency medical transport and care [26].

Time is of the essence. But, it's not just a matter of time before we all have the safety benefits of these new technologies. It's also a matter of societal urgency that will determine how many avoidable tragedies the nation must experience before the Automatic Lifesaving System is saving lives. Building a safer America is a matter of time, money, public policy, political leadership and most importantly – peoples lives – both those lost and those saved.
Note: Table 3 provides a ranking of the States by 1997 crash fatality rates per 100,000 population.

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REFERENCES

1. National Transportation Safety Board, Proceedings of the National Transportation Safety Board Public Forum on Air Bags and Child Passenger Safety, NTSB/RP-97/01, PB97-917001, October 1997, p. 17.
2. id., p. 18.
3. id., p. 27.
4. Testimony of Mortimer L. Downey, Deputy Secretary, U.S. Department of Transportation, before the U.S. Senate Committee on Environment and Public Works, Subcommittee on Transportation and Infrastructure, Feb. 13, 1997, p. 11.
5. NHTSA, Fatality Analysis Reporting System (FARS), Automated Data Files.
6. NHTSA, National Accident Sampling System (NASS), Automated Data Files.
7. NHTSA, The Economic Cost of Motor Vehicle Crashes, 1994, DOT HS 808 425, July 1996, pp. 1, 7, 8, 9, 59.
8. Stewart, RD, "Pre-hospital Care of Trauma," Chapter 3, p. 24, in McMurtry, R.Y. and McLellan, BA, Management of Blunt Trauma, Baltimore: Williams and Wilkins: 23-29; 1990.
9. JD Mayer, "Response Time and its Significance in Medical Emergencies," The Geographical Review, p.79. As noted by JD Mayer:
   "The Emergency medical Systems Service Act (EMSS Act) of 1973 was passed by Congress to promote systematic planning and evaluation of regional emergency systems. The Act represented an attempt to coordinate a number of components in pre-hospital emergency cases, such as transportation, personnel, and facilities. One of the provisions of the EMSS Act is that 95 percent of all ambulance response times must be within twenty minutes in rural areas and within ten minutes in urban areas." (In 1996, only the state of Mississippi had average response times of greater than ten minutes in urban fatal crashes.)
10. M Smith, "Mechanism of Injury," Paramedic Field Care: A Complaint-Based Approach, American College of Emergency Physicians, 1997, edited by PT Pons and D Cason, Mosby-Year Book, St. Louis, MO. As taught in the text book Paramedic Field Care: A Complaint-Based Approach:
    "Once a traumatic event has occurred, the survival clock begins ticking. The longer it takes to deliver a seriously injured patient to definitive care at the hospital, the less likely the patient's survival becomes. The time that passes during on-scene care is irreplaceable; whenever possible, it should be limited to 10 minutes or less."
11. NE McSwain, Jr., "Pre-hospital Care, Chapter 8," Trauma, 3rd Edition, DV Feliciano, EE Moore, KL Mattox, Appleton & Lange, 1996, pp. 109-110. As summarized in the reference work Trauma:
    "The standard that field time should be no longer than 10 minutes….gained rapid recognition and acceptance by most EMS services that had strong medical control. Because

of a lack of good physician leadership, some ambulance services did not adapt these tenets at an early point.

"Unfortunately, the time saved by good EMS services in the field was in many instances rapidly wasted in the emergency departments of hospitals, since most communities did not initially develop good trauma systems that mandated that patients be taken to a hospital that had a medical/surgical staff, nursing staff, OR staff, and protocols that rapidly took the patient to the operating room when required. Even in the mid-1990's many cities have still not developed such a trauma system. Time saved by efficient EMS services is lost by unprepared in-hospital emergency services that are unready to receive patients and not organized to provide rapid care. Hospitals that have not dedicated themselves to the management of trauma patients must be 'bypassed' for hospitals that are so prepared. Such trauma centers have a staff in house and immediately available to handle such patients.

12. NHTSA, 1998 Strategic Plan of the NHTSA, *Promoting Safe Passage into the 21st Century*, September 1998, DOT HS 808 785, p. 30.
13. NHTSA, Traffic Safety Facts 1996, DOT HS 808 649, December 1997, pp. 48, 158-161 and NHTSA, Traffic Safety Facts 1997, DOT HS 808 806, November 1998, pp. 48, 170-173.
14. W Evanco, "Reducing Accident Fatalities with Rural Mayday Systems," Mitretek Systems, Inc. WN 96W0000048, April 1996, as referenced in U.S. Department of Transportation, Federal Highway Administration, Review of ITS Benefits: Emerging Successes, Publication No. FHWA-JPO-97-001, HVH-1/10-96(1M) E, p. 19.
15. HR Champion, JS Augenstein, B Cushing, KH Digges, R Hunt, R Larkin, AC Malliaris, WJ Sacco, JH Siegel, "Automatic Crash Notification," AirMed, March/April 1998, p. 36. Also in HR Champion, JS Augenstein, B Cushing, KH Digges, R Hunt, R Larkin, AC Malliaris, WJ Sacco, JH Siegel, "Urgency for a Safer America," AirMed, March/April 1999, pp.18-23.
16. AC Malliaris, KH Digges, JH DeBlois, "Relationships Between Crash Casualties and Crash Attributes," SAE 970393, February, 1997. The development of the ***URGENCY*** triage algorithm reported in this paper was part of a multidisciplinary team's effort and was presented to the NHTSA Administrator in a briefing March 27, 1997. The multidisciplinary team was led by HR Champion, and included JS Augenstein, B Cushing, KH Digges, RC Hunt, R Larkin, LV Lombardo, AC Malliaris, W. Sacco, JH Siegel.
17. JS Sampalis, R Denis, P Frechette, R Brown, D Fleiszer, D Mulder, "Direct Transport to Tertiary Trauma Centers versus Transfer from Lower level Facilities: Impact on Mortality and Morbidity among Patients with Major Trauma," Journal of Trauma, Vol. 43, No. 2, August 1997, p. 288.
18. 17 RE Falcone, H Herron, H Werman, M Bonta, "Air Medical Transport of the Injured Patient: Scene versus Referring Hospital," Air Medical Journal, Vol. 17, No. 4, October-December 1998, p 161.
19. ***Asia Pulse***, "Toyota, Other Automakers to Begin Automatic Emergency Call Service," Nihon Keizai Shimbun, Nationwide Financial News, August 24, 1998. The Europeans also are working on reducing EMS response times with on-board Mayday systems. Europeans estimate that the systems will increase survival rates by 15%. See ERTICO, A Twenty Year Vision for Europe, "Expected Benefits of ITS," http://www.ertico.com/ertico/vision/5con.html. For a U.S. Government agency's view of the potential benefits see US Department of Transportation, Federal Highway Administration, ITS Benefits: Continuing Successes and Operational Test Results, Publication Number: FHWA-JPO-98-002,12/97(1.5M)EW, October 1997, Washington, DC.

20. Dohring Co., Automotive News, Feb 10, 1997, p. 56.
21. Advocates for Highway & Auto Safety, @ www.saferoads.org/general/highlights.html
22. GM, AARP Bulletin, Vol. 39, No. 11, Dec. 1998, p. 24. On February 25, 1999 GM's OnStar announced a reduction in the manufacturer's suggested retail price to $695 including installation (from the previous MSRP of $1,300).
23. Catherine Strong, Associated Press, "Feds Test Auto Crash Rescue System," May 11, 1998 (15:47 EDT).
24. Cellular Telecommunications Industry Association (CTIA), Thomas E. Wheeler, Press Release, May 20, 1997, and updated in ComCARE Alliance, Press Release, May 12, 1998, and CTIA, Press Release, February 24, 1999.
25. IS Jones, HR Champion, "Trauma Triage: Vehicle Damage as an Estimate of Injury Severity," Journal of Trauma, Vol.29, No. 5, May 1989, p. 646.
26. Committee on Injury Prevention and Control, Institute of Medicine, National Academy of Sciences, Reducing the Burden of Injury, Advancing Prevention and Treatment, Washington, DC, 1999, pp. 1-17.

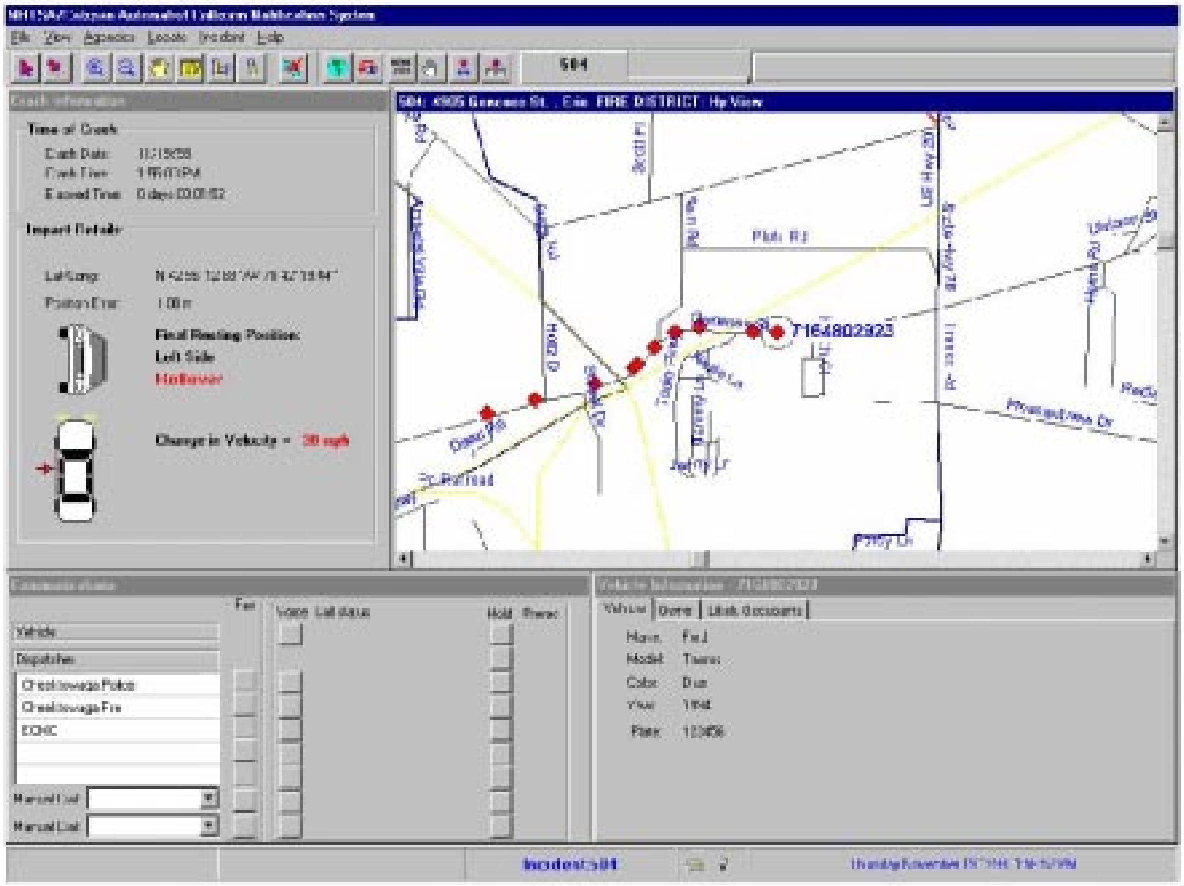
504
Time of Crash
Impact Details
Final Resting Position:
Left Side
Rollover
Change in Velocity =
7164802923
Vehicle
Dispatcher
Cheektowaga Police
Cheektowaga Fire
ECMC
Manual Dial
Voice
Hold
Make
Model
Color
Year
Plate

Figure 1

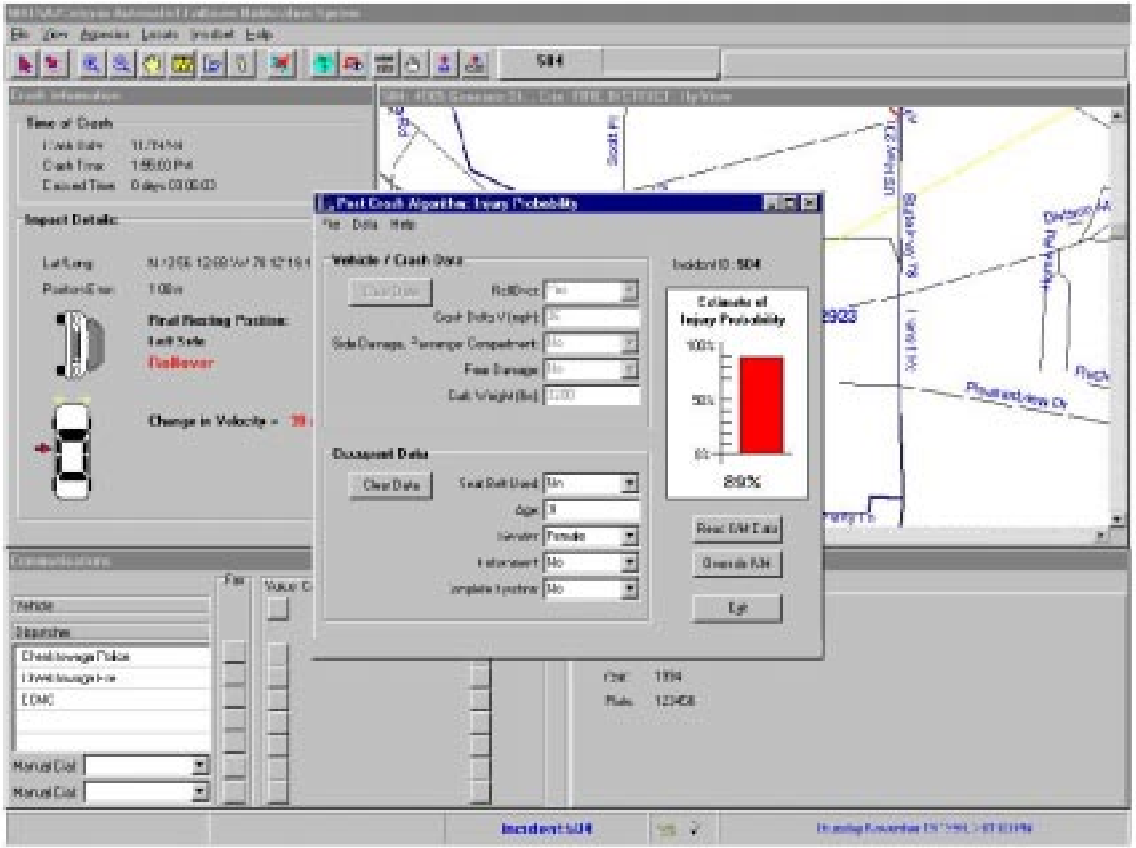
Time of Crash
Impact Details:
Final Resting Position:
Left Side
Rollover
Change in Velocity =
Post Crash Algorithm: Injury Probability
Vehicle / Crash Data
Clear Data
Occupant Data
Clear Data
Seat Belt Used
Age
Gender
Female
Incident ID: 504
Estimate of Injury Probability
100%
50%
89%
Exit
Vehicle
Dispatcher
Manual Call
Manual Call
Incident 504
504

Figure 2

Table 3:

1997 Crash Deaths & Death Rates per 100,000 Population by State & Rank			
State	1997 Deaths	Death Rate	U.S. Rank
MS	861	31.5	51
MT	265	30.1	50
WY	137	28.5	49
NM	484	28.0	48
AL	1,189	27.5	47
AR	660	26.2	46
OK	838	25.3	45
SC	903	24.0	44
TN	1,223	22.8	43
MO	1,192	22.1	42
KY	857	21.9	41
ID	259	21.4	40
GA	1,577	21.1	39
LA	913	21.0	38
AZ	951	20.9	37
WV	379	20.9	36
NV	347	20.7	35
SD	148	20.1	34
NC	1,483	20.0	33
DE	143	19.5	32
FL	2,782	19.0	31
KS	481	18.5	30
NE	302	18.2	29
TX	3,510	18.1	28
UT	366	17.8	27
IA	468	16.4	26
ND	105	16.4	25
VT	96	16.3	24
OR	523	16.1	23
IN	935	15.9	22
CO	613	15.7	21
ME	192	15.5	20
MI	1,446	14.8	19
VA	984	14.6	18
WI	725	14.0	17
PA	1,557	13.0	16
OH	1,441	12.9	15
MN	600	12.8	14
AK	77	12.6	13
WA	676	12.0	12
MD	608	11.9	11
IL	1,395	11.7	10
CA	3,688	11.4	9
DC	60	11.3	8
HI	131	11.0	7
NH	125	10.7	6

CT	338	10.3	5
NJ	774	9.6	4
NY	1,643	9.1	3
RI	75	7.6	2
MA	442	7.2	1
1997 U.S.	Total: 41967	US Avg 15.7	

Recording Automotive Crash Event Data

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Keywords: Highway/Automotive/Event/Recorder

INTRODUCTION

The National Transportation Safety Board has recommended that automobile manufacturers and the National Highway Traffic Safety Administration work cooperatively to gather information on automotive crashes using on-board collision sensing and recording devices. Since 1974, General Motors' (GM) airbag equipped production vehicles have recorded airbag status and crash severity data for impacts that caused a deployment. Many of these systems also recorded data during “near-deployment” events, i.e., impacts that are not severe enough to deploy the airbag(s). GM design engineers have used this information to improve the performance of airbag sensing systems and NHTSA researchers have used it to help understand the field performance of alternative airbag system designs. Beginning with the 1999 model year, the capability to record pre-crash vehicle speed, engine RPM, throttle position, and brake switch on/off status has been added to some GM vehicles. This paper discusses the evolution and contents of the current GM event data recording capability, how other researchers working to develop a safer highway transportation system might acquire and utilize the information, and the status of the NHTSA Motor Vehicle Safety Research Advisory Committee’s Event Data Recorder Working Group effort to develop a uniform approach to recording such data.

EVOLUTION OF GM EVENT DATA RECORDING

GM introduced the first regular production driver/passenger airbag systems as an option in selected 1974 production vehicles. They incorporated electromechanical g-level sensors, a diagnostic circuit that continually monitored the readiness of the airbag control circuits, and an instrument panel Readiness and Warning lamp that illuminated if a malfunction was detected. The data recording feature utilized fuses to indicate when a deployment command was given and stored the approximate time the vehicle had been operated with the warning lamp illuminated. In 1990, a more complex Diagnostic and Energy Reserve Module (DERM) was introduced with the added capability to record closure times for both the arming and discriminating sensors as well as any fault codes present at the time of deployment.

In 1992, GM installed sophisticated crash-data recorders on 70 Indy race cars. While impractical for high volume production, these recorders provided new information on human body tolerance to impact that can help improve both passenger vehicle occupant and race car driver safety. As an example, the data demonstrated that well restrained healthy, male race car drivers survive impacts involving a velocity change of more than 60 mph and producing more than 100 g's of vehicle deceleration. Such information will be helpful to biomechanics experts refining their understanding of human injury potential.

Changes in race car design have also been made using data obtained from the on-board recording capability. Specifically, it was observed that a substantial deceleration pulse occurred when the vehicle’s differential "bottomed out" during rear impact crashes. Knowing this, a simple, light weight impact attenuator was designed that, in combination with improved head padding, is believed to have substantially reduced the number of serious driver injuries during the 1998 racing season.

For the 1994 model year, the multiple electromechanical switches previously used for crash sensing were replaced by the combination of a single solid state analog accelerometer and a computer algorithm integrated in a Sensing & Diagnostic Module (SDM). The SDM also computed and stored the change in longitudinal vehicle velocity (ΔV) during the impact to provide an estimate of crash severity. This feature allowed GM engineers to obtain restraint system performance data when a vehicle was involved in a deployment event or experienced an impact related change in longitudinal velocity but did not command deployment (i.e. a near-deployment event). The SDM also added the capability to record the status of the driver's belt switch (buckled or unbuckled) for deployment and near-deployment events.

Certain 1999 model year GM vehicles have the added capability to record vehicle systems status data for a few seconds prior to an impact. Vehicle speed, engine RPM, throttle position, and brake switch on/off status are recorded for the five seconds preceding a deployment or near-deployment event. Almost all GM vehicles will add that capability over the next few years.

Table 1 contains an abbreviated summary of the data recording capability provided with various GM production airbag systems.

Parameter	1990 DERM	1994 SDM	1999 SDM
State of Warning Indicator when event occurred (ON/OFF)	X	X	X
Length of time the warning lamp was illuminated	X	X	X
Crash-sensing activation times or sensing criteria met	X	X	X
Time from vehicle impact to deployment	X	X	X
Diagnostic Trouble Codes present at the time of the event	X	X	X
Ignition cycle count at event time	X	X	X
Maximum ΔV for near-deployment event		X	X
ΔV vs. time for frontal airbag deployment event		X	X
Time from vehicle impact to time of maximum ΔV		X	X
State of driver's seat belt switch		X	X
Time between near-deploy and deploy event (if within 5 seconds)		X	X
Passenger's airbag enabled or disabled state			X
Engine speed (5 sec before impact)			X
Vehicle speed (5 sec before impact)			X
Brake status (5 sec before impact)			X
Throttle position (5 sec before impact)			X

Table 1: Data Stored by Selected GM Airbag Systems

Technical Description of the Event Data Recording Process

The crash sensing algorithm used in 1999 model year GM vehicles decides whether to deploy the airbags based on calibration values stored in the SDM reflecting that vehicle model's response to a variety of impact conditions. This predictive algorithm must make airbag deployment decisions typically within 15-50 msec (.015-.050 sec) after impact.

The SDM's longitudinal accelerometer is low-pass filtered at approximately 400 Hz. to protect against aliasing, before being input to the microcontroller (see Figure 1). The typical SDM contains 32k bytes of ROM for program code, 512 bytes of RAM, and 512 bytes of EEPROM. Every 312 μsec, the algorithm samples the accelerometer using an A/D converter (ADC) and when two successive samples exceed about 2 gs of deceleration, the algorithm is activated (algorithm enable).

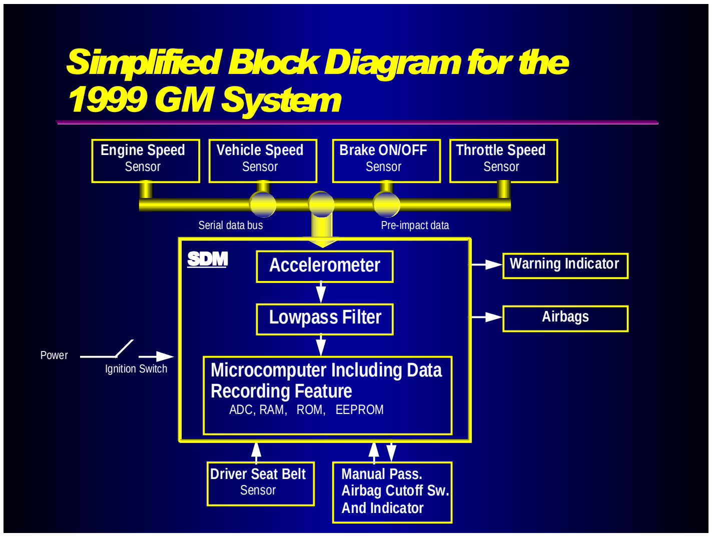

Figure 1: Simplified Block Diagram for the 1999 System

Because of EEPROM space limitations, the SDM does not record the actual deceleration data. However, the frequency content of the crash pulse that is of interest to crash reconstructionists typically does not exceed 60 Hz and the crash pulse can therefore, be well-represented by low frequency velocity change data (ΔV). The SDM computes ΔV by integrating the average of four 312 μsec acceleration samples and stores them at 10 msec increments in RAM. Figure 2 shows the ΔV values for a representative moderately-high severity crash at each 10 msec point with a smooth curve drawn through them.

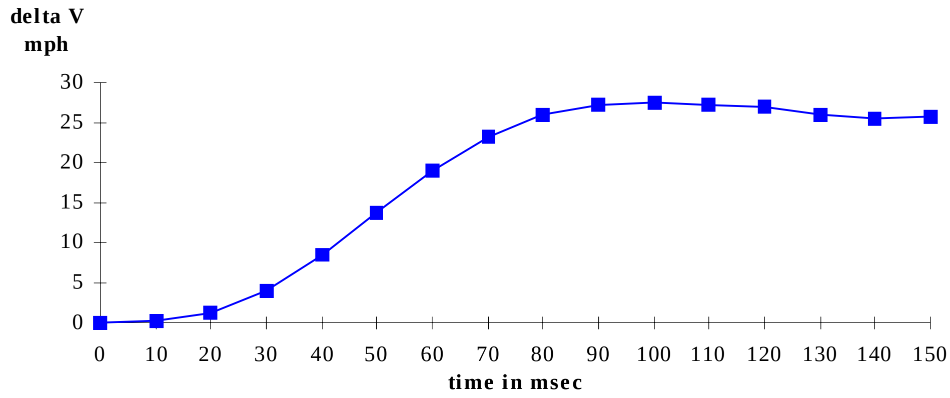

Figure 2: Post-impact ΔV vs. time

Several other sensors provide driver seat belt status, vehicle speed, engine RPM, brake on/off status, and throttle position. The driver seat belt switch signal is typically input into the SDM while the remaining sensors are monitored by one or more other electronic modules that broadcast their data onto the serial data bus. If there is an airbag deployment or a near-deployment crash, the last five seconds of data immediately preceding algorithm enable are stored in EEPROM. All stored data can later be recovered using a laptop PC equipped with appropriate software and interface hardware.

Figure 3 shows how the pre-impact sensor data would appear when downloaded. To understand this requires some knowledge of the serial data bus and the SDM's role. First, the serial data bus operates as a "contention" type of bus. Electronic modules transmit data based on a "send on change" design. For example, when engine speed changes by at least 32 RPM, the engine microcontroller broadcasts the new RPM value on the serial bus.

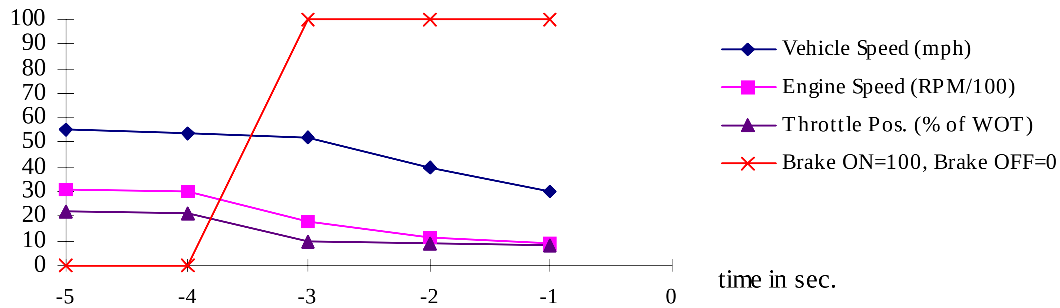

Figure 3: Pre-impact Vehicle Data vs. Time

Once each second, the SDM takes the most recent sensor data values and stores them in a recirculating buffer (RAM), one storage location for each parameter for a total of 5 seconds. When the airbag sensing system algorithm "enables" shortly after impact, buffer refreshing is suspended. Note that algorithm enable is asynchronous with the transmission of vehicle speed and other data. Hence, the data on the bus can be skewed in time from the crash by as much as one second.

The modules that broadcast the sensor data (engine RPM, brake status, etc.) also diagnose the sensors for faults and indicate the data's validity to the SDM. The bus is also constructed so failures of the serial link are detected by the SDM. At the time of deployment, the state of the driver's seat belt switch, the manual cutoff passenger airbag switch (if equipped), warning lamp state, and time to deployment are temporarily stored in RAM. The critical parameter values used to make the deployment decision are also captured in RAM.

When 150 msec have elapsed from algorithm enable, the data stored in RAM are transferred to the EEPROM. It requires about 0.7 sec to permanently record all information. Once a deployment record is written the data are frozen in EEPROM and cannot be erased, altered, or cleared by service or crash investigation personnel.

The recording of near-deployment data includes the pre-impact vehicle speed, engine RPM, etc. The criteria used to determine whether a near-deployment event is stored in EEPROM is based on the maximum ΔV observed during the event. If this maximum ΔV is larger than the previously recorded ΔV, the new near-deployment event is stored along with the corresponding pre-impact data. The near-deployment record is cleared after 250 ignition cycles. This is equivalent to an average of about 60 days of driving. Each time the algorithm is enabled and no deployment is commanded, the SDM compares the maximum ΔV previously stored with the maximum ΔV of this new event to decide whether to update the near-deployment event data.

Data Accuracy, Limitations, and Validation

Event information consists of discrete and variable data. Discrete data includes: brake switch status, manual passenger airbag cutoff switch position, and the driver seat belt switch status. Variable data includes: the analog acceleration information from which ΔV is computed, vehicle speed, engine RPM, and throttle position. Table 2 shows the accuracy and resolution for the variable-type parameters recorded for the 1999 SDM.

Parameter	Full Scale	Resolution	Accuracy	How Measured	When Updated
ΔV	± 55.9 mph	0.4 mph	~ ± 10%	integrated acceleration	recorded every 10 msec, calculated every 1.25 msec.
Vehicle speed	158.4 mph	0.6 mph	± 4 %	Magnetic pickup	vehicle speed changes by ≥ 0.1 mph
Engine Speed	16383 RPM	1/4 RPM	± 1 RPM	Magnetic pickup	RPM changes by ≥ 32 RPM.
Throttle Position	100% Wide open throttle	0.4 %	± 5%	Rotary potentiometer	Throttle position changes by ≥ 5%.

Table 2: Accuracy and Resolution of Data Recorded

There are three main sources of error in estimating ΔV. One error comes from the tolerance of the components in the SDM and the microcontroller. The hardware elements include the accelerometer, the analog-to-digital converter (ADC), low pass filter, and signal conditioning. The accelerometer and ADC contribute the largest portion of the total system error. Accelerometer accuracy is about 8% of full scale which equates to a ΔV error of $\pm$ 4.5 mph. ADC error is about 0.25 gs, not including quantization noise. Over a 150 msec recording period, the ADC contributes a maximum error of $\pm$ 0.8 mph.

The second ΔV error is due to integer-based arithmetic and representing ΔV using single data bytes. For a 56 mph full scale value, 7 bits (plus a sign bit) equates to a precision of 0.438 mph.

The third error source, which applies only to 1999 model vehicles, results from the crash sensing algorithm continuously applying a 1 g bias acceleration in the opposite direction to that seen in frontal impacts. This bias prevents inadvertent airbag deployments resulting from ΔV accumulation when driving on rough roads and contributes an underestimation error of 3.3 mph at the end of 150 msec. GM is in the process of updating its software to eliminate this error source. In the meantime, the downloading tool will utilize software to compensate for the bias.

In the worst case, the total error in ΔV is 5.7 mph (4.5 + 0.8 + 0.4) for a full scale reading of 56 mph. The RMS error, assuming independent error sources, is approximately 1.53 mph.

Another less predictable error comes from the potential for losing electrical power during the crash. While the SDM maintains the defacto industry standard energy reserve for airbag deployment, the reserve is insufficient to guarantee that all event data will be recorded in every crash. However, if it is not recorded, the SDM indicates this condition in the data record.

General Motors has historically verified proper SDM operation using component tests and laboratory simulations. Shock (thruster) tests have been run to verify crash recorder operation in deployment and near-deployment events. Crash tests have also been run and the event data verified when the vehicle was propelled by a tow system. Additionally, a crash test was conducted with the engine running at partial throttle before impact with a fixed barrier to further verify the pre-impact data recording capability. All data recorded prior to and during this crash were within defined error limits.

GM and the NHTSA have also cooperated in comparing event data and laboratory instrumentation for crashes conducted by NHTSA contractors for regulatory compliance and consumer information purposes. To date, the results have been satisfactory and will not be further discussed in this paper since the work is incomplete. Information from actual field events covering a variety of impact types are expected to confirm proper operation of the recording feature and offer insights about improvements that could aid crash investigators.

Uses of Event Data Recorder Information

Table 3 lists categories of uses for the data that can be obtained from an on-board data recording capability. Some of the major benefits relate to improving vehicle and roadway design so the following comments will focus on those objectives. Note, however, there are less direct but non-negligible benefits that can also be achieved over time.

Category	**Potential Examples**
Improve Vehicle Design/Highway Infrastructure	vehicle systems airbag sensing system deployment criteria highway systems roadside safety feature design standards
Provide a Basis for Regulatory & Consumer Information Initiatives	offset frontal impact severity average/extreme vehicle deceleration pulses
Provide Objective Data for Crash Reconstruction	alleged defects & litigation unintended vehicle acceleration crash & airbag deployment sequence
Develop an Objective Driver Behavior Database	pre-crash driver braking/steering belt use vehicle speed

Table 3: Categories of Uses for Event Data

Several examples of the general categories are now described.

1. Improving Airbag Sensing Systems

With some of the early airbag systems incorporating solid state accelerometers, rare instances of inadvertent deployments were reported for a particular vehicle type. Inspections revealed little or no vehicle damage other than what was judged to be normal wear and tear and the unanticipated deployments were not strongly correlated with seasonal weather patterns, geographic location, vehicle trim level, reported speed, or mileage. There was, however, a weak correlation with driving on gravel roads. Downloading the event data from a sample of the inadvertent deployment vehicles showed no fault codes present and that the SDM algorithm had commanded the airbags to deploy.

A typical vehicle ΔV vs. time history for a deployment event was illustrated in Figure 2. The typical ΔV increases smoothly until it levels off at approximately 70-120 msec and is usually at least 12 mph in magnitude. This confirms the design goal of deploying the airbags only if the change in longitudinal vehicle velocity is expected to exceed that observed in 9-14 mph fixed barrier impacts.

However, the history recorded for the inadvertent deployments was typically a short duration event (20 msec or less) with a total velocity change of less than 7 mph. This variation from the typical deployment event history suggested an unusual sensor deceleration environment. After extensive laboratory test and computer simulation work, the environment was found to be similar to that produced by small rocks or debris striking the underside of the vehicle with high impulsive energy. Ultimately a sensor calibration change was made to desensitize the SDM's response to these relatively rare events.

2. Improving Roadway Design

The Federal Highway Administration (FHWA) and the Transportation Research Board (TRB) through its Cooperative Research Programs with the states, are responsible for establishing most highway design standards. This work includes roadway design per se (e.g., side slopes, ditches, etc.) as well as the safety devices located along the roadside (e.g., guardrails, crash cushions, light poles, breakaway signs, etc.). To develop appropriate design tests and standards these groups need objective data about crashes that occur on the nation's highways. Typically local, state, and national databases are used that may not contain objective data about pre-crash vehicle speed, brake use, crash severity, etc. However, such data would be easily available if crash investigators could routinely download the event data as a normal part of their work.

3. <u>Developing Meaningful Motor Vehicle Regulations</u>
Recorded event data information can also help the NHTSA meet its responsibility for researching and issuing appropriate motor vehicle regulations in many ways. Not only will pre-crash data be useful for the Agency's crash avoidance research work, but the objective data recorded during a crash will be a major improvement for crashworthiness related activities.

We can consider the benefits on-board data recorders can provide using the Haddon matrix which divides the crash into three segments and looks at the human, vehicle, and environmental considerations of each. Table 4 shows the type of data that can be collected from a crash without on-board data recording. These data are primarily limited to post-crash observations.

	Human	**Vehicle**	**Environment**
Pre-Crash		Skid marks	
Crash		Calculated ΔV	
Post-Crash	Injury	Collision damage	Environment after collision

Table 4: Haddon Matrix Without Event Data Recording Capability

Table 5 shows the same matrix, this time populated with data which could be collected from vehicles equipped with enhanced on-board data recording capability. Here, there are numerous data from the pre-crash and crash portions of the event.

	Human	**Vehicle**	**Environment**
Pre-Crash	Belt Use Steering Braking	Speed ABS Other Controls	Conditions during Crash
Crash	Airbag Data Pre Tensioners	Crash Pulse Measured ΔV Yaw Airbag Activation Time	Location
Post-Crash	ACN (Automatic Collision Notification)	ACN	ACN

Table 5: Haddon Matrix With Enhanced Event Data Recording Capability

Technology allowing vehicle safety researchers to collect objective data on crashes would open the door to a new generation of understanding. The opportunities are immense since about 18,000 tow-away crashes occur each day.

Currently the primary metric used to represent crash severity is ΔV. NHTSA can use the output from on-board data recorders to supplement the ΔV crash severity estimate currently derived from post-crash vehicle inspections. NHTSA-sponsored National Automotive Sampling System (NASS), Special Crash Investigations (SCI), and Crash Injury Research and Engineering Network (CIREN) teams attempt to make such estimates for all crashes investigated. About 38 percent of the cases have ΔV information reported - typically for each vehicle when more than one vehicle is involved and for each impact in a multiple impact scenario.

However, the WINSMASH computer algorithm currently used to estimate ΔV, relies primarily on stiffness parameters derived from short duration 35 MPH rigid barrier impact tests. Longer duration real world crashes and less idealized crashes involving yielding fixed and narrow objects, underrides, or multiple impacts are beyond the capabilities of WINSMASH. On-board data recorders can provide crash severity data for most real world crashes (and confirm WINSMASH results for crashes against unyielding flat barriers) by directly measuring ΔV.

Figure 4 shows a field crash in NHTSA crash files involving a 1998 Chevrolet Malibu that struck a heavy, parked truck in a severe bumper underride impact. Such crashes typically generate long crash pulses. WINSMASH estimated a ΔV of 23 mph, while the investigator noted this ΔV estimate appeared to be low. The data from the on-board recorder indicated a ΔV of approximately 50 mph.

Figure 4: Chevrolet Malibu

Table 6 lists nine real world Special Crash Investigation cases involving GM vehicles with on-board recording capability. In four cases (44%), the on-board crash recording capability provided the primary or only source for ΔV information. In the remaining five cases, the ΔV measurements and the WINSMASH estimates differed. These differences may be due to constraints in the WINSMASH program. Thus on-board data recording capability can greatly enhance the quantity and quality of the crash severity data stored in government files.

#	Model Year/Make/Model	Driver Belted		ΔV(MPH)		Comments
		Field	EDR	SMASH	EDR	
1	1998 Chevrolet Malibu	Yes	No	23	50	Final seat belt determination was "not belted." Severe underride.
2	1995 Saturn SL	No	No	13	16	Very minor damage
3	1996 Geo Metro	Yes*	Yes	19	26	*Physical evidence indicated shoulder portion of the belt under the driver's arm
4	1995 Saturn	No	No	NR	11	Driver stated belt used, no physical evidence
5	1996 Oldsmobile 98	Yes	Yes	NR	17	Underride - visual of 14-18 mph
6	1995 Chevrolet Lumina	No	No	12	24	Underride, 24 mph @ 150 msec
7	1995 Geo Metro	Yes	Yes	14	9	The report writer specified the SDM ΔV data as more representative of this crash
8	1995 Geo Metro	No	No	NR	11	Undercarriage impact. Visual estimate of 9-14 mph
9	1998 Pont. Grand Prix	Yes	Yes	NR	2	Inadvertent deployment
NR = No Results						

Table 6: Special Crash Investigations Involving GM Event Data Recorder

Belt use data from on-board recorders will also enhance the NHTSA restraint use information files. The SCI, NASS, and CIREN restraint use data are determined from physical evidence that is not always definitive. On-board recorder data will be used as the primary indication of restraint use in cases where the physical evidence is not present or inconclusive.

On-board recorders will assist government and industry efforts to define appropriate test procedures for motor vehicle regulations and consumer information purposes. In the future, "electronic testing," (i.e., using a computer to model the crash) is likely to be utilized. Objective crash pulse data will facilitate cooperative work to define the crash types and severities that should be modeled.

NHTSA has expanded its databases to allow event data to be stored. For the 1999 data collection year, variables were added to identify if a vehicle is equipped with an on-board recorder and was downloaded and an open format field was provided for recording the data collected. No universal format for storing such data has been developed because GM is currently the only manufacturer striving to make the data and data recovery tools available to researchers. NHTSA plans to equip its NASS, SCI, and CIREN crash investigation teams with the new GM downloading tools as soon as they are available. Since GM has been equipping most of its vehicles with some type of on-board recording capability for several years, NHTSA plans to routinely collect data from these vehicles.

In 1998, NHTSA requested that its Motor Vehicle Safety Research Advisory Committee (MVSRAC) approve a working group for Event Data Recorders under its Crashworthiness Subcommittee. The Working Group consists of representatives from the motor vehicle industry, academia, and federal and state governments. NHTSA's MVSRAC Working Group meetings are closed to the public. Their mission is to collect facts and report them to the parent Subcommittee. The Subcommittee and full committee meetings are open to the public. The Working Group invites experts to assist in the fact finding mission and maintains the public file discussed below.

The technical objectives of the Working Group include: 1) defining functional and performance requirements for event data recorders, 2) understanding present technology, 3) developing a set of data definitions, 4) discussing various uses for the data, 5) considering related legal & privacy issues, and 6) standardization of publicly usable data.

Thus far, the Working Group has held two meetings in Washington, D.C. The meetings were attended by about 25 working group members and other NHTSA and FHWA interested parties. During these meetings, manufacturers have presented information on the current status of event recording technology at their respective companies. Government and other interested safety researchers have presented their needs for event data. The Working Group has started an effort to list the most desired data for inclusion in on-board recorders and is currently discussing privacy concerns, data ownership, and other policy and legal issues.

It is anticipated that the Working Group will continue its activities until the objectives are met. The group plans on writing a report which will include the fact finding results of the group, which should be completed by late 2000. The Working Group places its public material in the DOT Docket system. This information will be available by mid-1999 from the Docket Management System. Access can be gained on the Internet at: http://dms.dot.gov/ - click on "Search" about half-way down the page - click on "Docket Search Form" - fill in the docket ID with "5218" - select "NHTSA" for the agency - and "1999" for the calendar year and press search.

Retrieving Event Data from GM Vehicles

Currently GM uses a proprietary Event Data Retrieval Unit (EDRU) which interfaces with a standard Tech 1 scan tool to download data through the vehicle diagnostic connector. Data can be viewed on the Tech 1 or printed from the EDRU's printer, and all data is displayed in a hexadecimal format. For vehicles that have sustained electrical system damage, interface cables are provided for powering the system and connecting the SDM directly to the EDRU (see Figure 5).

Figure 5: GM Event Data Retrieval Unit

To make EDR data available to all interested researchers, GM has selected Vetronix Corporation of Santa Barbara, California to develop software and interface cables allowing the data to be downloaded to commonly used laptop computers (see Figure 6). Data useful to such researchers (ΔV, belt use, pre-impact data, etc.) will be stored and displayed in a standard format using engineering units while data requiring expert knowledge to interpret will continue to be stored in hexadecimal format. The new tool will also allow the user to input other pertinent information (e.g., investigator's name) and export the data to a remote database. Like the current EDRU, interface cables will be provided for vehicles that cannot be powered up after a crash. These kits are expected to be commercially available during the summer of 1999 with the initial units going to GM and NHTSA crash investigators.

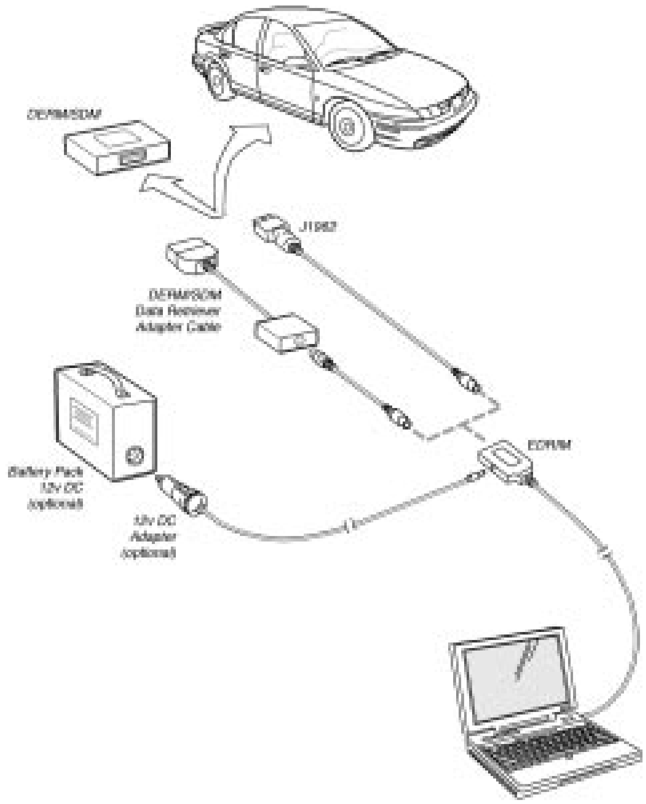

Figure 6: Vetronix Event Data Recovery System

Conclusions

- On-board vehicle recorders have the potential to greatly improve highway safety by providing regulators, vehicle manufacturers, and other researchers with objective data on vehicle crashes and pre-crash scenarios.

- Well-coordinated efforts by all parties sharing highway safety responsibility will be needed to achieve the results envisioned when the NTSB issued it's recommendation for cooperative efforts to utilize crash recording technology.

- The Motor Vehicle Safety Research Advisory Committee's Event Data Recorder Working Group will establish guidelines for future on-board data recording capability including prioritization of the data required to improve highway and traffic safety and recommendations on the need for all manufacturers to install such equipment.

- NHTSA is taking the necessary steps to collect and store data from on-board vehicle recording devices in its Motor Vehicle Research databases.

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Biographies
Augustus "Chip" Chidester is with the Special Crash Investigations program at NHTSA. He is responsible for the case selection, investigation, quality control, and distribution of in-depth crash data which are of special interest to the NHTSA. These in-depth crash investigations address a broad range of motor vehicle engineering and technical issues involving the safety and performance of the various occupant protection systems, potential safety defects, alternative fuel vehicles, and school buses.

Mr. Chidester has been involved in crash investigation since 1977. Prior to joining the NHTSA SCI Program, he was the National Automotive Sampling System's (NASS) Southern Zone Center Manager and an SCI Crash Investigator with the Calspan Corporation.

John Hinch works in NHTSA's Office of Research and Development as a staff engineer. He provides engineering guidance to many programs within R&D. Previously, Mr. Hinch worked in NHTSA's Office of Defect Investigations as a staff assistant and defects engineer. Prior to working for NHTSA, Mr. Hinch worked for a small research firm in the Washington, DC area where he was the Manager of its Highway Research Activities. During that ten-year, Mr. Hinch operated the company's full scale crash test facility and was the lead engineer for a Federal Highway Administration project to design and construct their FOIL, an outdoor impact laboratory capable of conducting crash tests at speeds up to 60 mph. Mr Hinch is a graduate of the College of Engineering at the University of Michigan and served 4 years in the USMC.

Thomas C. Mercer is with the Engineering Center at the General Motors Technical Center in Warren, Michigan. He is responsible for the development of electronics and sensing systems used in GM's airbag systems as well as establishing engineering requirements for the event data recording capability. Mr. Mercer has over 28 years of automotive electronics experience and has worked with airbag systems since 1987. He holds a Bachelors and Masters degree in Electrical Engineering from the University of Michigan.

Keith Schultz has been with General Motors Corporation for the past 14 years. Currently he is a Sr. Staff Engineer working in the North American Engineering Product Investigations Department. His responsibilities include coordinating investigations regarding information requests initiated by NHTSA-Office of Defects Investigation. Prior to joining Product Investigations, Mr. Schultz worked in the GM Safety Center - Product Analysis Department. He was responsible for supplying engineering technical support regarding alleged product defects in product liability litigation. During this period he performed accident reconstruction and evaluated the field performance of vehicle restraint systems. Mr. Schultz earned a Bachelor of Science Degree in Mechanical Engineering from the University of Cincinnati in 1983. He also earned a Master of Science Degree in Mechanical Engineering from the University of Michigan in 1984.

Proactive Use of Recorded Data for Accident Prevention

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KEYWORDS

Rail, investigation, recorders, history

INTRODUCTION

In its railroad accident investigations, the National Transportation Safety Board (NTSB) relies on data recovered from recorders to determine train speed, direction of travel, distance traveled, throttle position, brake application, cab and/or wayside signals, and applicable communications from before and during the accident. Since 1995 the Federal Railroad Administration (FRA) has had the regulatory responsibility for establishing the minimum parameters to be recorded and the standards that event recorders must meet. The railroad industry also voluntarily records information on train movements and warning devices for its own use. This paper will address the use of recorders, the regulations that govern them, the history of the Safety Board's use of event-recorder data in its investigations, and the future of event recorders in accident investigation.

PROACTIVE USE

No Federal regulations require the use of recorders or monitors. Since the creation of the Safety Board in 1967, the Board's Railroad Division has investigated more than 192 major railroad accidents. The reports about these investigations present a record of the Board's use of recorders and the development of safety recommendations for regulatory requirements, improved maintenance, better standards, and improved utilization of recorded data.

Recorded data yield a more accurate assessment of the events leading up to an accident and corroborate witness statements, helping to eliminate much of the guesswork involved in accident investigation.

Initially, railroads voluntarily installed recorders and monitors on their locomotives as a way of overseeing the engineer's operation of the train and the locomotives operational performance over the territory. However, since May 1995, the FRA has required an event recorder on any train operated faster than 30 miles per hour (49 Code of Federal Regulations [CFR] 229.5 and 229.135). Under the requirement a recorder must, at a minimum be tamper resistant and capable of recording the following: train speed, direction of motion, time, distance, throttle position, brake applications and operations, and where the locomotive is so equipped, cab signals during the most recent 48-hours of operation.

In addition, the railroad industry has voluntarily developed other uses of recorders. Recorders allow the railroads to verify the remote operation of devices that provide for safe train operations as well as for public safety. Recorders monitor rail-highway grade crossings interconnected for pre-emption of traffic signals for time, train speed, and activation of pre-emption circuitry. Selected centralized traffic controlled interlockings use recording systems to record time, sequential position of relays (signals) controlling train movements through an interlocking, and position of the switches in the interlocking. Some of these systems can record relay positions for the related intermediate signals. Railroad wayside-equipment defect detectors can detect certain defects as a train passes over sensors/scanners at track level and can record and send important messages to the train crew. Each of these recording systems can maintain a record of the activity for parameters as prescribed by the railroad.

Railroads also voluntarily record radio communications between their dispatchers and train crews as well as the communications among railroad-emergency coordinators, emergency and law-enforcement agencies, and other organizations during an emergency. Thus railroads can monitor the dispatchers' instructions to train crews for compliance with the railroad's own rules and with the instructions authorizing train operations. Likewise, the railroads can monitor their communications with outside agencies for effectiveness, timeliness, and accuracy of information provided during emergencies.

SAFETY BOARD RECORDER HISTORY

Since the creation of the Safety Board in 1967, the Board's Railroad Division has conducted more than 192 major railroad accident investigations. The following is a chronological history of some the Safety Board major railroad accident investigations that involved the use of or need for recorders.

The first report in which a locomotive event recorder was mentioned was the one about a head-on collision on the New York Central Railroad in 1967[1]. During the late 1960s and much of the 1970s many investigations had to rely on getting train operation information from surviving crewmembers, with very few instances of data being available from a recorder. Early recorders on locomotives were of the paper-tape variety, recording only speed and distance.

In the late 1970s, few investigations involved trains that had 8-track multi-event recorders. Many railroads were still using the paper tape recorders. The railroads used the event-recorder data to monitor and evaluate the train-handling practices of their train crews, but rarely to oversee rules compliance. Early Safety Board accident investigations did not document whether improved train safety could be related to the railroads' review and evaluation of event-recorder data. However, during investigation of a 1972 head-on collision[2] the Safety Board examined more than 33 speed recorder tapes from various trains. The Board's report stated that 13 tapes showed train speeds in excess of what was allowed and that the carrier had not reviewed the tapes.

Some reports have noted problems with paper-tape recorders. More times than not the

[1] Title—*New York Central Railroad Company, Train 1/NY-4 Extra 2020 East and Train ND-5 Extra 5305 West, Head-on Collision, New York City, New York, May 22, 1967* (NTIS order number PB-190198).
[2] Railroad Accident Report—*Head-on Collision of Two Burlington Northern Freight Trains near Maquon, Illinois on May 24, 1972* (NTSB-RAR-73-4).

recorder was inoperative[3] for one reason or another. Paper had not been put in the recorder, the pen was out of ink, or the recorder had jammed. In such cases, Safety Board investigators had to rely on surviving crewmembers' statements supplemented by any available dispatcher recordings of communications between the dispatcher and the train crew. At the extreme end of paper-tape recorder problems, a Safety Board accident investigation was stymied in 1974 by the railroad management's decision to not put paper in a working recorder, thus rendering it useless.[4]

Sometimes, however, the paper-tape recorders were helpful. The recorder from another 1974 accident[5] provided information about the train's speed and evidence of a severe run-in when the emergency brakes were applied as the train entered a curve. In still another accident, a paper-tape recorder confirmed the speed and speed changes of a train that derailed.[6] A recorder provided the speed of the train in the investigation of the October 1975, derailment of an Amtrak train in Pulaski, Tennessee.[7] After the 1976 derailment of a freight train in Hastings, Nebraska, the investigators used a speed tape to determine that the crewmembers had used the train brakes more than they said, thus causing a slack run-in and derailment of the train.[8] The investigators of a derailment of an Amtrak train on the Burlington Northern near Ralston, Nebraska, found from a speed recorder that the speedometer was improperly calibrated; thus, the recorded speed was 20 mph higher than it should have been.[9] Another derailment investigation, of a freight train in a 1979 accident involved a speed recorder that registered 17 mph under the actual speed.[10]

During these early accident investigations the Safety Board recognized the inadequacies of the investigation when event-recorder data was not available. Also recognized was the inability of a railroad to conduct proper operational oversight of a train crew and their performance in train handling when locomotive event recorders were not standard equipment on all trains on main tracks outside of yard limits. Following the Board's investigation of a 1977 derailment on the Louisville and Nashville[11] the Safety Board issued Safety Recommendation R-78-044 to the FRA, asking it to require event-recorder regulations. (See appendix.)

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[3] Railroad Accident Report—*Burlington Northern Incorporated Derailment of Extra 5701 East at Sheridan, Wyoming on March 28, 1971* (NTSB-RAR-72-4).
[4] Railroad Accident Report—*Collision of Missouri Pacific Railroad Company Freight Train Extra 615 South Collided with a Standing Locomotive in Cotulla, Texas June 1974* (NTSB-RAR-74-3).
[5] Railroad Accident Report—*Derailment and Subsequent Burning of Delaware and Hudson Railway Freight at Oneonta, NY* (NTSB-RAR-74-4).
[6] Railroad Accident Report—*Derailment of Amtrak Train on the Tracks of Atchison, Topeka and Santa Fe Railway Company at Melvern, Kansas July 5, 1974* (NTSB-RAR-75-1).
[7] Railroad Accident Report—Derailment of an Amtrak train on the Louisville and Nashville Railroad in Pulaski, Tennessee on October 1, 1975 (NTSB-RAR-76-6).
[8] Railroad Accident Report—Union Pacific Railroad Freight Train Derailment, Hastings, Nebraska on August 2, 1976 (NTSB-RAR-77-1).
[9] Railroad Accident Report—*Derailment of Amtrak Train on the Burlington Northern near Ralston, Nebraska, December 16, 1976* (NTSB-RAR-77-8).
[10] Railroad Accident Report—Derailment of Union Pacific Railroad Freight Train Granite, Wyoming, July 31, 1979 (NTSB-RAR-79-12).
[11] Railroad Accident Report—*Louisville and Nashville Railroad Company Freight Train Derailment and Puncture of Anhydrous Ammonia Tanks Cars at Pensacola, Florida, November 11, 1977* (NTSB-RAR-78-04)

The earliest noted usage of 8-track event-recorders in Safety Board investigations were the 1978 derailment of a passenger train at Elma, Virginia,[12] which cited excessive speed, and the 1979 derailment of an Amtrak's "Southwest Limited" at Lawrence, Kansas.[13] Since this was new technology for the time, the carrier and/or the manufacturer could only read the 8-track event-recorder cassette tapes. The Safety Board had to either rely on the carrier's ability to do an adequate readout or take the cassettes to the manufacturer of the recorder for a detailed readout.

> The Safety Board's major railroad accident investigation reports from the 1980s show that speed (paper-tape)/event recorders (8-track) were beginning to be used on more trains. Following the investigation of the 1980 rear-end collision of two Union Pacific freight trains near Hermosa, Wyoming the Safety Board commended the Union Pacific for having installed 8-track event recorders in its locomotives.[14] The Safety Board issued six safety recommendations about event recorders: three to the Union Pacific and three to the Association of American Railroads (Safety Recommendations R-81-45 through -47 and R-81-49 through -51). The recommendations addressed modifying event recorders so they could record the activation of the cab signal acknowledging lever, relocating the recorders so they would be better protected in crashes, and providing emergency power so the recorders could be operated when normal power was lost. (See appendix.)
>
> In the Safety Board's investigation of a 1984 rear-end collision of two Conrail freight trains,[15] the data recorders provided evidence that contradicted the statements provided by the operating crewmembers. According to Conrail operating rules the train should have been operated at "restricted speed," that is …not exceeding 15 mph prior to the accident. The crewmembers stated they had operated the train at "restricted speed." The data from the event recorder, however, did not support their statements.

Event-recorder data confirmed that excessive speed was a contributing factor in the derailment and release of hazardous materials from a freight train in 1985.[16] After reviewing the information from the train's event recorders the Safety Board investigators determined that the St. Louis Southwestern Railway Company (Cotton Belt) was lax in enforcing speed restrictions.

In the investigation of a1985 head-on collision between two Amtrak trains at Astoria, Queens, New York,[17] Safety Board investigators performed a comparative analysis of the data from the recorders. The recorded train operator activity data was compared to crewmember statements for cab signal indications and applicable wayside signal indications to develop findings in the investigation.

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[12] Railroad Accident Report—*Derailment of Southern Railway Company Train No. 2, The Crescent, at Elma, Virginia, December 3, 1978* (NTSB-RAR-79-4).
[13] Railroad Accident Report—*Derailment of Amtrak Train No. 4, the Southwest Limited on the Atchison, Topeka and Santa Fe Railway Company, Lawrence, Kansas, October 2, 1979* (NTSB-RAR-80-04).

[14] Railroad Accident Report—*Rear End Collision of Union Pacific Railroad Freight Trains near Hermosa, Wyoming, October 16, 1980* (NTSB-RAR-81-03).
[15] Railroad Accident Report—*Rear End Collision Between Conrail Trains OIPI-6 an ENPI-6X, near Saltsburg, Pennsylvania, February 26, 1984* (NTSB-RAR-85-02).
[16] Railroad Accident Report—*Derailment of St. Louis Southwestern Railway Company (Cotton Belt) Freight Train Extra 4835 North and Release of Hazardous Materials near Pine Bluff, Arkansas, June 9, 1985* (NTSN-RAR-86-04).
[17] Railroad Accident Report—*Head On Collision of National Railroad Passenger Corporation (Amtrak) Passenger Trains Nos. 151 and 168, Astoria, Queens, New York, July 23, 1984* (NTSB-RAR-85-09).

Erroneous data or the failure of a recorder to record has affected several investigations. The first reported tampering with an event recorder was noted in the investigation of a 1982 side collision of two freight trains near Possum Grape, Arkansas.[18] A deadheading conductor stated the speed-recording device was working properly prior to the accident; but several hours after the accident, a railroad official found the case broken open and the tape missing, even though the locomotive cab had not been damaged. In the investigation of a 1987 collision between two freight trains in Yuma, Arizona,[19] the Safety Board's lab determined that some information was incorrect. The digital word channel recording automatic brake, locomotive brake, throttle, dynamic brake, and direction of travel elements were being erroneously recorded. On sections of the data pack the digital word signal was weak and intermittent; however, the time, speed, distance, and power elements were all being recorded normally.

Additionally, the investigation of a 1989 derailment with the release of hazardous materials from a freight train near Freeland, Michigan was noted as being hindered by the absence of multi-event-recorder data.[20] The Safety Board's report stated that train-handling information was derived from what the train crew stated. The paper-tape-recorded train speed was of limited usefulness since the manner in which the train was controlled was more important than its speed. Vital information, such as quantified braking, throttle manipulation, and the chronological relationship between power-to-braking and braking-to-power, was not available. In the investigation of a 1990[21] collision between two freight trains on the Norfolk Southern, Safety Board investigators found that because of a splice in the recording tape media, no data had been recorded by one of the train recorders. The first time the Board mentioned an anomaly with the data from an event-recorder with an 8-track tape was in its report about the December 12, 1990, derailment and collision of an Amtrak train with an MBTA commuter train in Boston, Massachusetts.[22] The Safety Board attributed the anomaly to the carrier's improper handling of the data pack.

In the late 1980s there still were no required uniform standards for recording data on train movements. The Safety Board had recommended that the FRA require locomotives to have event recorders (Safety Recommendation R-78-044). The Safety Recommendation was closed unacceptable on August 12, 1985 following the FRA's response stating that they were not going to pursue a regulation and would, instead defer to the railroads' voluntary installation plans.

The Safety Board's report of the July 30, 1988 head-on collision between two trains near Altoona, Iowa,[23] further addressed the need for Federal requirements for standardization of event recorders. The Safety Board issued Safety Recommendation R-89-050 to the FRA to expedite the rulemaking process ordered by Congress in the Rail Safety Improvement Act of 1988 for event recorders. Provisions in the Act called for the FRA to issue, within 18 months, such rules, standards, orders, and regulations as necessary, for a requirement for event recorders on trains within 1 year of the issuance of the regulations. Following the August 1988 derailment of an Amtrak train on the Burlington Northern

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[18] Railroad Accident Report—*Side Collision of Two Missouri Pacific Railroad Company Freight Trains at Glasie Junction, near Possum Grape, Arkansas, October 3, 1982* (NTSB-RAR-83-06).
[19] Railroad Accident Report—*Head-on Collision of Southern Pacific Transportation Company Freight Trains, Yuma, Arizona, June 15, 1987* (NTSB-RAR-88-02).
[20] Railroad Accident Report—*Derailment of CSX Transportation, Inc. Freight Train and Hazardous Material Release near Freeland, Michigan, July 22, 1989* (NTSB-RAR-91-04).
[21] Railroad Accident Report—Collision and Derailment of Norfolk Southern Train 188 with Norfolk Southern Train G-38 at Sugar Valley, Georgia, August 9, 1990 (NTSB-RAR-91-02).
[22] Railroad Accident Report—*Derailment and Collision of Amtrak Passenger Train 66 with MBTA Commuter Train 906 at Back Bay Station, Boston, Massachusetts, December 12, 1990* (NTSB-RAR-92-01).
[23] Railroad Accident Report—*Head-on Collision between Iowa Interstate Railroad Extra 470 West and Extra 406 East with Release of Hazardous Materials near Altoona, Iowa, July 30, 1988* (NTSB-RAR-89-04).

near Saco, Montana,[24] the Safety Board noted that 8-track event recorders were becoming commonplace in the industry. In the report the Safety Board said that recorded information is an effective tool for monitoring, evaluating, and improving the safety of train operations. In addition the report stated that event recorded information must be accurate, consistently prepared, and credibly interpreted and that ideally each locomotive on a train should be equipped with an operating multi-event-recording device. The status of the Safety Board's Safety Recommendation R-89-050 to the FRA was classified as "closed acceptable" on August 2, 1993, when the FRA advised that the final rule on event recorders, was published in the Federal Register on July 8, 1993 and would become effective on November 5, 1993. The rule required the lead locomotive on all trains operating over 30 mph to be equipped with an event recorder and specified minimum recording parameters.

The new Federal regulations cover all rail carriers that are a part of the general railway system. This excludes the rail rapid transit industry over which there is no Federal oversight regulatory authority. Rail rapid transit is not a new industry. Several large cities (Chicago, San Francisco, and New York City for example) have had intercity transportation for some time. Commuters, who want to avoid problems associated with intolerable driving conditions, have encouraged their local and state governments to rethink local transportation systems. With the help of Federal funding from the Federal Transit Administration rail rapid transit systems are being rediscovered in many other cities and are being modernized to provide fast efficient service. The Safety Board has been concerned that rail rapid transit systems may experience the same evolutionary understanding of problems in the value of event recorders that occurred on the railroads in the early 60's and 70's. In the Board's report for the 1996[25] collision of a Washington Metropolitan Area Transit Authority train with another standing train it was noted that no rail rapid transit system in the United States is required to or does record and monitor vital train systems and system events. The Board issued Safety Recommendation R-96-046 to the Federal Transit Administration and to the American Public Transit Association asking them to develop guidelines for monitoring/recording devices and to install them on rapid transit trains. (See appendix.)

Since the enactment of the FRA's new regulatory requirement for event recorders the Safety Board's investigations have uncovered new concerns. The event recorder's maintenance and its location within a locomotive were addressed in the Safety Board's report of the 1996 freight train derailment near Cajon, California.[26] The post-accident testing of the microprocessor type of event recorder showed that one event recorder had a broken wire in the axle generator, as a result of an improper modification, and that another was improperly programmed. In addition, the self-diagnostic indicators were insufficient to fully examine the recording status of the units. The pre-accident inspections had been inadequate. In its final rule on event recorders the FRA said that it "has determined that the recorder will be most helpful if it records the events happening in the locomotive occupied by the engineer, that is, the lead locomotive." However, the FRA later changed the rule to allow the event recorder to be positioned elsewhere, other than in the locomotive, stating it was "unnecessarily geographically strict"(*Federal Register*, Volume 60, Number 102, May 26, 1995). As a result the Safety Board issued four safety recommendations (R-96-70 through –73) to the FRA, asking the agency to revise the regulations to address the placement, location, maintenance, and testing of event recorders. (See appendix.)

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[24] Railroad Accident Report—*Derailment of National Railroad Passenger Corporation Train 7 on Burlington Northern Railroad near Saco, Montana, August 5, 1988* (NTSB-RAR-89-03).
[25] Railroad Accident Report—*Collision of Washington Metropolitan Area Transit Authority Train T-111 with Standing Train at Shady Grove Passenger Station, Gaithersburg, Maryland, January 6, 1996* (NTSB-RAR-96-04).
[26] Railroad Accident Report—*Derailment of Freight Train H-BALTI-31 Atchison, Topeka and Santa Fe Railway Company near Cajon Junction, California, on February 1, 1996* (NTSB-RAR-96-05).

The investigation of the 1996 near head-on collision and derailment of two commuter trains near Secaucus, New Jersey,[27] found that one of the event recorders did not register brake applications because the tape had not been fully inserted. The investigation disclosed that the FRA had granted the carrier a temporary waiver, with an extension until May 1997, for compliance with certain provisions of Federal regulation (49CFR229.135) that required all trains operating over 30 mph be equipped with event recorders by May 1995. The report states that the failure of the event recorder to provide information on the engineer's braking application hampered the Safety Board's investigation.

A railroad accident, whether it is a collision and/or derailment with or without fire, usually destroys the event recorder. The aviation industry has long recognized the importance of having event recorders that can survive an accident and has been addressing their improvement for crashworthiness and fire resistance; however, these issues are only now being addressed for railroad event recorder standards. Granted, many recorders have survived accidents, but in some accidents, the complexity of the investigation has increased and the event recorders' survivability has become more important for providing information to prevent future accidents.

In the Safety Board's report of the November 1990 collision and derailment of two freight trains near Corona, California,[28] the Board noted that significant data were lost when the multi-event recorders were destroyed by fire. The report noted that the FRA should develop requirements for crash- and fire-resistant event recorders similar to the requirements used for recorders on aircraft. However, the Board did not issue any safety recommendations because it anticipated that the FRA would address the concerns in its pending regulations that were still being developed.

Crashworthiness of event recorders was addressed again in the Safety Board's investigation of the September1993 derailment of an Amtrak train near Mobile, Alabama.[29] A solid-state memory event recorder did not sustain significant damage from the impact, but large amounts of water and mud were found inside the enclosure. Although at this time the FRA's new rule on event recorders acknowledged the need for crashworthiness of event recorders, it did not address the subject.

In November1993 two freight trains were involved in a head-on collision and derailment at Kelso, Washington.[30] The locomotives had a combined total of eight 8-track event recorders. However, only two were in good enough condition to yield any information; the others were either severely damaged by the fire or the impact of the collision. The FRA regulations (49 CFR Part 229.135a) only required the lead or controlling locomotive to have an event recorder. Following this investigation Safety Board staff held several discussions with the FRA concerning the need to address the crashworthiness of event recorders and the development of standards including the location of the event recorder on a locomotive. The FRA established a "Railroad Safety Advisory Committee" (RSAC) working group that included representatives from the event recorder industry, labor unions, and the railroad industry. The RSAC group was assigned to address these concerns and develop proposed regulatory requirements including crashworthiness standards, the proper location of the recorders within a locomotive, and the minimum parameters to record for the next generation of event recorders.

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[27] Railroad Accident Report—*Near Head-on Collision and Derailment of Two New Jersey Transit Commuter Trains near Secaucus, New Jersey, February 9, 1996* (NTSB-RAR-97-01).
[28] Railroad Accident Report—*Atchison, Topeka and Santa Fe Railway Company (ATSF) Freight Trains ATSF 818 and ATSF 891 on the ATSF Railway Corona, California, November 7, 1989* (NTSB-RAR-91-03).
[29] Railroad Accident Report—*Derailment of Amtrak Train No. 2 on the CSXT Big Bayou Canot Bridge near Mobile, Alabama, September 2, 1993* (NTSB-RAR-94-01).
[30] Railroad Accident Report—*Head-on Collision and Derailment of Burlington Northern Freight Train with Union Pacific Freight Train, Kelso, Washington, November 11, 1993* (NTSB-RAR-94-02).

In the 1994 investigation of rear-end collision of between a moving freight train with a standing freight train at Cajon, California,[31] the Safety Board again found that 3 of the 4 solid state multi-event recorders had been destroyed by fire. Only the carrier's quick action to remove the data pack, as the fire approached the locomotive, salvaged the fourth event recorder, which provided important data for the investigation.

In June 1997 two freight trains collided and derailed in Devine, Texas.[32] All of the event-recorder data were lost because impact forces or fire, or both destroyed the recorders. The Safety Board issued Safety Recommendation R-98-030 to the FRA, asking them to develop and implement event recorder crashworthiness standards for all new or rebuilt locomotives by January 1, 2000. (See appendix.)

The increasing acceptance and use of solid state multi-event recorders has resulted in the railroads voluntarily recording more parameters than required by the FRA's current regulations. Consequently the railroads have more information with which to evaluate the performance of both the train crew and the locomotive.

The locomotive event recorder is not investigator's only source of recorded data. They can get information from telephone recordings, radio communications, signal relay recorders, weather services, and wayside equipment detectors. In recent railroad accident investigations Safety Board investigators have been able to relate much of the additional information to the accident. The information from these additional sources and from the added parameters being recorded, allows the investigators to assess the circumstances of the events leading up to an accident more accurately and to corroborate witness statements more thoroughly.

One of the first times investigators used a railroad's telephonically recorded information was in the investigation of the 1982 derailment of an Amtrak train in Emerson, Iowa.[33] The information concerned the severe weather and flooding conditions being relayed to railroad personnel. The first time investigators used information from a wayside signal event recorder was in the investigation of the1987 collision of an Amtrak train on the high-speed Northeast Corridor with a light unit Conrail train at Chase, Maryland.[34] Both locomotives had event recorders; Amtrak's locomotive had a recorder with an 8-track tape, and the Conrail locomotive had a paper speed tape. The data from both the signal event recorder and the locomotive event recorders were used to analyze the movement of both trains with respect to the recorded displayed signals. Recorded data from the train's event recorders as well as from the wayside signal system were used as input in a computerized simulation to determine stopping distances for both trains.

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[31] Railroad Accident Report—*Rear-end Collision of Atchison, Topeka and Santa Fe Railway Freight Train PBHLA1-10 and Union Pacific Railroad Freight Train CUWLA-10 near Cajon, California, December 14. 1994* (NTSB-RAR-95-04).
[32] Railroad Accident Report—*Collision and Derailment of Union Pacific Railroad Freight Trains 5981 North and 9186 South in Devine, Texas on June 22, 1997* (NTSB-RAR-98-02).
[33] Railroad Accident Report—*Derailment of Amtrak Train No. 5 (the San Francisco Zephyr) on the Burlington Northern Railroad, Emerson, Iowa, June 15, 1982* (NTSB-RAR-83-02).
[34] Railroad Accident Report—*Rear-end Collision of Amtrak Passenger Train 94, The Colonial and Consolidated Rail Corporation Freight Train ENS-121, on the Northeast Corridor, Chase, Maryland, January 4, 1987* (NTSB-RAR-88-01).

The collision and derailment of an Amtrak train at a grade crossing accident in 1993 near Intercession City, Florida,[35] reported using of a wayside equipment defect detector for determining the passing time and speed of the train before the accident. The detector provided information that could not be recovered from the paper speed tape because the paper tape had been stained by diesel fuel. In the investigation of a 1994 multiple freight train accident,[36] Safety Board investigators used data from the multi-event recorders of three trains and the signal system's event recorders to reconstruct and simulate each train's movement.

The Safety Board's aviation accident investigators have used animated videos for some time. An animated video is developed from recorded information and is used in the analyzing and simulating the events leading up to the accident. Recently the Safety Board's railroad accident investigators have been developing animated videos for the same purpose.

The investigation of the 1996 Safety Board accident involving a Maryland Rail Commuter train and an Amtrak train near Silver Spring, Maryland,[37] demonstrated the potential benefits of having data from solid-state event recorders, wayside signal event recorders, and dispatcher recordings. The recorded data permitted investigators to thoroughly develop the sequence of events before the accident and to provide an animated video simulation of the sequence of events of the accident.

The most recent completed Safety Board investigation to use recorded data from the recording media was the investigation of the August 9, 1997, Amtrak train derailment near Kingman, Arizona.[38] This accident investigation had recorded data from multiple sources. Data was available from the train's solid-state multi-event recorders, the wayside signal event recorder, the equipment defect detectors, the high water detectors, the dispatchers' communications with the affected trains, and the recorded communications between the railroad operations center and local law enforcement agencies during the accident notification and response. One of the important discoveries was the Safety Board's finding that certain information recorded by the train's event recorder could not be read with the software provided to the carrier. The Safety Board issued Safety Recommendation R-98-057 to the FRA asking them to require that event recording system specifications be kept as a part of the locomotive records. (See appendix.)

The Safety Board has investigated 192 major rail accidents since 1967; the results have included more than 16 safety recommendations related to the use of recorded data to improve transportation safety.

The Safety Board is working closely with the FRA and the RSAC event-recorder-working group. The Safety Board is providing its technical expertise and experience to help develop new standards for additional recording parameters and crashworthiness to be incorporated in the proposed revisions to the present Federal recorder regulations. The future offers innovative uses of audio/visual recorded media utilizing the technical developments and experience in other modes and within the recorder industry. The implementation of audio/video recorders will enhance accident investigation and performance evaluations.

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[35] Highway Accident Report—*Collision of Amtrak Train No. 88 with Rountree Transport and Rigging, Inc., Vehicle on CSX Transportation Inc., Railroad near Intercession City, Florida, November 30, 1993* (NTSB-HAR-95-01).
[36] Railroad Accident Report—*Collision and Derailment Involving Three Burlington Northern Freight Trains near Thedford, Nebraska, June 8, 1994* (NTSB-RAR-95-03).
[37] Railroad Accident Report—*Collision and Derailment of Maryland Rail Commuter "MARC" Train 286 and National Railroad Passenger Corporation "AMTRAK" Train 29 near Silver Spring, Maryland on February 16, 1996* (NTSB-RAR-97-02).
[38] Railroad Accident Report—*Derailment of Amtrak Train 4, Southwest Chief, on the Burlington Northern Santa Fe Railway near Kingman, Arizona, August 9, 1997* (NTSB-RAR-98-03).

FUTURE RECORDING MEDIA FOR RAILROADS

The Safety Board's main concern regarding the use of recorded data is to increase the safety of our country's transportation systems by learning from the mistakes of the past, and enhancing the safety of the systems by insuring to the maximum extent possible, that these mistakes are not repeated. Though significant advances have been made in recent decades with regard to improving the availability of recorded rail data in the event of accidents, the Safety Board vehemently feels that there is much room for improvement in this area. The Safety board feels that by maximizing the availability of data as well as increasing the amount and type of data available, the safety of the nation's transportation systems can still be greatly enhanced.

The Safety Board currently has several recommendations open that address these issues, as presented earlier in this document.

The crashworthiness standards considered for these regulations include fire protection, impact shock protection, crush protection, fluid immersion protection, and hydrostatic pressure protection. The issuance of these standards as a regulatory requirement is a highly anticipated event at the Safety Board. When fully implemented, these standards will increase the survivability of event recorders involved in an accident. The availability of data, as stated earlier, is invaluable in determining cause and initiating change as a result of both major and minor rail accidents.

The RSAC group is also discussing regulating the location of the recorders on the locomotives to allow for the highest chance of survival in the event of a catastrophic accident. The group is also addressing expanding the requirement for recording specific operational parameters. This regulation will make the recovery of event recorder data following an accident more likely, thus making causal determinations and safety improvements easier, more efficient, more accurate, and more timely.

Through accident investigation, the Safety Board's Vehicle Recorders Division has noticed what may be an industry wide problem with the maintenance of railroad event recorder systems. The Board has received problematic data sets and recorders from a variety of railroads, during the course of its investigations. Problems with missing or erroneous data continue to occur at an alarming rate.

These problems are not unique to a particular manufacturer or model of recording system, or to any specific railroad. The one common thread to almost all of these "failures" is the fact that the actual recording device *itself* is seldom, if ever, at fault. The recording devices themselves (particularly the microprocessor-based devices) appear to be the most reliable component in these variously configured recording systems. In fact, *none* of the microprocessor recorders that the NTSB has had tested thus far (by their respective manufacturers) has ever been found to have failed, be out of tolerance, or to have malfunctioned. Unfortunately there is a frequently recurring problem with bad data from these types of recorders.

The anomalous (or missing) data is frequently the result of an inoperative, incorrectly installed, or out-of-calibration "sensors" in the recording system, such as an axle generator or other sensor that sends a signal to the recording device. For example, if an axle generator were to fail, and send a constant signal representing 0 mph to the recorder, then 0 mph would be continuously recorded regardless of the train's speed.

Other system problems include:

> Incorrectly configured recording systems: Many of the newer generation recorders can be configured, or programmed, to suit specific needs. Improper setup or programming can cause certain parameters to be recorded incorrectly, or not recorded at all.
>
> Outdated or incorrect readout software: In most applications, microprocessor based recording systems are configured differently, to meet the customer's specific requirements. One operator's requirements may be different form another's, an individual operator may change their own requirements over time, and the recorder manufacturers periodically update or revise configuration as technology advances.

As a result, a single recorder (or recording system) may have a wide variety of different configurations, each requiring a particular software program to read the recorded data. A recording system installed on a particular operator's locomotive requires a readout program that is unique to that operator. The same recording system installed on another operator's locomotive, may be configured differently, and would require a different readout program. A single recorder manufacturer may support 50 or more different recording systems, each requiring it's own readout program to properly extract the data.

If a recorder is read out using an incorrect or outdated readout program, its possible that certain parameters will be missing, or erroneous. The resulting data could be misleading.

Current FRA regulations do not adequately address the maintenance of event recorders. There are no requirements for records to be kept about recorder system specifications, or applicable readout software. The existing requirements for the testing and inspection of recorder systems are insufficient. While a readout of the data is required every 92 days for tape-based recorders only, there is no requirement (for any type of recorder) to test the sensors or other system components or to verify that accurate data is actually being recorded.

Furthermore, under current FRA regulations, microprocessor based recorders are not required to be readout, tested, or examined unless the recorder itself indicates a fault from its self-diagnostic test. Operators must check the recorder's self-test status every 92 days, which is typically indicated by a light on the recorder case. Unless a fault is indicated, the recorder system may go its entire life without any maintenance, readouts, or further inspection.

Most self-test functions on modern day recorders do a reasonable job of testing the general "health" of the recording device itself, but they cannot assure proper operation of the other components that actually send the signals to the recorder. Virtually all recorder self-diagnostic tests cannot detect any of the problems noted above. While some recorders can test for the presence of certain sensors (whether or not they are connected, and powered if applicable) they cannot test the validity of the signals coming from the sensors. If an errant axle generator continuously sends a signal representing 0 mph, the self-test feature will not detect a malfunction. Failures such as this one may never be detected**,** because there are no requirements to ever read out, test, or evaluate this type of recorder. Additionally, self-test features can not detect improper "programming" or set-up of the recording system. Many systems have optional software configuration settings that can be adjusted by the operator. These settings may be inadvertently set to omit or restrict the data that the recorder stores limiting the information that would otherwise be available after an accident. Because these types of optional settings simply configure the recorder to do what the operator desires, they are not "faults" of the recorder.

As a result of these maintenance problems, the reliability of event recorders to provide vital information after an accident is significantly jeopardized. The NTSB has issued several recommendations to the FRA that address these very issues. The FRA has elected to delegate the evaluation of these recommendations to the RSAC. To date, no action has been taken by the RSAC or the FRA to address these maintenance issues.

The development of new technologies within the rail industry creates new opportunities for data gathering to further aid in the pursuit of safer systems. Since the early 1980's, the railroad industry has recognized the possibility of using data radio communications, emerging microprocessor-based systems, and other technologies to perform enhanced train control functions. These concepts have matured to form a system now referred to as Positive Train Control (PTC). PTC utilizes radio signals to automatically control certain brake applications on trains in order to insure proper separation between trains running on the same set of tracks. This system makes high-speed rail traffic safe in areas of high rail traffic, and all rail traffic separated at a safe distance respective to the speed of the train.

PTC should make it possible to prevent most train-to-train collisions, enforce restrictions on train speed, and enhance protection for roadway workers, at a cost lower than would be expected using traditional approaches. The business benefits of such a system make it attractive to the rail industry, and the potential safety benefits make it attractive to the Safety Board.

This new system presents an entire new way of controlling a train, and presents a new set of data elements that need to be tracked and recorded. PTC is an example of new technology that, when introduced, creates a need for a recording mechanism, be it on board the train or at the control point, to track the data and make it available in the event of an accident.

Since 1964 all transport category aircraft have been required to maintain a Cockpit Voice Recorder (CVR). Providing the same capability for locomotives can hardly be labeled as new technology. The technology has existed for some time to make this equipping a practical measure. The data from the many CVRs recovered by the Safety Board in accident investigation have proven extremely valuable in solving for cause in a great number of aviation accidents. The CVRs provide a level of detail about the cockpit environment before, during, and after incidents and accidents that are generally not available in the many instances where the crew does not survive. CVRs are also used to study noises in the cockpit and to identify potential sources of problems in accidents where the pilots and much of the aircraft have not survived.

The Safety Board issued Safety Recommendation R-97-009 to the FRA that calls amending the regulations to require the recording of train crewmembers' voice communications for exclusive use in accident investigations and with appropriate limitations on the public release of such recordings. Considering the unfortunate yet oft encountered circumstances of a locomotive crew not surviving an accident, a cab voice recorder could provide pieces to the accident puzzle that have heretofore not been available. Cab voice recorders could provide information concerning ambient conditions within the locomotive cab, back-up data concerning control inputs made from the cab position, information involving signal calling from within the cab, and identification of conditions within and without the cab that may have contributed to an accident or incident. They can also record crew conversations, radio transmissions, and alerts and alarms that occur within the cab. (See appendix.)

Use of cab video recording is another area that the Safety Board feels the rail industry could benefit from. Video footage of the locomotive's controls, as well as the outside viewpoint from inside the cabin and outside the cabin, if made available in the investigation of an accident, could provide information that could bring to light reasons for accidents in many circumstances. Video could provide data on signals viewed by the crew, weather that may affect visibility conditions, and provide back up to the event recorders and crew statements on circumstances of any accident or incident. Again, in the unfortunate event of crew fatalities, the video could provide information that would otherwise be completely unavailable.

Already the utility and necessity of capturing video feed from locomotive operations has been acted upon. The Arkansas & Missouri Railroad has installed cameras at the front and rear of all of its trains. The reasons that this short line railroad has undertaken this program are many.

The railroad is responding to a need for more information regarding train operations, specifically in the investigations into grade crossing incidents. The railroad also has used video to address the issue of locomotive cab blind spots. Video monitors have been placed in the cab to provide the crews with live feed of any activity occurring in areas that are not visible from within the cab. The railroad also uses the recorders to enhance their crew efficiency program. Each crew has their own 12-hour tape that they install at the start of a shift and remove at the end of a shift. This allows the railroad to monitor crew efficiency at regular intervals instead of removing a crew from active service and test-running them on separate trains at annual reviews. The videos created by this system are used as an aid for training crews for locomotive operations. The reality that the videos present make them an invaluable tool in training crews for actual operations. Finally, the railroad has used video to monitor various passive grade crossings and identify any unsafe practices by both locomotive operators and highway drivers at the crossings.

The Arkansas & Missouri Railroad has recognized the benefits of video recording in day-to-day operations as a crew aid and efficiency monitor, as a valuable source if information to augment the locomotive event recorders, and as a preventive measure concerning safety at passive grade crossings. The Safety Board is hopeful that other railroads recognized the vast benefits of video recording and begins their own video programs.

The three goals of the Safety Board with regard to the future of locomotive event recorders are:

- Insure the availability of recorded data by housing the data memory unit in a crash protected environment,
- insure the integrity and accuracy of the data by utilizing appropriate inspection and maintenance techniques, and
- take advantage of available technology (PTC, Audio, Video) to make available the greatest amount and types of data practicable.

Creating an environment where these three concepts are applied will insure ease in accident investigation, maximize the lessons learned from mistakes of the past, and create a safer railroad transportation environment for rail employees and customers both.

CONCLUSIONS

The appropriate data from recorders can provide a more accurate assessment of the circumstances of the events leading up to an accident; and, corroboration of witness statements can be derived from this data which helps eliminate much of the guesswork involved in accident investigation.

BIOGRAPHIES

Ed Dobranetski is the Safety Recommendations Coordinator for the Office of Safety Recommendations and Safety Accomplishments of the National Transportation Safety Board. His previous NTSB positions were in the NTSB's Office of Railroad Safety as Track and Signal Specialist, Chief Major Investigations, and National Resource Specialist. He has been with the NTSB for about 13 years and prior to joining the NTSB he was an engineering manager with a former Class I railroad for more than 19 years.

Dave Case is the Mechanical Engineer for the Office of Research and Engineering (RE) of the National Transportation Safety Board. He is a recorder specialist for the Vehicle Recorders Division within RE. He was a General Engineer for the U. S. Department of Energy for 6 years prior to coming to the NTSB.

A P P E N D I X

SAFETY RECOMMENDATIONS

Recommendation # R-78-044
Issue Date 7/31/78 PENSACOLA, FL
Overall Status CUA

ABOUT 6:06 P.M. ON NOVEMBER 9, 1977, 2 SD-45 LOCOMOTIVE UNITS AND 35 CARS OF LOUISVILLE AND NASHVILLE FREIGHT TRAIN NO. 407 DERAILED WHEN ENTERING A 6 DEGREES 04' CURVE AT PENSACOLA, FLORIDA. THE ADJACENT TANK HEADS OF THE 18TH AND 19TH CARS WERE PUNCTURED DURING THE DERAILMENT BY A LOOSE WHEEL AND AXLE ASSEMBLY; THIS RELEASED ANHYDROUS AMMONIA INTO THE ATMOSPHERE. TWO PERSONS DIED AND 46 WERE INJURED AS A RESULT OF THE DERAILMENT, RELEASE OF ANHYDROUS AMMONIA, AND EVACUATION OF ABOUT 1,000 PERSONS. PROPERTY DAMAGE WAS ESTIMATED TO BE $724,000.

THE NTSB RECOMMENDS THAT THE FEDERAL RAILROAD ADMINISTRATION: PROMULGATE REGULATIONS TO REQUIRE LOCOMOTIVES USED IN TRAINS ON MAIN TRACKS OUTSIDE OF YARD LIMITS TO BE EQUIPPED WITH OPERATING EVENT RECORDERS.

FRA CLOSED - UNACCEPTABLE ACTION

Recommendation # R-81-045
Issue Date 4/22/81 HERMOSA, WY
Overall Status CAA

ON OCTOBER 16, 1980, UNION PACIFIC RAILROAD COMPANY (UP) FREIGHT TRAIN EXTRA 3749 WEST (NPH-16) STRUCK THE REAR OF UP GRAIN TRAIN EXTRA 3557 WEST (SGTLB-635) WHILE IT WAS STANDING ABOUT 100 FEET WEST OF INTERMEDIATE SIGNAL NO. 5517 NEAR HERMOSA, WYOMING. TWO TRAIN CREWMEMBERS WERE KILLED AND TWO CREWMEMBERS WERE INJURED. THE 3 LOCOMOTIVE UNITS OF NPH-16 AND 16 CARS, INCLUDING THE CABOOSE, OF SGTLB-635 WERE DERAILED. TOTAL DAMAGE WAS ESTIMATED TO BE $993,000.

THE NTSB RECOMMENDS THAT THE UNION PACIFIC RAILROAD COMPANY: MODIFY EVENT RECORDERS TO RECORD ACTIVATION OF THE CAB SIGNAL ACKNOWLEDGING LEVER.

UNION PACIFIC RAILROAD CLOSED - ACCEPTABLE ACTION

Recommendation # R-81-046

Issue Date 4/22/81 HERMOSA, WY

Overall Status CNLA

THE NTSB RECOMMENDS THAT THE UNION PACIFIC RAILROAD COMPANY: RELOCATE EVENT RECORDERS SO AS TO LESSEN THE LIKELIHOOD OF THEIR BECOMING DAMAGED IN AN ACCIDENT.

UNION PACIFIC RAILROAD CLOSED - NO LONGER APPLICABLE

Recommendation # R-81-047

Issue Date 4/22/81 HERMOSA, WY

Overall Status CUA

THE NTSB RECOMMENDS THAT THE UNION PACIFIC RAILROAD COMPANY: PROVIDE THE CABS OF LOCOMOTIVES WITH EMERGENCY POWER SO THAT EMERGENCY LIGHTS, RADIOS, AND EVENT RECORDERS CONTINUE TO OPERATE WHEN NORMAL POWER IS LOST.

UNION PACIFIC RAILROAD CLOSED - UNACCEPTABLE ACTION

Recommendation # R-81-049

Issue Date 4/22/81 HERMOSA, WY

Overall Status CNLA

THE NTSB RECOMMENDS THAT THE ASSOCIATION OF AMERICAN RAILROADS: ENCOURAGE MEMBER RAILROADS TO HAVE EVENT RECORDERS WHICH RECORD ACTIVATION OF CAB SIGNAL, AUTOMATIC TRAIN STOP, OR OTHER SIMILAR SAFETY SYSTEM DEVICES.

ASSOCIATION OF AMERICAN RAILROADS CLOSED - NO LONGER APPLICABLE

Recommendation # R-81-050

Issue Date 4/22/81 HERMOSA, WY

Overall Status CNLA

THE NTSB RECOMMENDS THAT THE ASSOCIATION OF AMERICAN RAILROADS: ENCOURAGE MEMBER RAILROADS TO INSTALL OR RELOCATE EVENT RECORDERS SO AS TO LESSEN THE LIKELIHOOD OF THEIR BECOMING DAMAGED IN AN ACCIDENT.

ASSOCIATION OF AMERICAN RAILROADS CLOSED - NO LONGER APPLICABLE

Recommendation # R-81-051

Issue Date 4/22/81 HERMOSA, WY

Overall Status CNLA

THE NTSB RECOMMENDS THAT THE ASSOCIATION OF AMERICAN RAILROADS: ENCOURAGE MEMBER RAILROADS TO PROVIDE THE CABS OF LOCOMOTIVES WITH EMERGENCY POWER SO THAT EMERGENCY LIGHTS, RADIOS, AND EVENT RECORDERS CONTINUE TO OPERATE WHEN NORMAL POWER IS LOST.

ASSOCIATION OF AMERICAN RAILROADS CLOSED - NO LONGER APPLICABLE

Recommendation # R-89-050

Issue Date 7/14/89 ALTOONA, IA

Overall Status CAA

ABOUT 11:44 A.M. CENTRAL DAYLIGHT SAVINGS TIME ON JULY 30, 1988, IOWA INTERSTATE RAILROAD LTD. (IAIS) FREIGHT TRAINS EXTRA 470 WEST AND EXTRA 406 EAST COLLIDED HEAD ON WITHIN THE YARD LIMITS OF ALTOONA, IOWA, ABOUT 10 MILES EAST OF DES MOINES, IOWA. ALL 5 LOCOMOTIVE UNITS FROM BOTH TRAINS; 11 CARS OF EXTRA 406 EAST; AND 3 CARS, INCLUDING 2 TANK CARS CONTAINING DENATURED ALCOHOL, OF EXTRA 470 WEST DERAILED. THE DENATURED ALCOHOL, WHICH WAS RELEASED THROUGH THE PRESSURE RELIEF VALVES AND THE MANWAY DOMES OF THE TWO DERAILED TANK CARS, WAS IGNITED BY THE FIRE RESULTING FROM THE COLLISION OF THE LOCOMOTIVES. BOTH CREWMEMBERS OF EXTRA 470 WEST WERE FATALLY INJURED; THE TWO CREWMEMBERS OF EXTRA 406 EAST WERE ONLY SLIGHTLY INJURED. THE ESTIMATED DAMAGE (INCLUDING LADING) AS A RESULT OF THIS ACCIDENT

EXCEEDED $1 MILLION.

THE NTSB RECOMMENDS THAT THE FEDERAL RAILROAD ADMINISTRATION: EXPEDITE THE RULEMAKING REQUIRING THE USE OF EVENT RECORDERS IN THE RAILROAD INDUSTRY.

FRA CLOSED - ACCEPTABLE ACTION

Recommendation # R-96-046

Issue Date 11/14/96 GAITHERSBURG, MD

Overall Status CAA

ABOUT 10:40 P.M. ON 1/6/96, WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY (WMATA) METRORAIL SUBWAY TRAIN NO. T-111, OPERATING ON THE 'RED LINE" SEGMENT OF THE METRORAIL SYSTEM, FAILED TO STOP AS IT ENTERED THE ABOVE-GROUND SHADY GROVE PASSENGER STATION NEAR GAITHERSBURG, MARYLAND, THE FINAL STATION ON THE RED LINE. THE FOUR-CAR TRAIN RAN BY THE STATION PLATFORM & CONTINUED ABOUT 470 FEET INTO THE METRORAIL YARD NORTH OF THE STATION, WHERE IT STRUCK A STANDING, UNOCCUPIED SUBWAY TRAIN WAS AWAITNG ASSIGNMENT. THE T-111 TRAIN OPERATOR WAS FATALLY INJURED; THE TRAIN'S TWO PASSENGERS WERE NOT INJURED. TOTAL PROPERTY DAMAGES WERE ESTIMATED TO BE BETWEEN $2.1 & 2.6 MILLION.

THE NTSB RECOMMENDS THAT THE FEDERAL TRANSIT ADMINISTRATION: DEVELOP, WITH THE ASSISTANCE OF THE AMERICAN PUBLIC TRANSIT ASSOCIATION GUIDELINES FOR MONITORING/RECORDING DEVICES THT CAPTURE CRITICAL PERFORMANCE & EVENT DATA FOR RAPID RAIL TRANSIT CARS & URGE TRANSIT AGENCIES TO INSTALL THESE DEVICES ON NEW & REHABILITATED CARS.

FTA CLOSED - ACCEPTABLE ACTION

Recommendation # R-96-047

Issue Date 11/14/96 GAITHERSBURG, MD

Overall Status OAA

THE NTSB RECOMMENDS THAT THE AMERICAN PUBLIC TRANSIT ASSOCIATION: DEVELOP, WITH THE ASSISTANCE OF THE FEDERAL TRANSIT ADMINISTRATION, GUIDELINES FOR MONITORING/RECORDING DEVICES THAT CAPTURE CRITICAL PERFORMANCE & EVENT DATA FOR RAPID RAIL TRANSIT CAR & URGE TRANSIT AGENCIES TO INSTALL THESE DEVICES ON NEW & REHABILITATED CARS.

APTA OPEN - ACCEPTABLE RESPONSE

Recommendation # R-96-070

Issue Date 3/5/97 CAJON JUNCTION, CA

Overall Status OAA

ABOUT 4:10 A.M. ON 2/1/96, ATCHISON, TOPEKA & SANTA FE RAILWAY COMPANY (ATSF) FREIGHT TRAIN H-BALT1-31, EN ROUTE FROM BARSTOW, CALIFORNIA, TO LOS ANGELES, WAS TRAVELING WESTBOUND ON THE ATSF SOUTH MAIN TRACK WHEN IT DERAILED AT MILEPOST 60.4 NEAR CAJON JUNCTION, CALIFORNIA. AFTER THE DERAILMENT & THE SUBSEQUENT RAIL CAR PILEUP, WHICH INVOLVED FIVE CARS CONTAINING HAZARDOUS MATERIALS, A FIRE IGNITED THAT ENGULFED THE TRAIN & THE SURROUNDING AREA. THE CONDUCTOR & THE BRAKEMAN SUSTAINED FATAL INJURIES; THE ENGINEER SUFFERED SERIOUS INJURIES.

THE NTSB RECOMMENDS THAT THE FRA: REVISE 49 CODE OF FEDERAL REGULATIONS 229.25(E)(2) TO REQUIRE THAT EVENT RECORDERS, INCLUDING MICROPROCESSOR-BASED EVENT RECORDERS THAT ARE EQUIPPED WITH A SELF-TEST FUNCTION, BE TESTED DURING THE QUARTERLY INSPECTIONS OF THE LOCOMOTIVE IN SUCH A MANNER THAT THE ENTIRE EVENT RECORDING SYSTEM, INCLUDING SENSORS, TRANSDUCERS, & WIRING IS EVALUATED. SUCH TESTING SHOULD INCLUDE, AT A MINIMUM, A REVIEW OF THE DATA RECORDED DURING ACTUAL OPERATION OF THE LOCOMOTIVE TO VERIFY PARAMETER FUNCTIONALITY AS WELL AS CYCLING ALL REQUIRED RECORDING PARAMETERS & DETERMINING THE FULL RANGE OF EACH PARAMETER BY READING OUT RECORDED DATA.

FRA OPEN - ACCEPTABLE RESPONSE

Recommendation # R-96-071
Issue Date 3/5/97 CAJON JUNCTION, CA
Overall Status OUA

THE NTSB RECOMMENDS THAT THE FRA: DEVELOP & IMPLEMENT A PROGRAM THAT SPECIFICALLY ADDRESSES CARRIER COMPLIANCE WITH 49 CODE OF FEDERAL REGULATIONS 229.25(E)(5).

FRA OPEN - UNACCEPTABLE ACTION

Recommendation # R-96-072
Issue Date 3/5/97 CAJON JUNCTION, CA
Overall Status OUA

THE NTSB RECOMMENDS THAT THE FRA: REVISE YOUR FORM F6180-49A TO INCLUDE EVENT RECORDERS IN THE OTHER ITEMS TO BE INSPECTED SECTION ON THE FORM.

FRA OPEN - UNACCEPTABLE ACTION

Recommendation # R-96-073
Issue Date 3/5/97 CAJON JUNCTION, CA
Overall Status OUA

THE NTSB RECOMMENDS THAT THE FRA: INFORM THE INDUSTRY THAT THE PLACEMENT OF EVENT RECORDERS OTHER THAN IN THE LEAD LOCOMOTIVE WILL NOT RECORD THE REQUIRED DATA AS THOUGH THE EVENT RECORDERS WERE IN THE LEAD LOCMOTIVE & ENSURE COMPLIANCE WITH 49 CODE OF FEDERAL REGULATIONS 229.135(A).

FRA OPEN - UNACCEPTABLE ACTION

Recommendation # R-97-009
Issue Date 8/28/97 SILVER SPRING, MD
Overall Status ORR

ABOUT 5:38 P.M. ON 2/16/96, EASTBOUND MARYLAND RAIL COMMUTER (MARC) TRAIN 286 COLLIDED WITH WESTBOUND NATIONAL RAILROAD

PASSENGER CORPORATION (AMTRAK) TRAIN 29, THE CAPITOL LIMITED, AT MILEPOST 8.55 ON CSX MAIN TRACK NEAR SILVER SPRING, MARYLAND. THE MARC TRAIN WAS OPERATING IN THE PUSH MODE IN REVENUE SERVICE BETWEEN BRUNSWICK, MARYLAND, & WASHINGTON, D.C.; IT CONSISTED OF A LOCOMOTIVE & THREE COMMUTER CARS. THE AMTRAK TRAIN, OPERATING IN REVENUE SERVICE BETWEEN WASHINGTON D.C., & CHICAGO, ILLINOIS, CONSISTED OF 2 LOCOMOTIVES & 15 CARS.

THE NTSB RECOMMENDS THAT THE FRA: AMEND 49 CODE OF FEDERAL REGULATIONS PART 229 TO REQUIRE THE RECORDING OF TRAIN CREWMEMBERS' VOICE COMMUNICATIONS FOR EXCLUSIVE USE IN ACCIDENT INVESTIGATIONS & WITH APPROPRIATE LIMITATIONS ON THE PUBLIC RELEASE OF SUCH RECORDINGS.

FRA OPEN RESPONSE RECEIVED

Recommendation # R-98-030
Issue Date 6/25/98 DEVINE, TX
Overall Status OAR

AT 10:52 P.M. ON 6/22/97, UNION PACIFIC RAILROAD (UP) FREIGHT TRAINS 5981 NORTH & 9186 SOUTH COLLIDED HEAD-ON IN DEVINE, TEXAS. THE TRAINS WERE OPERATING ON A SINGLE MAIN TRACK WITH PASSING SIDINGS IN DARK NONSIGNALIZED) TERRITORY IN WHICH TRAIN MOVEMENT WAS GOVERNED BY CONDITIONAL TRACK WARRANT CONTROL AUTHORITY THROUGH A DISPATCHER. THE CONDUCTOR FROM 5981 NORTH, THE ENGINEER FROM 9186 SOUTH, & TWO UNIDENTIFIED INDIVIDUALS WHO MAY HAVE BEEN RIDING ON 5981 NORTH WERE KILLED IN THE DERAILMENT SUBSEQUENT FIRE. THE ENGINEER FORM 5881 NORTH RECEIVED MINOR INJURIES & THE CONDUCTOR FROM 9186 SOUTH WAS SERIOUSLY BURNED. ESTIMATED DAMAGES EXCEEDED $6 MILLION.

THE NTSB RECOMMENDS THAT THE FRA: WORKING WITH THE RAILROAD INDUSTRY, DEVELOP & IMPLEMENT EVENT RECORDER CARSHWORTHINESS STANDARDS FOR ALL NEW OR REBUILT LOCOMOTIVES JANUARY 1,2000.

FRA OPEN - INITIAL RESPONSE 2/4/99

Recommendation # R-98-057

Issue Date 9/16/98 **KINGMAN, AZ**

Overall Status OAR

ABOUT 5:56 A.M., ON 8/9/97, NATIONAL RAILROAD PASSENGER CORPORATION (AMTRAK) TRAIN 4, THE SOUTHWEST CHIEF, DERAILED ON THE BURLINGTON NORTHERN SANTA FE RAILWAY (BNSF) TRACKS ABOUT 5 MILES NORTHEAST OF KINGMAN, ARIZONA. AMTRAK TRAIN 4 WAS ENROUTE FROM LOS ANGELES, CALIFORNIA, TO CHICAGO ILLINOIS, & HAD JUST LEFT THE KINGMAN STATION. THE TRAIN WAS TRAVELING ABOUT 89 MPH ON THE EASTBOUND TRACK WHEN BOTH THE ENGINEER & ASSISTANT ENGINEER SAW A "HUMP" IN THE TRACK AS THEY APPROACHED BRIDGE 504.1S. THEY APPLIED THE TRAIN'S EMERGENCY BRAKES. THE TRAIN DERAILED AS IT CROSSED THE BRIDGE. SUBSEQUENT INVESTIGATED REVEALED THAT THE GROUND UNDER THE BRIDGE'S SUPPORTING STRUCTURE HAD BEEN WASHED AWAY BY A FLASH FLOOD. OF THE 294 PASSENGERS & 18 AMTRAK EMPLOYEES ON THE TRAIN, 173 PASSENGERS & 10 AMTRAK EMPLOYEES WERE INJURED. NO FATALITIES RESULTED FROM THE ACCIDENT. THE DAMAGES WERE ESTIMATED TO TOTAL APPROXIMATELY $7.2 MILLION.

THE NTSB RECOMMENDS THAT THE FRA: REQUIRE THAT EVENT RECORDER SYSTEM SPECIFICATIONS BE KEPT AS PART OF THE LOCOMOTIVE'S RECORDS.

FRA OPEN - AWAIT RESPONSE

On-board Recorders: The "Black Boxes" of the Trucking Industry

Les Dole
Cadec Corporation
8 E. Perimeter Rd.
Londonderry, NH 03055

KEYWORDS

Highway

CHOOSE 3:

On-board	Accountability
Recorders	Parameters
Tachograph	Incentive
Parameters	

INTRODUCTION

From 1995 to 1997, the number of fatalities resulting from accidents involving large trucks increased from 5,091 to 5,355.[1] Most crashes involving automobiles and trucks occur in broad daylight, on straight and dry pavement, during normal weather, and with no indication of alcohol or drug use.

In the last four years especially, there has been an outcry across the country from various transportation, safety and trucking groups for a reduction in the number of accidents and deaths on the nation's highways involving trucks. Ongoing national hearings are being held by the United States House of Representatives Ground Transportation Subcommittee to examine this issue. In the past month, such heavy hitters as National Private Truck Council's President John McQuaid and Phyllis F. Sheinberg, Associate Director, Transportation Issues, Resources, Community and Economic Development, have been testifying before the committee.

A COMPLEX ISSUE

It is agreed throughout the industry that improving truck safety is a complex issue. Accidents cause not only injuries and death, but they also increase worker compensation costs, insurance premiums, property and personal injury claims, and vehicle downtime and repairs.

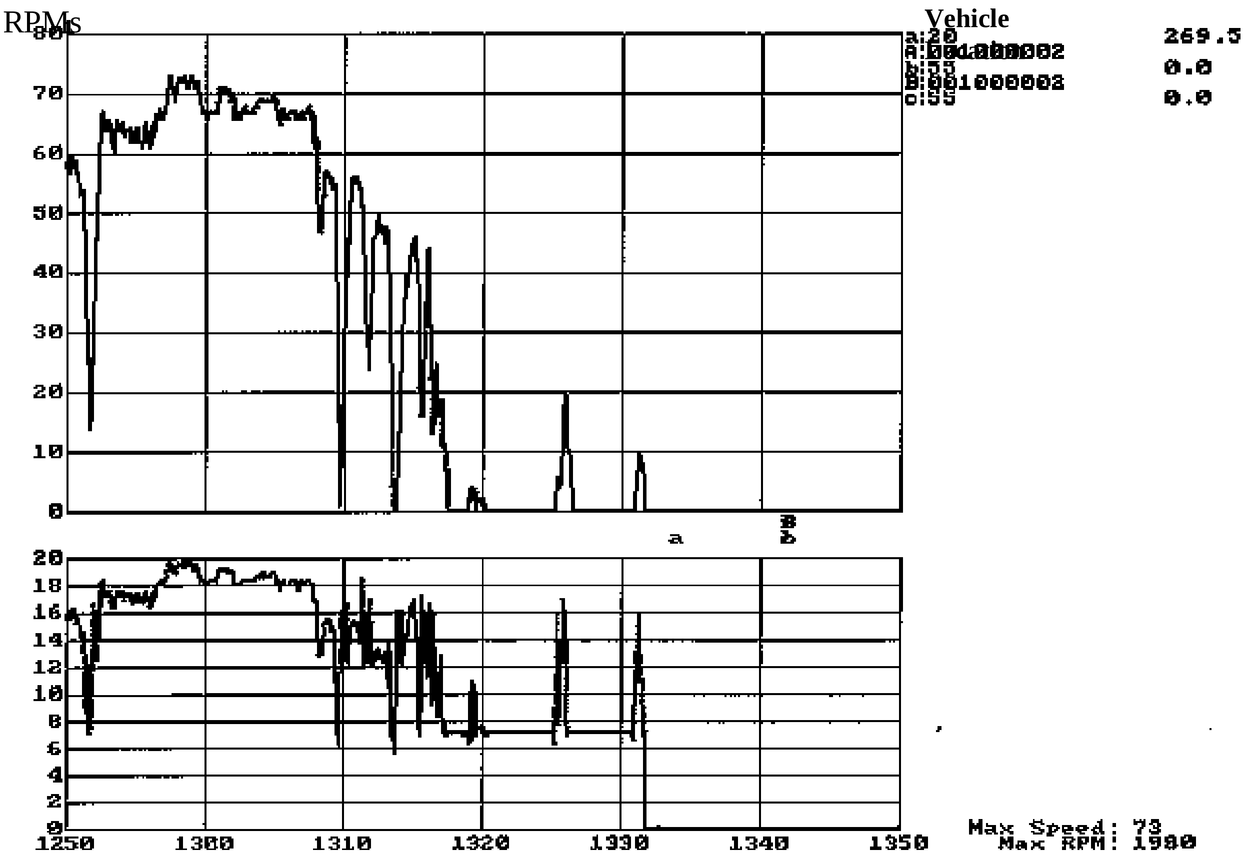
Even the most experienced and safest drivers are subject to the whims of other drivers on the road and to unanticipated changes in the weather. However, some factors that have been identified as causes of some of these accidents, including driver error, inattention, or fatigue.

The on-board recorder has evolved into a tool that companies can use to help their drivers become safer drivers. The real-time data that these devices generate point up the deficiencies of less skilled drivers and the strengths of safer, more experienced drivers. When combined with safety training, driver incentive programs, and coaching using this data, companies are producing safer drivers.

CAPABILITIES OF ON-BOARD RECORDERS

On-board recorders are the "black boxes" of the trucking industry. With today's technology, everything that drivers do in their job can be recorded in real-time. When combined with GPS systems, these systems provide a total picture of the drivers' day — how they drove and where they were at any given moment.

Safety related reporting capabilities include speeding violations, DOT hours of service violations, sudden decelerations, and exceeding company safety parameters. In particular, those units with the electronic tachograph capability graphically show simultaneous engine and vehicle speed, and show how a vehicle was driven for a 24-hour period. (See Figure 1.) This function identifies driver compliance with speed limit changes along routes. It also profiles basic driving habits. For example, if the graph shows that the vehicle's speed decreased suddenly but the engine speed did not, the driver may have been tailgating and had to slam on the brakes to avoid an accident.



Speed **Time (in minutes)**

Figure 1: This tachograph shows a representation of the engine's rpm (top) and the vehicle's speed (bottom) in a ten minute period.

Ideally, this objective data is used as a coaching tool to help drivers become safer, more efficient drivers. In the case of an accident, the data can be used to exonerate the innocent driver.

Today's recorders do much more than their initial purpose of automating DOT logs. Some devices now act as "on-board coaches"; they provide immediate feedback to the driver by emitting visual and audible signals when they are exceeding pre-set company safety parameters or approaching impending hours of service violation. If drivers do exceed legal hours, it is reflected on the downloaded data as part of a DOT Violations Report. Routing and scheduling changes may be necessary to help drivers avoid exceeding legal hours.

COACHING DRIVERS

On-board recorders can record speeding violations, sudden decelerations and braking incidents and other unsafe driving habits. If the data for one driver repeatedly shows these incidents or other violations, the prudent transportation manager uses this data as a coaching tool to improve this driver's performance. Likewise, for the safest drivers, these same reports and graphs can be used to reward good driving habits.

As part of their 5-point Journey Management approach, Schlumberger Oil Field Services now requires that all their vehicles have onboard recorders. Since the primary working environments for these vehicles is remote exploration oil well sites and much travel is done at night, fatal accidents were not rare occurrences. Combined with Defensive Driver Training, the onboard recorders have reduced the number of deaths from vehicle accidents significantly in one year. Mark Corrigan and Philippe Regnault of Schlumberger stated that "driver training and safety systems remain critical elements to lower the risk of oil field service fatalities."[5]

ON-BOARD RECORDERS AS MOTIVATORS

Modern behavioral psychologists contend that the ultimate reward in motivation is the feeling of self-worth, a job well done, and personal growth. Frederick Herzberger said that the most important motivator factors are recognition for the achievement, the work itself, responsibility and growth or advancement.[4]

With the on-board recorders, drivers are more accountable than ever for their job performance. Companies can use the data to either motivate and reward their drivers and or to punish them. Those companies who have the best safety records have used the data positively and have successfully instituted driver incentive programs. One large food distributor has been using on-board recorders coupled with a reward system for 13 years. This company was able to share $50,000 in saved operating costs with its drivers. Those drivers with the fewest violations and safest driving history received the greatest share of the money.

PERCEPTION IS EVERYTHING

The effectiveness of on-board recorders and the data they produce depends on the way that the devices are positioned to the drivers. If the drivers perceive them as "Big Brother" which collects data to monitor them for punitive purposes, driver performance suffers. If, however, drivers know that they will be rewarded for good performance, they will strive to drive within the company parameters. This, in turn, motivates them to be safer drivers.

From the outset, management needs to position the recorders as a tool to help drivers be more productive and drive more safely rather than as a way to catch drivers making mistakes. The on-board recording industry has found that training is the key to using recorders correctly and to their maximum potential. All levels of the organization should attend training, and it is helpful for drivers to be trained right alongside management. This helps drivers feel like an integral part of the team and that they share the same goals as management. Ideally, on-site training should be delivered by a driver who is well respected by his peers.

CONCLUSION

As the transportation industry struggles with how to reduce the number of accidents involving trucks, it is becoming apparent that on-board recorders can play a large part in this effort. Companies with the best safety records have a three-pronged approach of safety awareness programs, safety training, and measurement of driving performance with on-board recorders.

If positioned and used correctly as a training and coaching tool, managers and drivers working together can improve safety, productivity and profitability by using the data gathered by the recorder to help drivers improve their driving skills.

ACKNOWLEDGEMENTS

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The Automated Collision Notification System

KEYWORDS

highway, crash, mayday, injury

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INTRODUCTION

The NHTSA sponsored Automated Collision Notification (ACN) Project was initiated in October 1995 to design, develop, test, and evaluate a system that can detect and characterize crashes and then automatically send a data message to the public safety answering point (PSAP), see Figure 1. The system also opens a cellular telephone voice line between the PSAP and the vehicle occupants after the data message has been received. The system detects crashes in all directions and stores the acceleration time history experienced. The ACN system is able to determine the crash change in velocity, the principal direction of crash force, whether a rollover occurred and the potential for injury in the crash. The system also includes GPS equipment and provides PSAP dispatchers with a mapped location of the crash. The ACN system has been installed in 700 vehicles in Western New York and real world crash data and time of EMS response data is being collected and analyzed.

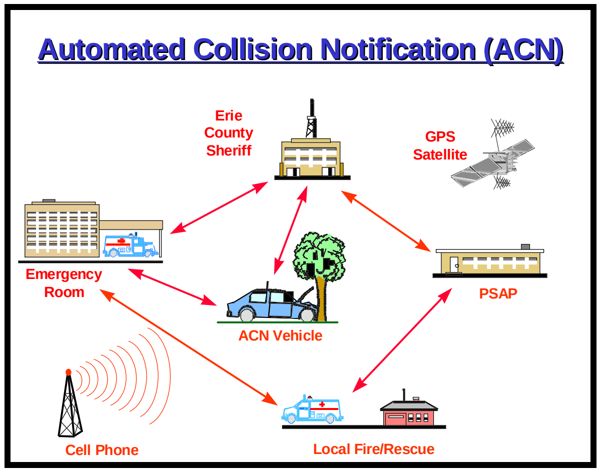

Figure 1: ACN System

IN-VEHICLE EQUIPMENT

The components of the ACN in-vehicle equipment suite are illustrated in Figure 2. These components include: the Veridian developed In-Vehicle Module (IVM), the cellular telephone handset, the cellular telephone transceiver (3 Watt), the back-up battery, and the associated antennas.

Figure 2: ACN In-vehicle Hardware

TRANSCEIVER

The transceiver selected for use the ACN system is the JRC 8820DR transceiver which allows automated control via a serial control channel. Commands are available to initiate call processing, dial a number, answer an incoming call, among others. The transceiver can also provide data such as the current RSSI level, active system (A or B or

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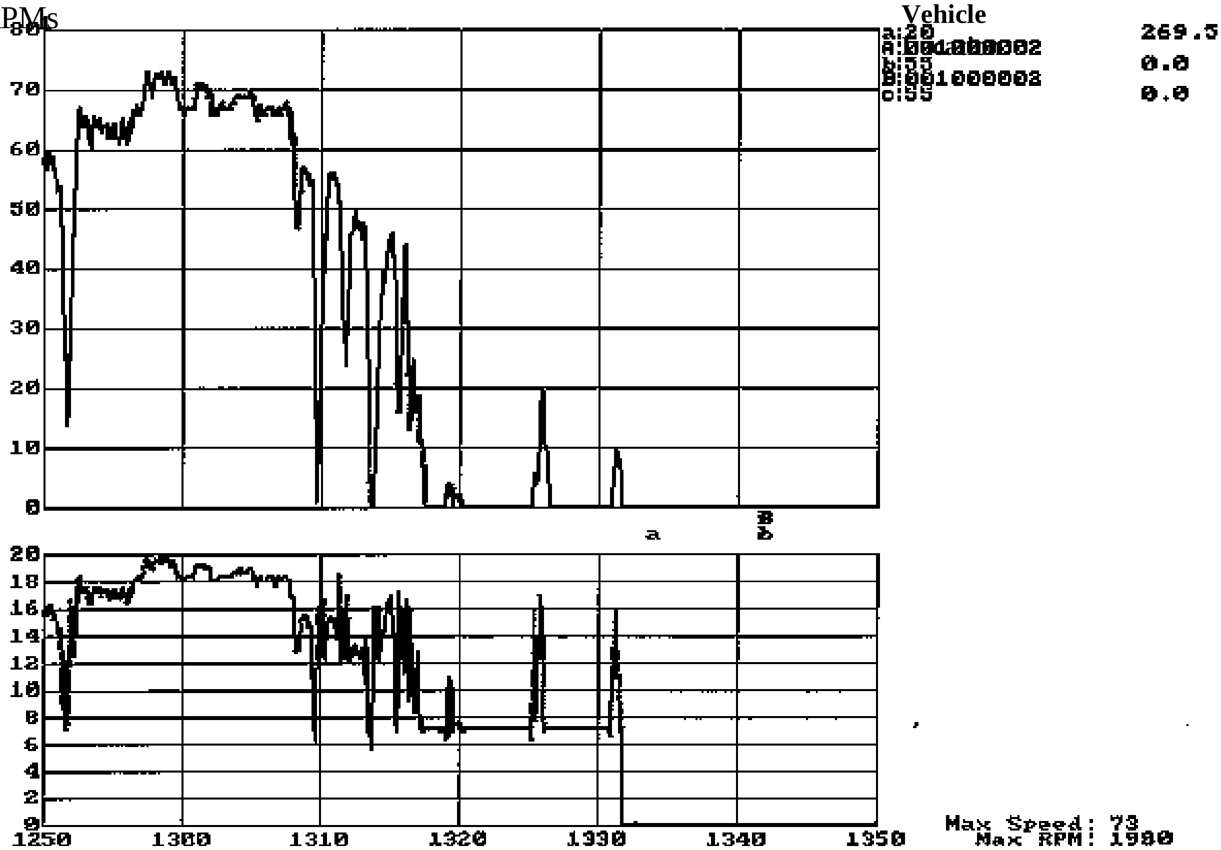

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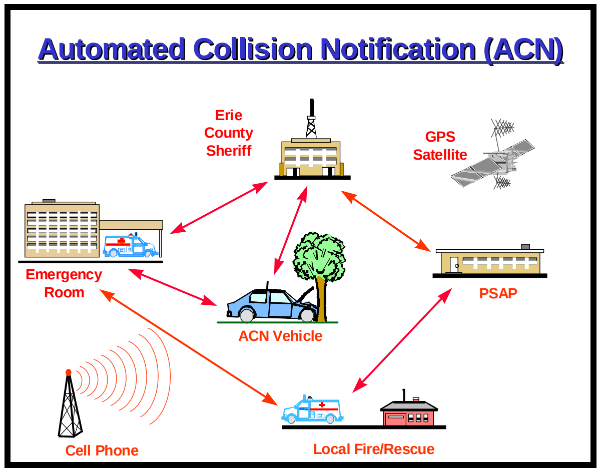

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The transceiver selected for use the ACN system is the JRC 8820DR transceiver which allows automated control via a serial control channel. Commands are available to initiate call processing, dial a number, answer an incoming call, among others. The transceiver can also provide data such as the current RSSI level, active system (A or B or no service available), in-use, roam, etc. These controls may seem trivial, but control of a cellular phone is not as straightforward as a land-line phone where placing a call involves merely dropping an appropriate “off-hook” load across the line, waiting for a dial tone, then sending DTMF tones of the appropriate length and spacing.

Other than the serial control line, the only other connections to the transceiver are a reset signal and audio in/audio out.

HANDSET
The handset chosen is a JRC 6030 handset. This handset also allows control via a single serial control channel. Messages are sent to the IVM (the “host computer” in the handset’s view) whenever any button is pressed or released. Further, a message is sent whenever the handset is placed in or removed from its cradle. The handset can be directed to operate as a normal “hand-held” unit, or can be operated in a “hands-free” mode in which the audio out is directed to the larger speaker underneath the keypad, and the incoming audio taken from the microphone above the LCD display (two lines of 8 characters, plus icons below). The “hands-free” mode, while obviously intended for use when the handset is in the cradle, is totally under software control via the serial control channel; when the ACN system detects a crash, the car’s occupants are connected to the dispatcher in hands-free mode regardless of the handset’s position.

BATTERY
The back-up battery is a gel-cell lead-acid battery kept constantly charged by the IVM and used to provide enough emergency power for collision reporting and an extended duration phone call or two should the car’s battery become disconnected or destroyed in an accident.

IVM
The IVM is the key element of the ACN in-vehicle equipment suite. The IVM is packaged in a rugged aluminum housing and contains a high performance (16 bit processor, 13.8 MIP) Digital Signal Processor (DSP), three orthogonally mounted micro-machined accelerometers, an Analog to Digital Converter, a single chip modem employing the robust and conservative V.23 Frequency Shift Keying data transfer protocol, a Rockwell Jupiter 12-channel GPS receiver board, power conditioning circuitry, and a non-volatile FLASH memory (128 Kbytes, expandable to 1024 Kbytes) to store detailed crash event time histories (see Figures 3 and 4).


Figure 3: IVM - Internal View

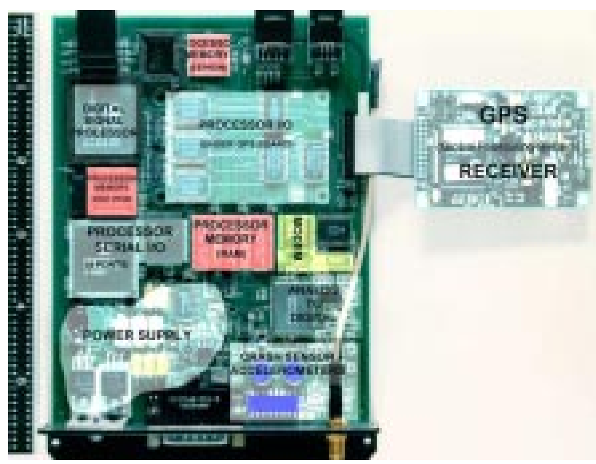

Figure 4: IVM Board With Functional Sections Highlighted

DSP
The IVM’s detection and sensor conditioning algorithms are very DSP-intensive; that is, many of the computations are tight loops of multiply-intensive convolutional equations. The IVM uses an Analog Devices DSP, the ADSP2105, to perform all the detection algorithms as well as

control all the various peripheral devices and telematics sequencing (see Figure 5).

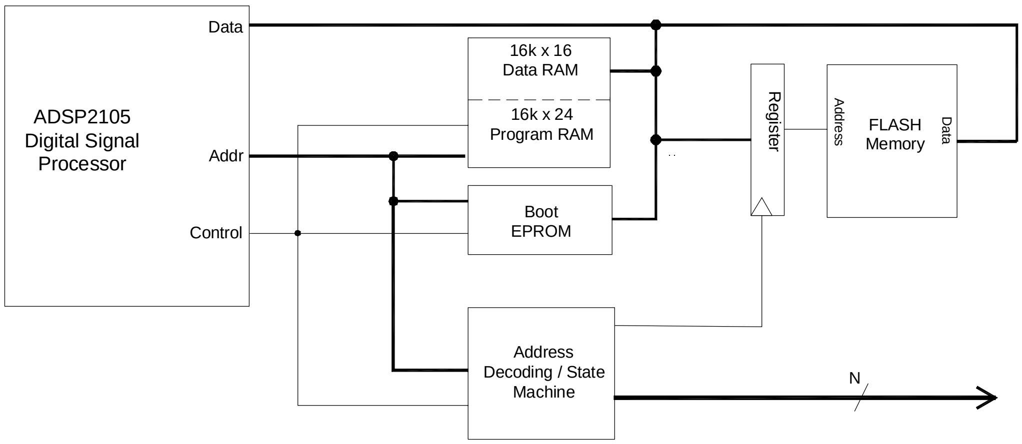

Figure 5: DSP Block Diagram

The ADSP2105 is a 16-bit fixed-point DSP with a modified Harvard architecture; i.e. it has a program data bus and a data data bus (internally) making it possible to, say, multiply an acquired data value by a stored coefficient (stored in program memory) and add it to a previous sum in a single instruction cycle.

The ADSP2105 can address 16k 16-bit words of data memory, including 0.5k words which are mapped to data memory internal to the chip, and 16k 24-bit words of program memory, including 1k words which are mapped to internal program memory. Since the access times required for zero wait state memory accesses are short enough to make EPROM, ROM, or FLASH memory prohibitively difficult to use, the processor is designed to use fast static RAM for all its external memory. Upon reset, a “bootup” program is transferred from a small, relatively slow BOOT EPROM to the DSP’s internal program memory. After transfer, that program in internal program RAM (PRAM) is executed.

The IVM has nearly a full compliment of RAM available to it; as much as the ADSP2105 can directly address, that is. The 2105 allows for 14 k words of external program RAM, allocating 2k words for internal addressing for compatibility with other DSP family parts. The ADSP2105 allows 14 k words of external data RAM also, mapping 1k of address space for its internal registers and 1k of address space for its internal data RAM (again for compatibility with other DSP family parts which have more internal RAM). Of the remaining 14 k words of externally addressable data RAM space, the IVM maps 13 k words into actual RAM, and allocates a 1 k address block for memory-mapped peripheral addressing. The decoding for the peripheral addresses is done with demultiplexors and a PLD; the PLD also includes a state machine to allow slower peripherals enough setup and hold times for their data for, even though the DSP has a programmable wait state generator built in, these wait states simply add time to the middle of the accesses.

Since the program and data busses are multiplexed into a single data bus for external RAM access, the IVM maps both program RAM and data RAM into the same physical set of devices: three 32k by 8 bit RAM chips.

The IVM stores many of its parameters, much of its operational code, and all of the data collected during a collision in FLASH memory. This memory is accessed using a set of memory-mapped address registers, and a single read/write address for data.

Serial I/O
A total of six serial ports are required for the IVM. Two are required for the modem since V.23 allows for an asynchronous bit rate transmission and reception (two different baud rates). One each for communication with the GPS receiver, the handset, the transceiver, and the diagnostic port.

The diagnostic port is used to upload the program and parameters into the IVM, including the transformation matrix provided by the Reference Correction Unit described below, and to upload measured event histories.

Modem and Audio Multiplexing
The IVM uses a TDK 73K321 single chip modem which employs CCITT V.23 standard modulation and signaling. The call is initiated by the IVM at "normal" V.23 originate baud rates of 75 baud transmit, 1200 baud receive. Since the IVM will transmit the preponderance of information and reception is required only for commands and verification, after connection the channels are immediately reversed so that the IVM transmits at 1200 baud, receives at 75 baud.

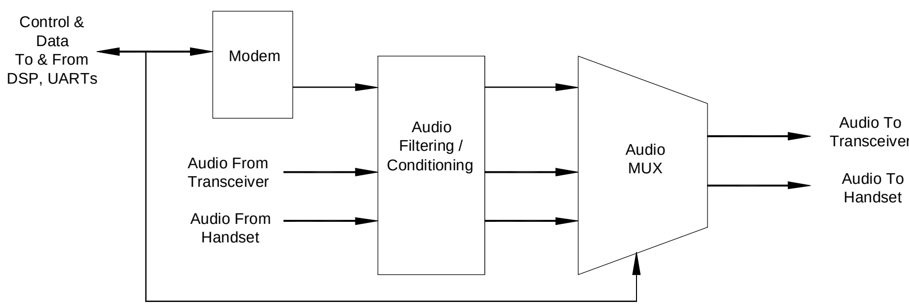

Figure 6: Modem, Audio Path Block Diagram

Audio path control is achieved using CMOS FET switches after proper conditioning, filtering, level shifting and amplification (see Figure 6).

GPS Receiver
As stated above, incorporated into the IVM is a Rockwell Jupiter GPS receiver. This "daughter board" is connected to and controlled by the DSP via a serial port and discrete lines.

Sensors, Conditioning, and A/D
The collision sensing is performed using three inexpensive monolithic micromachined accelerometers, two Analog Devices' ADXL50s and one Motorola MMAS40G, and a lot of signal conditioning in the DSP.

The two ADXL50s are arranged on the board so that their (linear) axis of sensitivity is parallel to the board and at right angles to each other. The MMAS40G has an axis of sensitivity that is perpendicular to the circuit board, so that all three of the sensors are mounted orthonormally without requiring a daughter board arrangement to achieve 3-axis sensitivity.

The acceleration outputs are anti-alias filtered before being converted to digital values by a 12 bit Analog to Digital converter.

Our pass band of interest extends up to 60 Hz, and the internal processing of the actual detection algorithm and storage of vehicle dynamics is done at 180 samples per second. However, in order to effectively and economically filter to 12 bit accuracy across automotive temperatures, the accelerations are oversampled by a factor of 8 at 1440 samples per second. The DSP filters to a 60 Hz cutoff and decimates the results from 1440 to 180 samples per second. This greatly reduces the demand on the order and accuracy of the analog filters.

The acceleration outputs from the ADXL50 are proportional to absolute voltage levels. However, the MMAS40G is a *ratiometric* device, where the measured acceleration is proportional to a percentage of the supply voltage, rather than an absolute voltage. Typically, the A to D converter's reference is driven by the same supply voltage so that any variance in the voltage is compensated. Either technique is workable, but mixing the two on a single A to D converter creates difficulties. The IVM solves the problem by monitoring the 5V analog supply voltage and correcting the ratiometric sensor in software.

Power Regulation and Control

Power for the IVM is derived from the automobile's power, diode isolated and diode "ORed" with the back up battery. After a series of protection and filtering components, the voltage is converted to 5V using a switching regulator from the National Semiconductor Simple Switcher® family.

Power for the transceiver and handset is taken from the diode "ORed" node, and switched under computer control using a FET.

The battery is float charged whenever the ignition line is on. The charging of the battery is current limited by a PTC (Positive Temperature Coefficient) thermistor.

The switching regulator, and thus the power for the preponderance of the IVM, is controlled by a tiny, extremely low power PIC microcontroller (see Figure 7). This processor is continually powered (through an independent micropower linear voltage regulator) running from the time of installation on so long as the IVM is connected to any power source (the main automobile power line or the back up battery). This processor serves as a power-up sequencer, a reset circuit, a wake-up timer, and a watchdog timer.

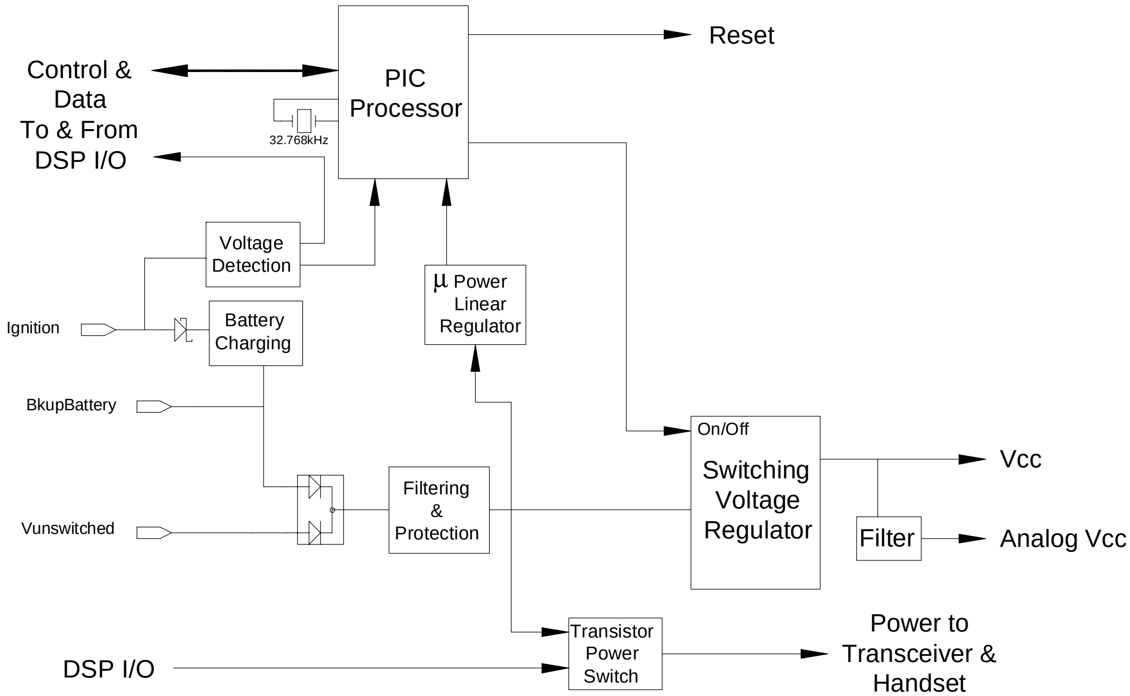

Figure 7: PIC and Power Conditioning Block Diagram

The PIC will monitor the ignition sense line (reduced to TTL voltage levels) and determine if the ignition comes on. If so, the PIC will turn on the power to the rest of the IVM, and hold the DSP reset line for an appropriate duration. The DSP can also read the ignition sense line. In normal operation, when there is no collision event and the phone is not in use, the DSP will poll the ignition line and, when it is de-asserted, will perform any “clean-up housekeeping” necessary. Then, it will inform the PIC by sending it a code that it wishes to be shut down, and woken up after a set duration. This allows the IVM to perform periodic self-test functions and report its status to a remote computer. If the DSP is in the process of reporting a detected collision, even if the ignition line becomes de-asserted the unit will remain powered on until the entire event is processed.

To guard against any momentary soft upsets, the PIC also acts as a watchdog timer. During normal operation, the DSP will toggle an I/O line being read by the PIC, setting it to one polarity in the Interrupt Service Routine (ISR), and to the other in the background processing loop. If the PIC does not detect this bit toggle after a few minutes, it will reset and re-initialize the IVM.

DISPATCHER INTERFACE (GATEWAY)

The ACN crash messages are received at the Erie County Sheriff’s Office on a PC based dispatcher interface console and a voice line is immediately opened between the Sheriff’s Office and the ACN equipped vehicle. The dispatcher interface monitor displays a map with the crash location, the previous ten seconds of vehicle location and speed, an icon showing the principal direction of crash force, the crash change in velocity, whether a rollover occurred and the vehicle final rest position (see Figure 8.). An estimate of the probability of serious injury is also available if desired. The voice line is opened as soon as the monitor display is complete and the dispatcher establishes contact with the occupant within two minutes of the crash if the occupant is able to respond. Medical advice can be tele-conferenced to the crash vehicle from the Erie County Medical Center if it is needed. For Erie County crashes, the dispatcher alerts the appropriate responding agency and EMS, Police and Fire response is initiated regardless of where the crash is located, whether the crash was observed by a bystander or passerby and whether or not the occupants were conscious. For out of area crashes, the Cross Country national message center is notified and the call is passed to the appropriate local response agency.

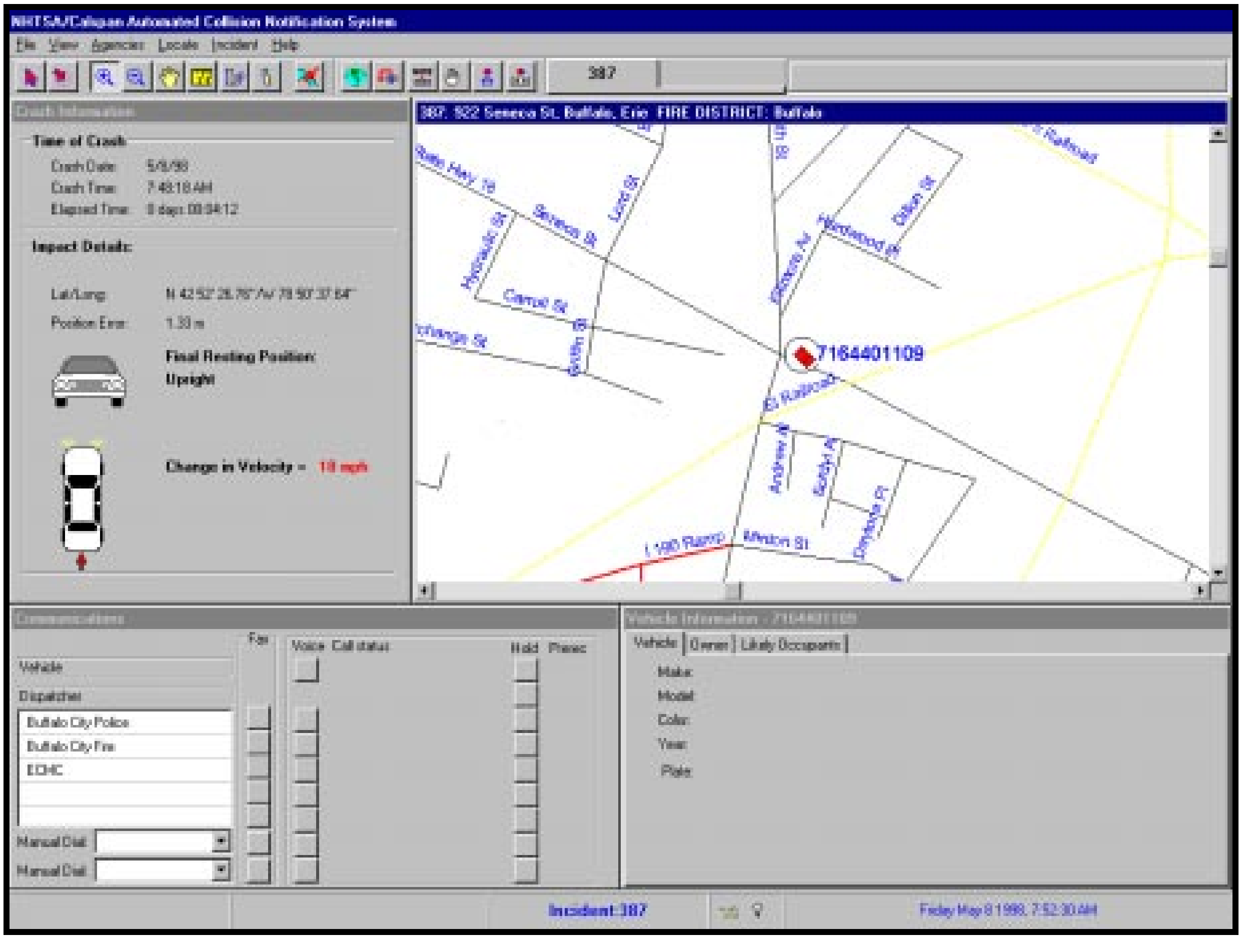

Figure 8: Dispatcher Interface Screen

DESCRIPTION OF THE FIELD OPERATIONAL TEST

ACN SYSTEM

Over 700 vehicles in Western New York have been equipped with ACN systems to provide over 1000 vehicle years of driving exposure. Volunteer participants from the more rural areas of Erie County were recruited to have the ACN in-vehicle equipment installed into their vehicles by Cell-One who also provided the cellular telephone service. In most cases the equipment was installed under the rear seat. The In-Vehicle Module (IVM) is calibrated in place after installation, using a reference correction unit (see Figure 9), such that the triaxial accelerometer output is in the standard SAE Cartesian vehicle coordinate system regardless of the vehicle or the installation location. Several cellular telephone usage plans were offered by Cell-One to the participants; however, emergency calls and calls to Veridian are always free of charge to the participant. After a crash occurs the crash is investigated in depth. A time line listing crash time, notification times, dispatch times and response times is constructed and analyzed to identify the effect of the ACN time on response time.

Figure 9. Reference correction unit.

CRASH EVENT TIMER

In addition to the ACN system, 3000 crash event timers (CETs) have been installed in vehicles in Western New York to collect the baseline notification and response times for crashes when ACN systems are not involved. The field operational test will include 4000 CET vehicle years in the field. These data provide the control times required to measure the improvement in notification and response time obtained with the ACN system. The CET consists of a small timer unit(see Figure 10) that is attached to the firewall of the vehicle and a small inertia sensor that recognizes a crash and starts the timer. The timer runs for three weeks before it automatically resets itself. After being notified of the crash by the vehicle owner, Veridian investigators go to the crash vehicle and read the timer to obtain the elapsed time since the crash. The actual crash time is calculated from the time of the reading and the elapsed time. The EMS, Police and Fire records then are analyzed to yield the baseline notification and response times for non-ACN crashes.

STATUS OF TEST

At the present time the program is approximately 60% complete in terms of days-in-the-field with 639 ACN equipped vehicles in the field and 2930 CET equipped vehicles in the field. To date nineteen CET crashes have been experienced of which six are rural and nine ACN crashes have been experienced of which three are rural. The operational field test will be complete in September 1999.

Figure 10. Crash Event Timer

RESULTS

To date thirty-six ACN crashes have occurred of which ten were above the crash threshold. These ten above threshold crashes are summarized in Table 1. In eight out of the ten cases the ACN system provided an emergency notification message to the Sheriff's office in less than two minutes. In the other two cases a message was not sent because (1)the in-vehicle equipment was not operational at the time of the crash due to incorrect wiring during installation and (2) the crash occurred in Chicago, Illinois and although the system did detect the crash and assemble a message it did not make a long distance telephone call to New York.

Crash #	ACN I.D. #	Incident or Crash?	Crash Date	Crash Location	Geographic Area	Total Occupants (all vehicles)	Injuries & Max. AIS	Medical Transport	Crash Type & Severity
1	440-1129	Crash	1/3/98	Chicago, IL	Urban	8	Neck strain and contusions (AIS-1)	2 of 8 occupants transported via ambulance	Car/Car Intersection Moderate impact
2	440-1104	Crash	2/18/98	Buffalo, NY	Urban	2	Sternum fracture (AIS-2)	Both drivers were transported via ambulance	Car/Car Intersection Moderate impact
3	440-1239	Crash	4/4/98	Marilla, NY	Suburban	1	Right shoulder contusion (AIS-1)	None	Single car - road side departure Moderate impact
4	440-1046	Crash	4/15/98	East Aurora, NY	Rural	1	No injury	None	Single car - road side departure Moderate impact
5	440-1109	Crash	5/8/98	Buffalo, NY	Urban	5	Right leg contusions (AIS-1)	4 of 5 occupants transported via ambulance	Minivan/SUV/ Car rear to front Severe
6	440-1254	Crash	8/31/98	Hamburg, NY	Suburban	3	No injury	None	Car/Car frontal Minor impact
7	440-1463	Crash	11/15/98	Rochester, NY	Urban	5	Driver - seat belt related contusions (AIS 1)	None	Car/Car intersection
8	440-1094	Crash	1/31/99	Cheektowaga, NY	Suburban	3	RF Passenger Fx vertebra - L1 (AIS 2)	Ambulance	Car/Car intersection
9	440-1346	Crash	3/3/99	East Aurora, NY	Suburban	2		Ambulance	Car/Car offset frontal
10	440-1343	Crash	3/4/99	Newstead, NY	Rural	1	No injury	None	Car/pole

Table 1: Summary of ACN Above-threshold Crashes

ACN CRASH 440-1109

Crash I.D. #440-1109 involved an ACN equipped 1993 Plymouth Voyager mini-van that was struck from the rear while waiting at a red traffic signal. The mini-van was pushed forward and into the rear end of the vehicle waiting in front of it. The result was two collisions, a rear and a frontal, both of which exceeded the crash thresholds of the IVM. Figure 11 summarizes the crash, shows photographs of the mini-van and shows the triaxial accelerometer data recorded by the IVM and stored in flash memory. Both events are clearly seen in the acceleration time history as a positive x acceleration excursion (the rear crash) followed by a quiescent period and a negative x acceleration excursion (the frontal crash). The IVM calculates the crash delta velocity and the principal direction of force (PDOF) for each crash event, indicates whether a rollover occurred and determines the final rest position of the vehicle after the crash is over (see Figure 11). Figure 12 is a crash scene diagram showing the events of the crash as reconstructed by a crash investigator. The IVM obtains the same information as post-crash reconstruction and makes it immediately available to EMS, Police and Fire dispatchers to be used in the dispatch process.

- Crash Time: ***03:21 am***
- Notification Time: ***03:22 am***
- Rollover: ***No***
- Final Rest Position: ***Normal***

- Principal Direction of Force (PDOF): ***6 o'clock*** ***12 o'clock***
- Delta Velocity (ΔV): ***30.3 kph*** ***15.8 kph***

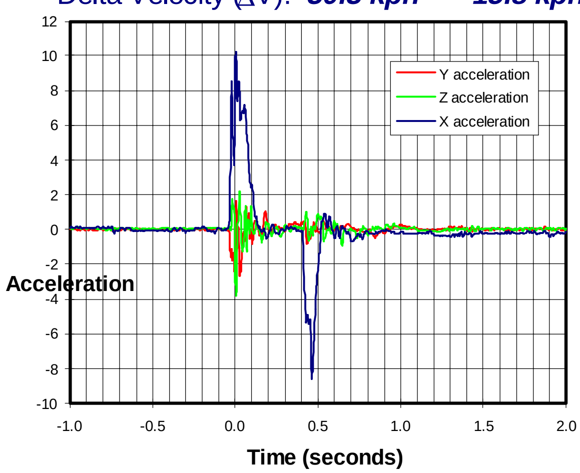

Figure 11. Crash summary for ACN Crash No. 440-1109.

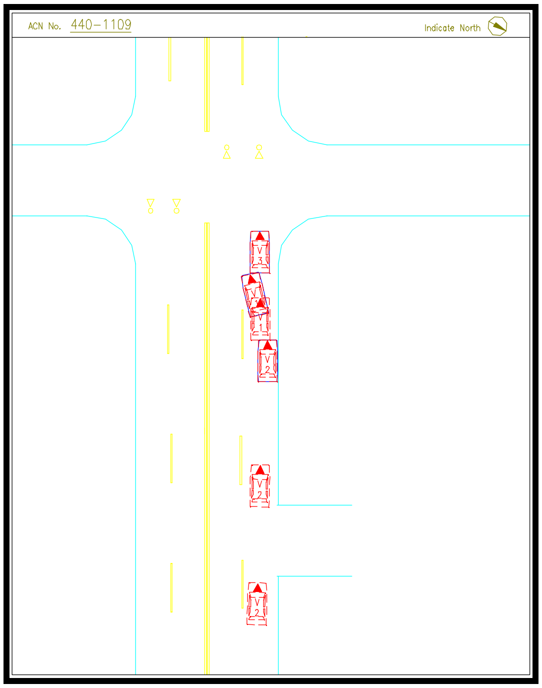

Figure 12. Crash scene diagram for ACN Crash No. 440-1109.

ACN CRASH 440-1094
Crash I.D. #440-1094 involved an ACN equipped 1991 Ford Explorer sport utility vehicle that was struck in the left side by a vehicle making a left turn across the Explorer’s lane. The Explorer went into a counterclockwise skid and subsequently struck a frozen snow bank on the right side of the road before finally coming to a controlled stop further down the road. The right front passenger of the Explorer was unrestrained and suffered a compressed fracture of a lumbar vertebrae during the event. Figure 6 summarizes the crash, shows photographs of both vehicles involved in the crash and shows the triaxial accelerometer data recorded by the IVM and stored in flash memory. Both the initial impact event and the snow bank impact are clearly seen in the acceleration time history as a positive y acceleration excursion (the initial side impact) followed by a negative y acceleration excursion (the snow bank impact). The IVM calculates the crash delta velocity and the principal direction of force (PDOF) for the crash event, indicates whether a rollover occurred and determines the final rest position of the vehicle after the crash is over (see Figure 13). Figure 14 is a crash scene diagram showing the events of the crash as reconstructed by a crash investigator.

It is interesting to note that the initial side impact crash was not sufficiently severe to trigger the IVM and make a call to the Sheriff. The snow bank impact that occurred subsequent to the side impact was sufficiently severe to trigger the IVM and a call was made to the Sheriff who answered in less than two minutes. There was no visible body damage to the Explorer and it was not clear during post-test reconstruction that the snow bank impact was more severe than the initial side impact. Analysis of the acceleration time history stored in the IVM made it clear that the snow bank impact, resulting in the right front passenger impacting the right interior door panel, was most likely the cause of this occupant’s lumbar vertebrae fracture. The availability of a complete acceleration time history for this real world crash led to an improved understanding of the crash kinematics and the injury causative mechanism.

- Crash Time: ***04:40 pm***
- Notification Time: ***04:41 pm***
- Rollover: ***No***
- Final Rest Position: ***Normal***
- Principal Direction of Force (PDOF): ***2 o'clock***
- Delta Velocity (ΔV): ***16 mph***

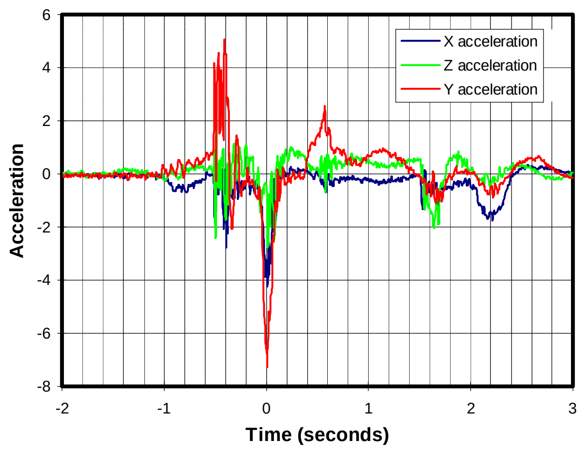

Figure 13. Crash summary for ACN Crash No. 440-1094.

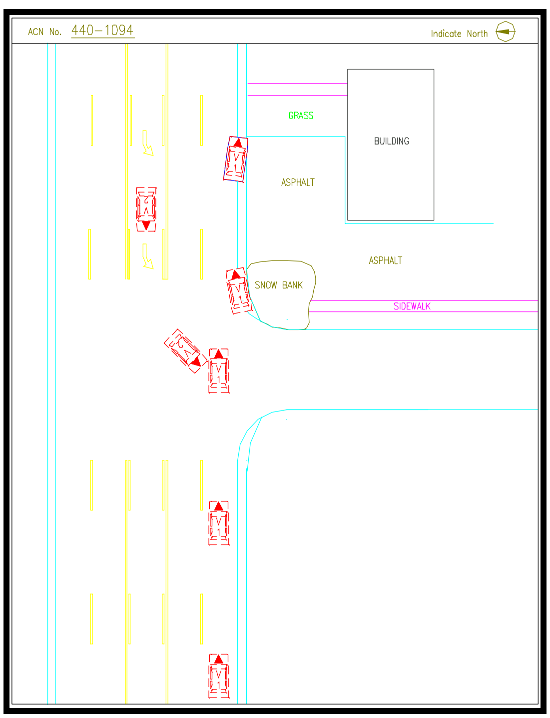

Figure 14. Crash scene diagram for ACN Crash No. 440-1094.

POTENTIAL BENEFITS OF ACN

The principal benefit of the ACN system is a significant decrease in notification and response time for crash injuries. An accurate crash location is provided through GPS and the dispatcher interface displays a map to aid in locating the crash . The ACN system also provides immediate in-vehicle medical assistance, if required, by conferencing the Emergency Medical Dispatchers, located at the Erie County Medical Center with the occupants by cellular telephone. The crash descriptive information and the prediction of injury severity allows the dispatcher to respond to a crash with the appropriate personnel and equipment. The immediate and automatic notification of EMS is especially beneficial in remote areas where a crash may not be observed or a telephone is not available to call for help.

Of particular interest to the crash analyst is the fact that ACN crash acceleration time histories, in digital form, are available for real world crashes. This allows the study of crash injury mechanisms in much greater detail than is normally possible. The acceleration time history can be used as input to occupant simulation models allowing careful study of the occupant kinematics and dynamics. This data will improve understanding of crash mechanics and aid in the development improved countermeasures for preventing or mitigating crash injury.

The ACN field operational test is also providing valuable information regarding institutional and infrastructure issues. The working relationships between and among the various emergency responders and the protocols that must be modified or developed for ACN response are as important as the hardware and the software. For example, a major issue in the development of ACN systems is that of how the initial call is handled. A PSAP such as the Erie County Sheriff might handle ACN calls or a privately operated message center might handle the call and transfer the relevant information to the PSAP. In the first case ACN dispatch stations must be installed at the PSAP location, which may be local or regional, and the crash information is directly available to the EMS dispatcher. In the latter case, the dispatch stations are required only at the message center but the crash information is transferred verbally by telephone or by Fax and is not directly available to the dispatcher.

CONCLUSIONS

The ACN system has been implemented in over 700 vehicles in Western New York and is currently providing improved emergency response in a real world environment. The ACN system alerts the EMS dispatcher to an ACN crash in less than two minutes. The system incorporates advanced technology and a more efficient infrastructure to provide immediate notification and response as well as improved communication and crash descriptive information. The ACN system allows the current emergency response system to deal with crashes more quickly and more efficiently. The most effective application of the system is in remote locations where a crash may not be observed and reported or where there may not be a telephone nearby to call for help. The ACN system also provides crash acceleration time histories form real world crashes to aid in understanding crash mechanics. Finally, the ACN program is providing information on institutional and infrastructure issues needed to implement ACN type programs in other locations.

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Erie County Division of Emergency Services

Digital Audio Recorders

Life Savers, Educators, and Vindicators

Prepared for:

International Symposium on Transportation Recorders

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Digital Audio Recorders
Life Savers, Educators, and Vindicators

Keywords: Marine, human factors, magneto optical, synchronization

Introduction:

"Those who do not remember the past are condemned to repeat it" (George Santayana). What better records of the past are there than those made by recording devices such as the U.S. Navy's recently developed RD-674A/UNH and RD-681/UNH digital audio recorders?

RD-681/UNH
Recorder-Reproducer

The use of recorders has increased dramatically as the value of recording devices for training and accident investigation and prevention has come to be recognized by both the government and the private sector. The transition from mechanical-based recorders to Personal Computer (PC) based recorders has greatly increased the flexibility and utility of today's modern recorder. The simple, single-channel audio signal recorders of the past have been superceded by today's complex multi-channel, analog and digital data recorders, which provide multi-channel simultaneous playback and recording of both digital and analog data. In addition to the ability to store massive amounts of data, this state-of-the-art technology has allowed the Navy's recorders to evolve from simple documentors of "what was said" to instrumental life-saving tools, educators, simulators, vindicators in the courtroom, and documentors.

Recorders Save Lives. The need to have a reliable state-of-the-art recorder is apparent from today's headlines: *Four deaths have Coast Guard pressing for new equipment*[1] and *Clamboat Sinkings Claim 8 Lives.*[2] The advent of computer-controlled recording technology greatly enhances the capabilities of today's recorders. Current generation recorders now permit a watchman monitoring distress channels to instantly play back a distress call without interrupting the recording process, even as additional voice or data signals are received. Weak, unintelligible signals can be enhanced and amplified by signal processing. This allows search and rescue workers to save lives that might otherwise be lost. Tapeless, magneto-optical drive systems provide immediate playback of data when there is uncertainty concerning the exact message that was received or transmitted. This not only saves precious time that would be lost during tape rewinding, but also allows the operator to obtain information that would otherwise have been lost. All of these features are critical and essential when lives are at stake and time is of the essence.

Enhancing Education and Simulation with Recorders. The Navy uses recording devices as training tools to improve air traffic control operations for both ship and shore-based facilities. Operators are given the opportunity to hear themselves and see the consequences of their actions in replicated scenarios. This enhances readiness by allowing total system simulation, and by providing both individual and team training. Managers and commanders can better measure readiness, identify whether proper operational procedures are being used, and evaluate the outcome of using those procedures. Recorders offer the opportunity for students to safely learn from their mistakes in an unbiased, objective mode.

Documentors And Vindicators – Recorders Provide Conclusive, Irrefutable Evidence. Competent personnel love them, while incompetent personnel loathe them. What better documentation for management to have in an incident than an exact record of actions that were (or were not) taken. Multi-tiered security systems imbedded in the design of today's naval recorders prevent unauthorized access to

USS *RADFORD* COLLISION DAMAGE

the recorded inform-ation, thus preserving the integrity of the data for use in accident investigations or analyses. Additional features prevent the overwriting of data previously recorded on another machine. Modern recorders can also be synchronized to a universal time standard such as global positioning system (e.g., Havequick time). This allows platform-unique data to be recorded and played back in synchronization with recording systems in other locations, thereby improving time-sensitive accident investigations. Recent headlines ("*navy destroyer heavily damaged in collision with container ship*"[3]) highlight the necessity for accelerating the installation of recorders on all navy ships and those in the merchant marine as well.

A Successful Recording System Merges Technology Integration with Human Factor Requirements. Today's explosion in technology poses new challenges to the system integrator of recording devices. It is not only prudent but also absolutely necessary for the system integrator to take into consideration the variety of technologies in conjunction with the intended application and associated human factors. For example, consider the recording media available today. They range from magnetic tape, to flash memory, to magneto-optical disks and beyond.

The selection of the recording medium will impact the operational and maintenance characteristics of the equipment. Selecting magnetic tape increases the time required to access data. If access to data is time critical, magnetic tape is probably not the proper media selection. Magnetic tape's impact on maintenance can be significant as well, with tape alignment, head wear, and capstan degaussing being all too common. Magnetic tape is also susceptible to temperature and humidity and generally requires storage in an environmentally controlled space. However, magnetic tape offers vast amounts of data storage at a moderate cost. Typical digital cassette tapes can archive 50 gigabytes of data. If your application is archiving data, magnetic tape may be a useful medium.

The magneto optical (MO) medium offers immediate access to data with a reasonably high storage capacity (5.2Gbtyes). MO has the added advantage of low maintenance: there are no heads to wear out and it never requires tape alignments or degaussing. And MO is much more durable and less susceptible to environmental conditions as compared to magnetic tape.

Flash Memory stores data in electronic chips and offers instant access to data with no maintenance. There are no moving parts in flash memory. The disadvantage to flash memory is its limited storage capacity. Improvements in flash memory technology will most assuredly increase today's storage capacity. Flash memory may be the preferred device for short-time storage (refer to Table I, below). It has many possible applications, such as in the crash recording system for the trucking industry.

TABLE I. COMPARISON OF RECORD MEDIA

Recording Medium	Capacity *	Advantages
Magnetic Tape	50 Gbytes	Large storage capacity, allows for multi-head synchronized recording.
Magneto Optical	5.2 Gbytes	Environmentally durable, low maintenance, immediate access to data.

Flash Memory	64 Mbytes	No moving parts, no maintenance, instant access to data.

**Subject to change with improvements to technology.*

The variety of recording media available today presents unique technical challenges. Earlier recorders incorporated multiple channels into their recorders by employing multi-head systems that were basically several recorders in one. To play back multiple data channels in synchronization (with respect to time) merely involved replaying the tape. Today's typical multi-channel recorders only employ one record-reproduce head. This makes synchronization critical and technically challenging. For example, how do you play back multiple data channels with only one record-reproduce head and make it appear there are multiple heads? One hearing study[4] showed the temporal order identification thresholds (TOT) for the human ear to be on the order of 10 msec. This TOT threshold means that with practice or repeated playbacks, humans can detect a shift in time between two audio events. If the listener has to make an interpretation of the audio events, this threshold may be even longer, but how much longer? We may be able to derive the answer from the Federal Aviation Administration (FAA) specifications that allow a 250ms delay[5] from the time the operator keys a microphone to the time the signal is radiated to the plane. This could be considered an acceptable TOT upper limit. Since operators will not always be discerning audio events that require interpretation (e.g., two people talking) from those that don't (e.g., an alarm), playing back different audio events within 10 msec or less should be the targeted threshold, to avoid a misinterpretation of any audio event. This audio relationship is compounded as the number of channels played back increases. Other challenges include synchronizing recorded digital computer information with audio channels.

Human factors play a significant role in integrating technology available today, from both an operational and technical perspective. Operationally, ease of use is important to those monitoring distress channels that require repetitive playbacks. Simplicity, with the fewest number of keystroke to retrieve data, is paramount. Yesterday's systems had that simplicity - "stop, rewind, and play" - but lacked the enhancements required of today's recording devices. For example, to enhance weak, unintelligible transmissions requires timely signal processing. Tangential issues now surface, such as whether a recording device should filter the signal prior to presentation to the operator or play it back for the operator as the operator heard it and then filter the signal to be replayed again. The method of integration affects not only response time, but operational procedures also, and may well affect its admission in a court of law. It would be unfair to admit "processed audio" into an incident investigation when an air traffic controller or any operator had made judgements based on unprocessed transmissions.

Magneto Optical - Data Storage for the 21st Century. Today's smart recording systems offer greatly increased storage capacity over tape systems of the past. The reel-to-reel recorder of yesterday ran continuously, 24 hours a day. They recorded even when no audio was present. Now, smart recorders, such as the U.S. Navy's RD-674A/UNH and RD-681/UNH, record only when audio is present. These recorders can discern between noise and audio and so only record when audio is present. All audio is time tagged, and "dead time" is not recorded. Thus the recording media (magneto optical disks on these recorders) are capable of storing up to ten days worth of information on a single disk. Some of the other benefits of using MO drives and disks for recording are: no environmentally controlled storage requirements, limited mechanical parts, and an absence of read-write heads contacting the media. MO drives and disks are also capable of thousands of read-write cycles and provide immediate access to recorded data since there is no need to rewind tapes.

Better Products and More Capability for Less Money. The Navy's RD-674A/UNH and RD-681/UNH recorder-reproducers are more reliable and require less maintenance and training than their obsolete, mechanical, reel-to-reel predecessor. As this new family of recorders was designed on nearly 100% incorporation of commercial-off-the-shelf (COTS) equipment, they are relatively inexpensive to acquire and are much easier and less costly to support and maintain throughout their extended lifecycle. To ensure the recorders would be rugged enough to withstand shipboard (Marine) and wartime conditions, they were shipboard shock and vibration qualified. They are PC-based systems with a Windows 95 operating system, are user-friendly with touch screen functionality, and require no special off-site classroom training. A computer-based training (CBT) module on CD-ROM is provided with the system. As with most PC-based systems they are extremely reliable, require minimal maintenance and can be easily upgraded to take advantage of the latest technology or to adapt to changing requirements. The Navy's RD-674A/UNH and RD-681/UNH Recorders have other failsafe features, such as alarms to indicate that media capacity is about to be exceeded or power has been lost, automatic switching to a back up power source, and the ability to search for a particular voice recording by time or channel.

Recorders - An Ounce of Prevention. Data recorders have evolved from simple data logging devices to sophisticated, versatile and essential tools capable of saving lives, training personnel, and aiding in accident investigation and prevention. The technology explosion has made available numerous options that require careful scrutiny before their integration and implementation into recording devices of today. Careful consideration needs to be given to the technology, to human factors, and to the application for which the recorder will be used. Since the current information revolution requires quantum increases in technology and in the speed at which information is processed, there is only one thing we know for sure – recorders of tomorrow are sure to bring new uses, provide new challenges and require even more advanced technology.

Acknowledgments:

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References:

[1]Adam Katz-Stone, "Four deaths have Coast Guard pressing for new equipment," The Times, 22 February 1999, sec. Newslines The Coast Guard, p. 22.

[2]Jack Sherwood, "Clamboat Sinkings Claim 8 Lives," Soundings, April 1999, p. 3.

[3]Jack Dorsey, "Navy Destroyer Heavily Damaged In Collision With Container Ship," The Virginian-Pilot, 6 February 1999.

[4]Pastore, R. E., Harris, L. B., & Kaplan, J. K. (1982) Temporal Order Identification: Some Parameter Dependencies. Journal of the Acoustical Society of America, 71 (2), 430-436.

[5]JTRS Government Day, 17 November 1998, Next Generation Air/Ground Communications System, p. 6.

Biography:

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INTERNATIONAL SYMPOSIUM

ON

TRANSPORTATION RECORDERS

MAY 3-5, 1999

CRYSTAL GATEWAY MARRIOTT

ARLINGTON, VIRGINIA

Prepared By: Lindsay Fenwick
Air Line Pilots Association

Prepared For: Session III
Access To Data; Privacy, Proprietary and Union Issues

SECURITY OF RECORDED INFORMATION

Security of recorded information is a highly sensitive issue within the global airline pilot community. This paper emphasizes that adequate security of recorded information is imperative if air safety investigators and other industry professionals are to retain access to recorded data, and other industry professionals are to retain access to recorded data.

Although the Air Line Pilots Association is known primarily as a force to improve wages and working conditions for pilots, many familiar with transportation issues are aware of the contributions of ALPA's safety professionals. Our members are vocal with their safety concerns. What our pilots are telling us - and there are about 52,000 of them in the United States and Canada - is that data recordings, and how they are used or abused, continue to be of paramount importance. This paper will discuss issues such as privacy, fairness, trust, legislation, and the need for pilot participation in the analysis of recorded data.

For these purposes, recorded information includes not just Cockpit Voice Recorder (CVR) and Cockpit Video View Recorder (CVVR) information, but also Digital Flight Data Recorder (DFDR) information, air safety reports that are electronically transmitted, as well as various forms of data-linked information, including ACARS. In this paper, the security of such information means protection against unauthorized or inappropriate use.

The Air Line Pilots Association is by no means against the use of recorded data to advance air safety. In fact ALPA has written policies which accommodate, and even encourage, the use of such devices. With regard to cockpit and cabin sound recorders, policy language almost 40 years old states that, "*ALPA representatives shall endeavor to obtain the maximum usefulness for such devices, while providing the greatest possible protection against the abuse and misuse of such devices by any government agency, carrier, or any other group*". More recently, ALPA has been a proponent of expanding the number of recorded parameters on DFDR devices and has encouraged the adoption of Flight Operations Quality Assurance (FOQA) programs which analyze recorded data in order to advance flight safety.

From an airline pilot's perspective, the cockpit voice recorder issue is probably the most sensitive. It has certainly been the most controversial. When CVRs were first installed, it was with the understanding that pilots would be sacrificing their rights to privacy to help advance air safety by accommodating a tool that was useful in accident investigation. The quid pro quo was that the recorded information be of a specific duration (30 minutes), be erasable by the flight crew on the ground, and be used only for its intended purpose, that is, accident investigation.

Thus there was a balance between a flight crew's individual right to privacy and the collective benefits for aviation safety. Over time certain of these constraints have become blurred, and the balance has tilted. Some of the newer CVRs - quite legal, and certainly more capable Technologically - have no erase feature, and up to 2 hours of voice data is recorded. Abuses of CVR information, including inappropriate release of the recorded information, and inclusion in transcripts of non-pertinent conversation, have been viewed by many airline pilots as violating the original compact.

Many who are not pilots, including numerous air safety experts, consider that pilots are being unreasonably sensitive in their demands that CVR information be provided the maximum protection. But it is imperative that we understand how much of a gut issue this remains. In the United States airline pilots are subject to various kinds of routine checks plus random drug testing, random alcohol testing, random line checks, as well as frequent security screening. Additionally, every word a pilot says in the cockpit is recorded, as are a host of aircraft performance parameters. This remains tolerable as long as there remains a balance between individual privacy and the benefits that accrue to air safety from such monitoring. Failure to treat CVR data as privileged information and afford it the security it deserves will not just alienate thousands of pilots, but will unquestionably harm the efforts of many air safety professionals. The use of CVR tapes in criminal cases is even more inflammatory, and this development is discussed later in the paper.

Many of us in this forum take for granted that recorded information is worthy of some measure of protection. Within the air transport industry the prevailing international view, evidenced by Chapter 5.12 of ICAO Annex 13 (which governs accident investigations in contracting states), is that the public interest in air safety is enhanced by limiting the disclosure and use of official accident records. However, the application of these protections is uneven at best, and the following discussion highlights some of the violations of this concept of privileged and protected information.

The world has changed greatly since recording devices were first placed on aircraft. In this information age, it is tempting to believe that all we need to solve a given problem is more data. Access to information in our society has been broadened considerably, and legislation such as the Freedom of Information Act has created an information entitlement mentality. Although there may be general areas of aviation safety information that are suitable for public consumption, access to detailed data, which would include most recorded information, would almost certainly be counterproductive. But you can bet that many in the media would like to get their hands on such information all the same. The fact remains that the public, and that includes most of the media, has neither the background knowledge, the analytical skills, nor the incentives to help us much with the painstaking, complex, and often frustrating task of furthering aviation safety.

One of the most powerful drivers of aviation safety initiatives in North America is money, specifically the money derived from civil litigation. The vast sums involved in settling aviation disasters place enormous pressure on access to recorded information. Although we have restrictions on how agencies such as the NTSB, TSBC, Transport Canada, and the FAA may use recorded data and other air safety documents, much of this information is discoverable by civil litigants. Plaintiffs' attorneys will naturally seek any and all information that will augment their case. In the aftermath of the Cali accident, plaintiffs' attorneys sought access to the confidential information contained in the ASAP (Airline Safety Action Program) program at American Airlines. In this instance access was denied by the judge, but future cases could be decided differently. Such disclosure could have sounded the death knell of the ASAP program at American and would likely have killed the efforts of other carriers and pilot groups to adopt similar programs.

The family rights (victims' relatives) movement has also gained tremendous strength in recent years, as evidenced by the ValuJet and TWA 800 investigations. This issue appears to be driven by politics as well as compassion, and plaintiffs' attorneys may also be fanning the flames. And always we must contend with the media. Replaying the last words of a crew, along with a video recreation of an accident, makes compelling entertainment and can be deceptively convincing. Over the years ALPA has had to lobby forcefully to prevent indiscriminate use of CVR information by the news media for sensationalist purposes.

Although civil litigation might keep insurance companies and their clients up at night, from the perspective of pilots - other than those called to testify - this is not the biggest threat. Most airline labor agreements indemnify pilots from financial liability. What is far more troubling is the realization that pilots throughout the world may be much more exposed to criminal litigation than we had previously supposed. This threatens to directly impact our access to recorded information.

The case that brought this issue to the fore was a 1995 accident in New Zealand. An aircraft experienced a landing gear problem while conducting a non-precision approach, and the aircraft impacted a hill on the extended runway centerline - a classic CFIT (controlled flight into terrain) accident. A few passengers were killed and the pilots survived. Although the technical aspects of the investigation were relatively straightforward, the legal wrangles have been anything but. The Police demanded access to the CVR - not just a transcript, but the actual tape - in order to discharge their responsibilities. The dictates of ICAO Annex 13 notwithstanding, the Court held that the Police did indeed have the right to obtain the actual CVR tape as part of a criminal inquiry. Incidentally, at the time of this accident, New Zealand, like many other states covered by the Chicago Convention, had no legislation mandating installation of cockpit voice recorders in air transport aircraft.

Many states, such as New Zealand, Canada, and the United States, have legal systems which have evolved from English Common Law, although each country has implemented different legislation to address the intent of the data protection provisions of ICAO Annex 13. For countries in which disclosure safeguards are not explicit or enforced it is reasonable to assume that police could access recorded information in order to criminally prosecute pilots. In fact numerous European, African, and Asian countries have a history of criminally prosecuting pilots, and recorded data has been used to aid the prosecution. The point here is not that airline pilots should be immune from prosecution, but that certain forms of recorded information (especially the CVR) have been used, in our view improperly and unwisely, to aid the prosecution. It is worth reiterating that the only argument ever advanced for the mandatory installation and use of cockpit voice recorders is to assist accident investigation for aviation safety purposes.

Although we in North America are not accustomed to criminal prosecution of pilots in the wake of accidents, our attorneys tell us that we are not immune. In fact after the USAir 5050 runway overrun accident at La Guardia, the District Attorney, for a time, intended to prosecute the flight crew. It is theoretically possible that the police, in building a criminal case, would seek access to recorded data, which could include CVR, DFDR, radar data, ACARS messages, electronically filed "confidential" safety reports, and more. In the United States, such a development would surely be met with strong opposition by pilot groups. Interestingly, and it is encouraging for both pilots and air safety investigators, the Canadians recently upgraded their legislation on recorded data. Section 28 of the Canadian Safety Board Act states that every on-board recording is privileged and, with very limited exception, no person shall knowingly communicate or be required to produce an on-board recording or give evidence relating to it in any legal, disciplinary or other proceeding. In the view of the Air Line Pilots Association, this is model legislation, and complies fully with the intent of ICAO Annex 13. We are hopeful that New Zealand and other countries will follow suit and enact legislation that provides a similar level of recorded data protection.

For the present, how has access to recorded data been impeded? We understand that of the aircraft in New Zealand with Cockpit Voice Recorders installed, many are no longer recording anything. The same goes for numerous foreign aircraft entering New Zealand's airspace. Obviously, this does not help the cause of air safety investigators, but it does reflect the volatility of the CVR issue and highlight the need for us to do what we can to ensure that recorded data is there when we need it. The fact that this is occurring in a distant country should give us no solace. Air transportation is a global enterprise - there are no "domestic" accidents. An unresolved accident, no matter where on the face of the earth it occurs, has consequences for all of us who have a concern with transportation safety. For this reason ALPA strongly advocates the installation of cockpit voice recorders and continues to lobby worldwide for the enactment of adequate data protection legislation.

Line pilots are probably most sensitive to CVR recordings, but they are also leery of routine monitoring of flight operations through digital flight data recorders. As many of you are aware, DFDR monitoring has been commonplace with many non-US carriers for many years. The reluctance of US carriers to embrace such programs has been based partly on the punitive and litigious environment. There has also been a healthy measure of skepticism and distrust amongst the pilots, along with an uneasiness with "big brother watching". In 1980 the ALPA Board of Directors (BOD) authorized a suspension of service as an expression of opposition to FAA plans to monitor cockpit voice recorder and flight data recorder tapes for the purpose of human factors research. This Notice of Proposed Rulemaking was stillborn, but the ALPA policy letter remains in place. Today's FOQA programs benefit from much more sophisticated technology than was hitherto available, but where digital flight data analysis has been implemented, it is the human elements of trust and cooperation, rather than the advances in hardware and software, which have made these programs workable.

Glass cockpits and advances in video recording technology have spurred interest in the use of cockpit view video recorders (CVVRs). This may help us determine what the crew actually saw or could have seen. Because digital recordings from signal generators may be too far upstream to accurately reflect the information presented to the flight crew, video recorders could preserve information that would otherwise not be recorded. Not surprisingly, given our experience with CVRs, ALPA has insisted that protective provisions be in place prior to installation of CVVR's. Such protective provisions must preclude the release of information obtained from the CVVR to anyone outside the accident investigation and must ensure that information obtained from the CVVR cannot be used as a basis for punitive action against a flight crew member by the airline or government agency. In addition, ALPA believes that the statutory protections in place for the CVR should be strengthened in terms of access of information to litigants, and that these strengthened protections should also apply to the CVVR. The ALPA provisions policy further states that cockpit video recorders should focus on and record only the instrument panel of the cockpit and not record flight crew activity.

With respect to video recorders, the NTSB and others would prefer a more liberal approach, with the goal of recording the complete cockpit environment, including the behavior of the occupants. Again, we need to balance what is technologically feasible and what investigators would like with the fundamental privacy issues. Nowhere is it written that pilots, when they close the cockpit door, should forfeit all rights to privacy. As with many potential advances in aviation safety, the technological challenges of CVVRs will be much more easily solved than the regulatory issues.

ACARS and other forms of data link are less controversial than the other recording devices mentioned, but they too present security challenges. It is not just the pilots who are exposed; recently a selection of ACARS messages from an air carrier were apparently intercepted and published on the Internet. One would assume that this method of data and text transmission would be slightly more secure than open VHF voice communication, but we must work on the presumption that if a system is vulnerable to hackers, the information is likely to be compromised. In some instances, ACARS messages may contain operationally sensitive information that need not be made public. Could encryption of ACARS messages be on the horizon?

An intangible but crucial aspect of recorded information security is that of trust. Most aviation safety experts agree that if we are to reach the holy grail which is the next level of safety, then there needs to be information sharing and trust among those who are directly involved with flight operations. This network would include manufacturers, operators, regulators, air traffic controllers, mechanics, and pilots. ALPA and other pilot groups endorse wholeheartedly the premise of working together to advance safety within the industry. Programs built on trust, such as American's Airline Safety Action Partnership (ASAP) and the FOQA programs such as those at United and US Airways have already shown that objective assessment of aircraft and crew performance in line operations can indeed improve aviation safety. A characteristic of these partnership programs is that pilot representatives play an equal role in evaluating the information and deciding on the appropriate course of action. The knowledge that their interests are being protected is of overwhelming importance to line pilots.

Encouragingly, the present FAA Administrator has advocated safety partnership programs. Regrettably, and typically, these initiatives seem to have stalled in Washington. The aborted "quick-ticket program" and the painful birth of legislation to enable partnership programs which incorporate data protective provisions demonstrates the gulf that separates the regulatory and punitive side of the FAA from those in the Agency dedicated to advancing aviation safety. As if we needed reminding, it is unrealistic for us to expect that the regulators can bring us to the next level of safety. This means that the rest of the air transport industry - which includes pilot groups along with manufacturers and air carriers - will have to take up the challenge.

To reiterate, pilots do not consider themselves above the law, or expect to be held blameless when they make mistakes. Pilots are not only self-critical, but also tend to be very harsh with their peers who have not measured up. But they do expect to be treated fairly. When pilots do make errors, they expect that the system will balance their shortcomings against the myriad other factors that came into play that particular day. Pilots have no problem with accountability, and are willing to be judged by peers (who have a gut feel for the issues, because they have been there and done that) or by those air safety professionals who accept the challenge of performing a thorough investigation. Justice demands accountability, but fairness dictates that not all recorded information will be available to aid the prosecution. Remember, the only rationale ever advocated for the mandatory installation of cockpit voice recorders was to aid in accident investigation for air safety purposes.

In conclusion, adequate security for recorded information is essential if air safety investigators are to have access to the tools necessary to craft the next level of safety. We can not take this security for granted - assaults on sensitive and privileged information are inevitable. Because air transportation is a global enterprise, we must make it our business to see that the intent of the recorded data protective provisions of ICAO Annex 13 are applied not just in North America but universally.

By suitably protecting recorded data it will be readily available to those who really can make a difference. Pilots are a crucial component of our air safety system, the robustness of which depends on cooperation and trust. Pilots ask that their rights as individuals not be neglected as technology makes even more extensive monitoring and recording feasible. Because if we lose the trust of line pilots it will not easily be regained; the tasks of air safety investigators will be made much more difficult and the traveling public will be done a disservice.

Aviation Recorder Overview

Dennis R. Grossi
National Transportation Safety Board

KEYWORDS

Aviation, Recordings, Overview, Investigation

INTRODUCTION

There are a wide variety of airborne and ground-based aviation recording devices that can provide vital information for accident prevention purposes. The primary information sources include the mandatory crash-protected flight recorders, airborne quick access data recorders, and ground-based recordings of air traffic control (ATC) radar returns and radio communications. Other sources of recorded information, such as aircraft system internal memory devices and recordings of airline operational communications, have also provided vital information to accident investigators. These devices can range from nonvolatile memory chips to state-of-the-art solid-state flight recorders. With the exception of the mandatory flight recorders, these devices were designed primarily to provide recorded information for maintenance trouble-shooting or specific operational requirements. Regardless of their original purpose, they have all been used in one form or another to investigate aviation accidents. This paper will give an overview of the evolution of flight recorder technology and regulatory requirements, and describe the capabilities and limitations of the various types of recorded information available to the aviation community for accident prevention and, in particular, accident/incident investigation.

CRASH-PROTECTED FLIGHT RECORDERS

Evolution of Regulatory Requirements

First Flight Data Recorder

The need for a crash-survivable recording device became apparent following a series of airline crashes in the early 1940s. This spurred the Civil Aeronautics Board (CAB) to draft the first Civil Aviation Regulations calling for a flight recording device for accident investigation purposes. However, recorder development was delayed by shortages brought about by World War II. As a result, such a device was not available, and after extending the compliance date three times, the CAB rescinded the requirement in 1944. The CAB issued a similar flight recorder regulation in 1947, after the war, but a suitable recorder was still not available and the regulation was rescinded the following year.

During the 9 years following the rescission of the 1947 flight recorder rule, the Civil Aviation Authority (CAA), the CAB, and aviation industry representatives studied the capabilities of recorder technology in an effort to develop new recorder requirements. Finally in 1957, after determining that suitable recording devices were available, the CAA issued a third round of flight recorder regulations. These regulations called for all air carrier airplanes over 12,500 pounds that operate above 25,000 feet to be fitted with a crash-protected flight recorder by July 1, 1958, that records altitude, airspeed, heading, and vertical accelerations as a function of time. This marked the introduction of the, first true crash-protected flight data recorder.

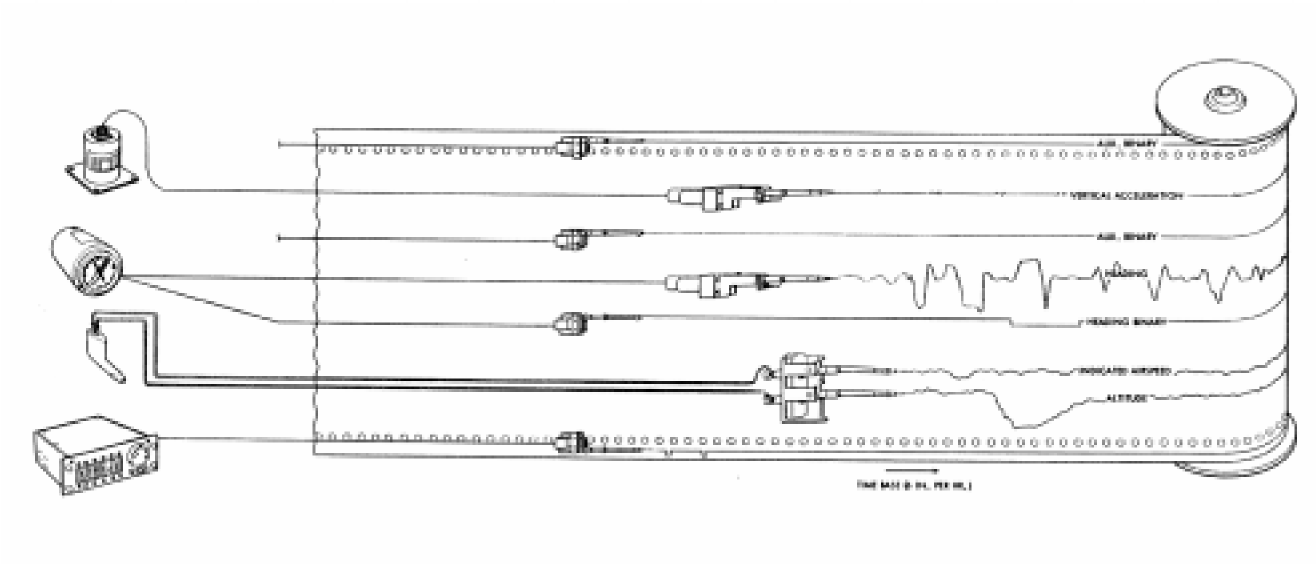


Figure 1 System schematic for a typical oscillographic foil recorder.

First Cockpit Voice Recorder (CVR)

As a result of a CAB recommendation to record flight crew conversation for accident investigation purposes, the Federal Aviation Administration (FAA) conducted a study in 1960 that established the feasibility of CVRs. The FAA produced airworthiness installation approval criteria and operating rules that called for the installation of a CVR in transport category aircraft operated in air carrier service. The compliance dates were July 1, 1966, for all turbine-powered aircraft, and January 1, 1967, for all pressurized aircraft with four reciprocating engines.

1972 Flight Data Recorder Rule Change

FDR requirements remained virtually unchanged until December 10, 1972, when the rules for transport category airplanes that received type certification after September 30, 1969, were amended to require an expanded parameter digital flight data recorder (DFDR) system. The expanded parameter requirements included existing parameters plus parameters for pitch and roll attitude; thrust for each engine; flap position; flight control input or control surface position; lateral acceleration; pitch trim; and thrust reverser position for each engine. Unfortunately, this rule change, which was retroactive to include the Boeing 747, did not affect airplanes such as the Boeing 707, 727, and 737, and the McDonnell Douglas DC-8 and DC-9, all of which had type certificates issued prior to 1969. Therefore, existing and newly manufactured versions of these older aircraft types could be operated under the same FDR rules established in 1957. The flight recorder requirements remained essentially unaltered until the issuance of rule changes in 1987 and 1988.

1987 and 1988 Flight Recorder Rule Changes

During the 30 years following the issuance of the original 1957 FDR regulations, the National Transportation Safety Board (NTSB) and its predecessor, the CAB, issued numerous safety recommendations to the FAA requesting upgraded recorder standards to meet the needs of accident investigators. The recommendations called for:

1. Replacement of original foil-type oscillographic recorder with digital recorders;
2. Retrofit of exiting transport category airplanes fitted with the five-parameter FDRs with six additional parameters;
3. Expanded parameter requirements for newly manufactured transport category airplanes;
4. Use of hot-microphones by the flight crew below 18,000 feet;

5. Recording of hot-microphone channels on CVR; and
6. CVR and FDR requirements for some air taxi and corporate executive aircraft.

The FAA repeatedly sighted cost as the primary reason for not adopting the recommendations. Following a series of high visibility accidents in the early 1980s, the FAA issued flight recorder rule changes in 1987 and again in 1988. These rule changes called for:

1. Replacement of oscillographic foil-type FDRs digital recorders by May 26, 1989;
2. The number of mandatory parameter for airplanes type certificated before October 1969, would be increased to include pitch and roll attitude, longitudinal acceleration, thrust of each engine, and control column or pitch control surface position. The original compliance date, May 26, 1994, was extended by 1 year to May 26, 1995;
3. Transport category airplanes (20 or more passengers) manufactured after October 11, 1991, would be required to record 28 parameters in a digital format;
4. Existing transport category airplanes (20 or more passengers) fitted with a digital data bus would be required to record 28 parameters in a digital format;
5. All multiengine turbine-powered air taxi aircraft capable of carrying 10-19 passengers manufactured after October 11, 1991, would be required to have a 17-parameter FDR;
6. The CVR requirements were extended to multiengine turbine-powered aircraft capable of carrying 6 or more passengers and requiring two pilots; and
7. Flight crews would be required to use existing CVR hot-microphone systems below 18,000 feet.

1997 Flight Data Recorder Rule Changes

Following two fatal Boeing 737 accidents (United Flight 585, Colorado Springs, CO, July 1989, and USAir Flight 427, Pittsburgh, PA, September 1994), the NTSB reexamined FDR parameter requirements. As a result, the NTSB made safety recommendations to the FAA that called for:

1. Additional parameters for most existing air transports that focused on recording crew flight control inputs and the resulting control surface movements; parameter retrofits to be completed by January 1, 1998;
2. Increased parameter requirements for transport airplanes manufactured January 1, 1996;
3. Urgent retrofit of all Boeing 737 airplanes with FDR parameters to record lateral acceleration, and crew flight control inputs and the resulting control surface movements by the end of 1995.

The FAA responded with rulemaking action that issued a notice of proposed rulemaking in August 1996 and a final rule on August 18, 1997. Although the final rule generally met the requirements of the safety recommendations, the compliance dates were significantly relaxed from those recommended by the NTSB. In addition, the FAA did not agree with the urgent recommendation to retrofit Boeing 737 by the end of 1995. However, the final rule did include the requirement that air transports record flight control crew inputs and control surface position. The final rule calls for:

1. Transport airplanes type certificated before October 1, 1969, and manufactured before October 11, 1991, to record as a minimum the first 18 to 22 parameters listed in the rule by August 18, 2001;
2. Transport airplanes manufactured after October 11, 1991, and before August 18, 2001, to record as a minimum the first 34 parameters listed in the rule by August 18, 2001;
3. Transport airplanes manufactured after August 18, 2000, must record as a minimum the first 57 FDR parameter listed in the rule;
4. Transport airplanes manufactured after August 18, 2002, must record as a minimum all 88 FDR parameter listed in the rule.

The specific parameter requirements are contained in Table 1.

March 9, 1999, NTSB and TSB Flight Recorder Recommendations

A recent set of flight recorder recommendations was a combined effort of the Transportation Safety Board of Canada (TSB) and the NTSB of the United States. These recommendations followed the September 2, 1998, accident of Swissair flight 111, an MD-11, on a regularly scheduled passenger flight from New York to Geneva, Switzerland. The flight diverted to Halifax after the crew reported smoke in the cockpit; the airplane crashed into the waters near Peggy's Cove, Nova Scotia, killing all 229 passengers and crew on
board. The investigation has been severely hampered by the lack of data from the CVR and FDR, which stopped nearly 6 minutes before the airplane hit the water.

Part 121.344, Flight Data Recorders for Transport Airplanes

MANUFACTURED On Or Before October 11, 1991 *(see Note:)*

Compliance Dates: Next heavy maintenance after August 18, 1999, but no later than Aug. 18, 2001

No FDAU — **FDAU***

MANUFACTURED After October 11, 1991

Compliance Date: August 18, 2001

NEWLY MANUFACTURED

Manufactured After August 18, 2000 — **Manufactured After August 18, 2002**

1. Time
2. Pressure Altitude
3. Indicated Airspeed
4. Heading
5. Vertical Acceleration
6. Pitch
7. Roll
8. Mic. Keying
9. Thrust (each eng.)
10. Autopilot Status
11. Longitudinal Accel.
12. Pitch control input
13. Lateral control input
14. Rudder pedal pos.
15. Pitch control surface
16. Lateral control surface
17. Yaw control surface
18. Lateral Accel. **
19. Pitch Trim (except 82)
20. Trailing edge flaps (except 85)
21. Leading edge flaps(except 86)
22. Thrust Rev. (each eng.)
23. Ground spoilers (except 87)
24. OAT
25. AFCS modes/status
26. Radio altitude
27. Localizer deviation
28. G/S deviation
29. Marker beacon
30. Master Warning
31. Air/Ground switch
32. Angle of Attack #
33. Hydraulic pres. low
34. Ground Speed #
35. Ground Prox.
36. Landing gear pos.
37. Drift angle #
38. Wind speed #
39. Latitude/Longitude #
40. Stall Warning #
41. Windshear #
42. Throttle lever pos.
43. Additional engine prms.
44. TCAS Warn.
45. DME 1&2 distance
46. NAV 1&2 frequency
47. Selected Baro. #
48. Selected Altitude #
49. Selected Speed #
50. Selected Mach #
51. Selected Verticla Spd. #
52. Selected Heading #
53. Selected Flight Path #
54. Selected Decision Height #
55. EFIS display format #
56. Mult-function eng/alers #
57. Thrust commanded #
58. Thrust Target #
59. CG Trim fuel #
60. Primary Nav. Sys.
61. Icing #
62. Eng. Wrn. Vibration #
63. Eng. Wrn. Temp. #
64. Eng. Wrn. Oil Press. #
65. Eng. Wrn. Ovr. Spd. #
66. Yaw Trim pos.
67. Roll Trim pos.
68. Brake Press. (sel. sys)
69. Brake Ped. Pos. (lt.&rt.)
70. Yaw angle #
71. Engine Bleed Vlv. #
72. De-iceing #
73. Computed CG #
74. AC bus status
75. DC bus status
76. APU bleed vlv. #
77. Hyd. press (each sys)
78. Loss of cabin press.
80. Heads-up #
81. Para-visual #
82. Trim input-pitch
83. Trim input-roll
84. Trim input-yaw
85. Flap cntl. pos. TE.
86. Flap cnt. pos. LE
87. Grnd. Spoiler/Spd. Brk. pos. & sel.
88. All flight control input forces.

Note: The following recommended parameters were not listed for Non FDAU aircraft:
Pitch trim, OAT, AOA, Thrust Rev. , Flaps, Grnd. Spoilers, AFCS modes Roll & Yaw Trim
The following recommended parameters were not listed for FDAU aircraft mfg. before 10-11-91:
OAT, AOA, AFCS modes, Roll & Yaw Trim
The following recommended parameters were not recorded for aircraft mfg. after 10-11-91:
Roll & Yaw Trim.

*	**FDAU - Flight Data Acquisition Unit**
**	**For Airplanes with more than 2 engines, Lateral Acceleration is not required unless capacity is available**
#	**Not intended to require a change in installed equipment**
Transport Airplane	**- 20 or more passengers**

Airplanes that need not comply:
Convair 580, 600, 640, de Havilland DHC-7, Fairchild FH227, Fokker F-27 (except Mark 50), F28, Mark 1000 & 4000, Gulfstream G-159, Lockheed E10-A, E10-B, E10-E, Maryland Ind. F-27, Mitsubishi YS-11, Shorts SD330, SD360

Table 1 Parameter Requirements for Air Carrier Flight Data Recorders.

The Swissair accident was just the latest in a long history of accident and incident investigations that were hindered by the loss of flight recorder information due to the interruption of the aircraft electrical power to the flight recorders. However, recent innovations in recorder and power supply technologies have made it possible to provide an independent power source that would provide sufficient power to operate a solid-state flight recorder for 10 minutes. In addition, the availability of combined voice and data recorders has introduced the possibility of fitting two combined recorders on newly manufactured airplanes, placing one recorder near the cockpit to reduce the probability of a mechanical or electrical interruption of the signals and power supply, and the second recorder as far aft as practical to enhance survivability.

As a result, the U.S. NTSB and TSB of Canada issued safety recommendations on March 9, 1999, to require:

1. By January 1, 2005, the retrofit of a 2 hour solid-state CVR that is fitted with an independent power supply capable of operating the CVR and area microphone for 10 minutes when aircraft power to the CVR is lost;
2. By January 1, 2003, all newly manufactured airplanes required to carry both a CVR and FDR be fitted with two combined voice and data recorders, one recorder located as close to the cockpit as practical and the other as far aft as practical;
3. Amend Title 14 U.S. *Code of Federal Regulations* to require that CVRs, FDRs, and combination flight recorders be powered from separate generators busses with the highest reliability.

In a March 19, 1999 letter, the FAA agreed to the recommendations without revision and promised to issue a notice of proposed rulemaking by the end of the summer.

EVOLUTION OF FLIGHT RECORDERS

Flight data recorders can be traced back to the origins of power flight. Wilbur and Orville Wright's historic first flight was documented by the first flight data recorder. This rudimentary device recorded propeller rotation, distance traveled through the air, and fight duration. Charles Lindbergh's airplane the *Spirit of St. Louis* was also fitted with a flight-recording device. Lindbergh's recorder was a bit more sophisticated, employing a barograph that marked changes in barometric pressure or altitude on a rotating paper cylinder (see Figure 2).

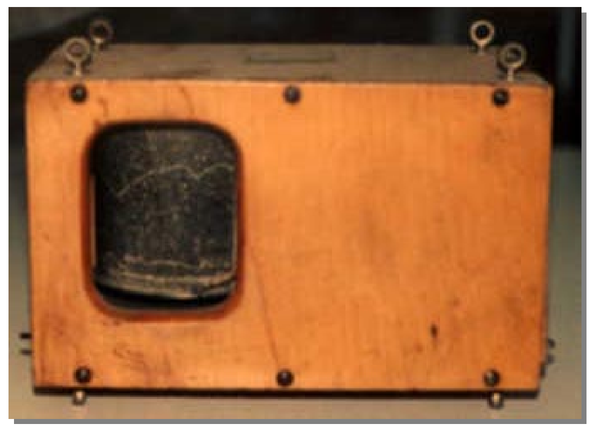


Figure 2 *Spirit of St. Louis* flight recorder.

These early recordings survived because they were designed to record historical events, not mishaps. The first practical crash-protected flight data recorder was not introduced until 1953. This recorder used styli to produce individual oscillographic tracings for each parameter on metallic foil. Time was determined by foil movement, which typically advanced at a rate of 6 inches per hour. This often resulted in an entire accident sequence being recorded within a 0.1 inch of foil movement. Investigators recovered the recorded information by optically reading the scribed markings through a microscope, and then converting the displacement of the scribed marks from the reference line to engineering units. This process was very time consuming and required a significant amount of reader interpretation.

The 1957 regulations that mandated the installation of FDRs by July 1958 created a market for FDRs that attracted other manufacturers who also use the metal foil oscillographic technique (see Figure 3 and 4). The regulations also required compliance with Technical Standards Order TSO C-51. This TSO defined the range accuracy, sampling interval, and type parameters to be recorded (altitude, airspeed, heading, vertical acceleration and time) and specified the requirement to survive a crash shock of 100 Gs and being enveloped in a 1100°C flame for 30 minutes. The TSO also defined three basic types of flight recorders:

Type I: Non-ejectable recorder, unrestricted location.
Type II: A non-ejectable recorder, minimum15 minutes fire test, restricted to any location more than ½ of the wing root chord from the main wing structure through the fuselage and from any fuel tanks.
Type III: An ejectable recorder, minimum 1.5 minutes fire test, unrestricted location.

The early recorders were all of the Type I design and most were mounted in the cockpit area or in the main gear wheel well. Unfortunately, these locations subjected the recorders to fire and impact forces that destroyed or severely damaged the recording medium. Type II and III recorders were never fitted to commercial air carriers; however, ejectable recorders are currently in use on some military aircraft.

Figure 3 Early Lockheed model 109.

Figure 4 Sundstrand Model 542 FDR, 1/2 ATR long format.

In the early 1960s, the CAB made a series of recommendations to the FAA that called for additional protection for FDRs against impact force and fire damage, and also recommended the relocation of the recorders to the aft area of the fuselage to provide maximum protection of the recording media. As a result, the FAA issued rule changes that specified the location of the recorder as far aft as practical and upgraded the performance standards in TSO C-51 and reissued it as C-51a. The upgraded TSO specifications increased the impact shock test from 100 Gs to 1,000 Gs and introduced static crush, impact penetration, and aircraft fluid immersion tests. The fire test was not changed.

Unfortunately, neither TSO contained an adequate test protocol to ensure uniform and repeatable test conditions.

	TSO C84 CVR Requirements	**TSO C-51 FDR Requirements**	**TSO C-51a FDR Requirements**
Fire	1100°C flame covering 50% of recorder for 30 minutes	1100°C flame covering 50% of recorder for 30 minutes	1100°C flame covering 50% of recorder for 30 minutes
Impact Shock	100 Gs	100 Gs	1000 Gs for 5 ms
Static Crush	None	None	5,000 pounds for 5 minutes on each axis
Fluid Immersion	None	None	Immersion in aircraft fluids (fuel, oil, etc.) for 24 hours
Water Immersion	Immersion in sea water for 48 hours	Immersion in sea water for 36 hours	Immersion in sea water for 30 days
Penetration Resistance	None	None	500 lb. dropped from 10 ft. with a ¼-inch-diameter contact point

Table 2 Early flight recorder crash/fire survivability standards.

At about the same time as the foil recorders were being developed in the United States, recorders that used magnetic steel wire as a recording medium were being developed in the United Kingdom. The wire recorders were the first to use digital pulse coding as a recording method. The robust design of the wire recorder made it a fairly reliable recorder for its time. Although the wire recording medium was fairly impervious to post impact fires it did not fair as well with impact shock. The wire would often brake into several sections and become entangled making it difficult and tedious to reassemble in the proper sequence.

In the late 1940s, the French developed an FDR that used a photographic system that recorded data on light- sensitive paper. It had obvious disadvantages: inflammability and the tendency of the recording to disappear when subjected to light. The French later adopted the metal foil oscillographic recorder.

Cockpit Voice Recorder

In response to CAB recommendations, the FAA conducted a study in 1960 to determine the feasibility of recording the spoken words of the flight crew for accident investigation purposes. Although cockpit ambient noise levels posed a significant obstacle to 1960 recording technology, it was determined that recording crew conversation was feasible. The following equipment capabilities were initially proposed:

1. Record each crewmember's conversation, both transmitted and received, with ground facilities and on the airplane's intercommunication system. Also, other conversation in the cockpit not conducted over those media should be recorded. Sufficient channels should be provided so that there will be no possibility of more than one crewmember recording on a channel at one time.
2. Retain the last 30 minutes of the crew's conversation.
3. Contain provisions for stopping the recorder in the case of a crash so that the last 30 minutes of conversation is not erased or overwritten.
4. Recorder should withstand the crash conditions required in TSO-C51.
5. Recording should be intelligible over the ambient noise of the cockpit or it should be possible to filter out the unwanted noise from the record with appropriate ground equipment.
6. Recorder should be capable of recording crew voices, other than on the communication and intercommunication systems, without the use of lip or throat microphones.
7. It should contain indicating provisions to inform the crew when it is operating properly.

As a result, the FAA issued rules that mandated the use of CVRs on all transport category aircraft and issued TSO C-84, which established crash fire survivability and equipment approval standards.

Figure 5 Fairchild model F800 DFDR, 1/2 ATR long format.

Magnetic Tape Flight Recorders

The introduction of the CVR in the late 1960s and DFDRs in the early 1970s made magnetic tape the recording medium of choice until the introduction of solid-state flight recorders in the late 1980s. There were a variety of tapes and tape transports used by the various recorder manufacturers. The most widely used tapes were mylar, kapton, and metallic. The tape transports were even more varied, using designs such as coplaner reel to reel, coaxial reel-to-reel, endless loop reel packs and endless loop random storage. Tape CVRs record four channels of audio for 30 minutes, and the DFDR records 25 hours of data. CVRs and FDRs record over the oldest data with the newest data in an endless loop-recording recording pattern. The DFDR tape transport and protective enclosure shown in Figure 5 is an endless loop real pack design adapted from a 1960s CVR.

All of the magnetic tape flight recorders, including the units that used metallic tape, were found to be susceptible to thermal damage during postcrash fires. Although the TSOs called for a high intensity fire test, the lack of a detailed test protocol allowed for a less-than-adequate design to be approved. In addition, the real world experience would show magnetic tape flight recorders to be most vulnerable when exposed to long duration fires, a test condition not required at the time tape flight recorders received TSO approval. In addition, metallic tapes were found to be vulnerable to impact shock, which had a tendency to snap the tape releasing the spring tension and unwinding the tape, causing further tape damage and loss of data.

Digital Recording Method

The DFDR and its companion recorder, the quick access recorder (QAR), were introduced about the same time. DFDRs and QARs use the same recording techniques, but as the name implies, the QAR can be quickly accessed and downloaded. Most early model QAR systems recorded far more parameters than the mandatory DFDR systems. As nonmandatory recorders, QARs were not designed to survive a crash impact and postimpact fire, although a number have survived fairly significant crashes.

Most DFDRs and QARs require a flight data acquisition unit (FDAU) to provide an interface between the various sensors and the DFDR. The FDAU converts analog signals from the sensors to digital signals that are then multiplexed into a serial data stream suitable for recording by the DFDR. Industry standards dictated the format of the data stream, which for the vast majority of tape-based DFDRs is 64 12-bit data words per second. The recording capacity of the tape DFDR is limited by the length of tape that can be crash-protected and the data frame format. The capacity of the tape DFDRs was adequate for the first generation of wide-body transports, but was quickly exceeded when aircraft like the Boeing 767 and Airbus A320 with digital avionics were introduced.

Digital Avionics Systems

The introduction of digital avionics systems into commercial aviation in the early 1980s significantly increased the amount of information available to DFDRs and QARs. Digital avionics also brought about digital data buses, which carry digital data between systems. This made vast amounts of critical flight and aircraft system information available to the DFDR and QAR simply by tapping into the buses. The introduction of digital data buses also brought about digital FDAUs (DFDAU). The FDAU and DFDAU perform the same function except that DFDAUs can interface with the data buses and analog sensors.

Solid-State Flight Recorders

The introduction of solid-state flight recorders in the late 1980s marked the most significant advance in evolution of flight recorder technology. The use of solid-state memory devices in flight recorders has expanded recording capacity, enhanced crash/fire survivability, and improved recorder reliability. It is now possible to have 2-hour CVRs and DFDRs that can record up to 256 12-bit data words per second, or 4 times the capacity of magnetic tape DFDRs.

Figure 6 Typical solid -state CVR and DFDR.

Survivability issues identified during over the years have been addressed with new crash/fire survivability standards developed in close cooperation between accident investigators and the recorder industry (see Table 3). The lack of moving parts in solid-state recorders has greatly improved recorder reliability.

	TSO C123a (CVR) and C124a (DFDR)
Fire (High Intensity)	1100°C flame covering 100% of recorder for 30 minutes. (60 minutes if ED56 test protocol is used)
Fire (Low Intensity)	260°C Oven test for 10 hours
Impact Shock	3,400 Gs for 6.5 ms
Static Crush	5,000 pounds for 5 minutes on each axis
Fluid Immersion	Immersion in aircraft fluids (fuel, oil etc.) for 24 hours
Water Immersion	Immersion in sea water for 30 days
Penetration Resistance	500 lb. Dropped from 10 ft. with a ¼-inch-diameter contact point
Hydrostatic Pressure	Pressure equivalent to depth of 20,000 ft.

Table 3 Current flight recorder crash/fire survivability standards.

Future Flight Recorder Capabilities Requirements

As proposed in the Safety Board's March 9, 1999, recommendation letter to the FAA, two combination voice-data recorders built to TSO C123a and C124a standards will provide the redundant recording capabilities that separate CVRs and DFDRs cannot. Locating one recorder in the nose of the aircraft and the other in the tail will further enhance the probability of capturing catastrophic events that would otherwise compromise the CVR and DFDR when they are colocated. The forward-mounted flight recorder will be in close proximity to the cockpit and the avionics compartment, which reduces the possibility of signal loss. The addition of a 10-minute, independent alternate power supply adjacent to the flight recorder will further enhance the possibility that the recorder will be powered and critical data will be recorded until the end of the flight.

The next-generation combination flight recorders will be required to record more than the traditional voice and data parameters. The FAA anticipates that by 2004, the use of Controller Pilot Data Link (CPDL) messages will reach a level that will mandate recording of data link messages by a flight recorder. Recent advancements in video technology have made video recording a distinct possibility in the not-too-distant future. The International Civil Aviation Organization (ICAO) Flight Recorder Panel has concluded that video technology has matured to the point where specific technical aspects must be determined, and that the ongoing work of European Organisation for Civil Aviation Equipment (EUROCAE) and Aeronautical Radio Inc. (ARINC) should be considered when developing video recorder standards and recommended practices.

AIR TRAFFIC CONTROL RADAR AND AUDIO RECORDINGS

Ground-based recordings of the air traffic control (ATC) radar and radio transmissions provide aircraft communication and position time history information. The FAA records all radio communications between controllers and pilots, and also landline communications between controllers. Air Route Traffic Control Centers (ARTCC) provide complete radar coverage of the United States and parts of Canada and Mexico. In addition, most ATC airport approach radar facilities also record.

ATC Communication Recordings

Recordings of the two-way radio communications between controllers and pilots and inter-controller communications via landlines are maintained for 30 days. In the event of an accident or incident, the original recording of the event can be set aside and retained for investigators, otherwise the recording medium will be reused and the information lost.

The ATC communications recordings have provided vital information to investigators. In instances where the aircraft are not fitted with a CVR these recordings provide the only record of flight crew communications and have at times provided background sounds (e.g., wind noise, rotor speed, sounds of cockpit warnings, etc.) that have proven to be vital to the investigations. A time code is also recorded with the audio communications to provide a time reference independent of any subtle recording anomalies.

ATC and Other Radar Recordings
Recorded radar data can provide aircraft position time history information. This is accomplished by recording the position coordinates of individual radar returns, time, and when available, altitude and identification information transmitted from the aircraft. The altitude and identification data are produced by a transponder fitted to the aircraft that also reinforce the radar return. A transponder is a receiver/transmitter, which will generate a reply signal upon proper interrogation from a radar facility.

The rate at which the radar antenna rotates will determine the sampling interval between returns. ARTCC rotate at between 5 to 6 revolutions per minute (i.e., generating radar returns every 10 to 12 seconds), whereas airport approach radar antennas do a complete rotation every 4.8 seconds. The most accurate position coordinates recorded by the ARTCC are in latitude and longitude, whereas approach radar records position coordinates as range and azimuth values, and both record the transponder-generated altitude values.

Military and private radar facilities can provide similar position time history information. Military aircraft (AWAC) and naval vessel radar data are also recorded and are available to investigators upon request.

Utilization of ATC Recordings by Accident Investigators
The importance of ATC recorded data will be determined by the circumstances surrounding an accident or incident. Accidents or incidents involving very dynamic conditions, such as aerodynamic stall and loss of control, are difficult to evaluate with ATC data alone. ATC data are more significant for less dynamic accidents, such as controlled flight into terrain, or when used in conjunction with FDR and CVR data.

The correlation of events common to the ATC recordings and the FDR and CVR recordings can provide a very accurate local time reference. This can become critical because the FDR and CVR are only required to record relative time and the local time reference may vary from one ATC facility to the next. ATC radar and FDR data can be correlated by comparing the altitude time histories whereas ATC communication recordings can be correlated by the radio transmission time histories recorded by the various ATC facilities and the CVR and FDR.

In addition to a time reference, ATC-recorded information will also provide ground track reference, which is essential in performance-related accidents. A wind model can be developed when radar flight path data are combined with FDR parameters such as altitude airspeed and heading and airplane acceleration parameters. This is particularly useful in accidents or incidents involving dynamic meteorological conditions such as wind shears or crosswind and turbulence conditions.

ATC radar data are particularly useful in evaluating the relative position of aircraft when multiple aircraft are involved. Investigations of mid-air collisions and wake turbulence encounters rely heavily on this information.

There are significant accuracy and resolution limitations that must be taken into consideration when using recorded radar data. The accuracy limitations are known and should be factored into the ground track calculations. The sampling intervals of 4.7 to 12 seconds, presents a significant limitation on usefulness of recorded radar data.

NONVOLATILE MEMORY DEVICES
Modern aircraft utilize an increasing number of microprocessor-based electronic devices for operational and maintenance purposes. As a result, aircraft are fitted with nonvolatile memory (NVM) to store information such as flight crew entries to the navigation data base, system fault messages generated by electronic control devices and system status messages. These devices, generally known as electronically erasable read-only memory (EEROM) provide temporary storage of transitional information during power interruptions. The term "nonvolatile" implies that the stored information will be available regardless of whether the system is electrically powered or not.

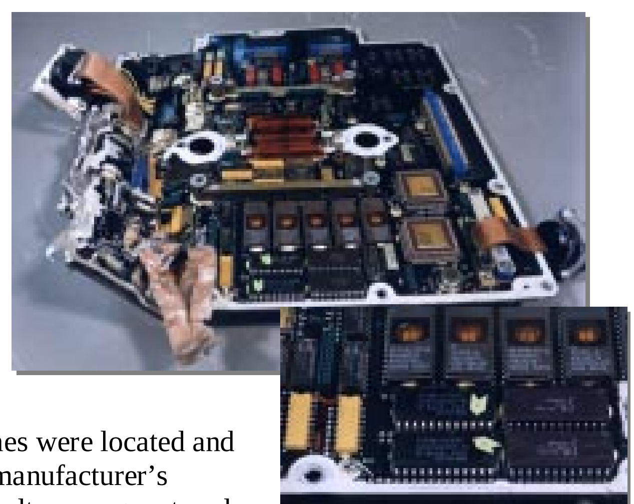
Accident investigators have found NVM to be a valuable source of information. However, because NVM is not crash- or fire-protected, there is no assurance that it will be available following a catastrophic accident. With that said, there have been a significant number of cases where NVM has survived severe impacts and postimpact fires.

The recovery of information from NVM undamaged systems can be as simple as powering the system and reading or downloading the information. Damaged units may require a trip to the manufacturer's facility where system experts can disassemble the unit to recover the information using specialized equipment and software.

The amount of effort and technical expertise needed to recover information from NVM will generally be determined by the amount of damage and system complexity. The first step in the recovery process is a visual inspection of the disassembled unit to determine the amount of damage. It may be possible to simply replace a damaged connector or place the circuit board containing the memory device in a serviceable unit to recover the data. However, extreme caution must be taken when applying power to units that are suspected of receiving impact shocks that exceed the normal design requirements: an undetected short or open circuit might result in the loss of the stored data.

Example: Lauda Air, Flight NG004, May 26, 1991
The May 26, 1991, fatal accident of Lauda Air flight NG004, a Boeing 767 that crashed in Suphan-Buri Province, Thailand, demonstrated the importance of NVM. The aircraft departed controlled flight while climbing through 24,000 feet and experienced an in-flight breakup during the recovery maneuver and subsequently crashed into the jungle. The FDR magnetic tape recording medium was destroyed by the postcrash fire and provided no data. However, the crew comments recorded by the CVR indicated a problem with an engine thrust reverser just prior to the loss of control.

Figure 7 Damaged electronic engine control (EEC).



The electronic engine control (EEC) units for both engines were located and removed from the aircraft wreckage and brought to the manufacturer's facility in Windsor Locks, Connecticut, to recover the fault messages stored in its NVM (see Figure 7). The EECs showed signs of severe impact shock. As a result, the EEROMs (identified in Figure 7 by the chevron symbols) containing the NVM were removed from the circuit board and mounted on an identical laboratory test unit. A normal fault message download was performed and the data were subsequently processed using the manufacturer's proprietary software.

Each time an EEC fault message was generated, the following information was captured and stored in NVM:

- Diagnostic fault messages codes;
- Values for N_1 (high pressure compressor rotation speed), P_2 (fan inlet total pressure), mach number, temperature (cold junction compensation);
- Fault time in elapsed hours;
- Logging of flight and leg cycles.

The recovered data contained diagnostic messages from the last 390 hours of operation, which spanned 95 flights. The EECs from the left engine, which experienced the uncommanded thrust reverser deployment, provided a significant amount of information specifically relating to the faulty thrust reverser and ancillary altitude, airspeed, and engine thrust values provided key reference values, which gained added significance in light of the loss of the FDR data. The EEC from the right engine, which did not record any faults during the accident flight, yielded little additional information.

CONCLUSIONS

As far back as the early 1940s, it became apparent to the aviation community that public confidence must be gained and maintained if commercial aviation were to prosper. It was also recognized that to do this would require a quick and accurate determination of probable cause of any aviation mishap. It was also obvious that the nature of aviation accidents would make it necessary to fit air transports with recording devices to provide accident investigators with the information needed to determine the cause of a mishap and take the proper corrective action to prevent it from recurring.

The first flight recorders introduced over 40 years ago gave accident investigators their first appreciation of the recorder's safety potential. However, the data provided by these early recorders was limited and often of such poor quality that the investigators could only determine, at best, what happened but could not determine with a high degree of certainty why it happened.

Flight recording technology has had to adapt to a rapidly evolving commercial aviation industry, and the corresponding needs of accident investigators. One of the most significant changes in recorder technology occurred in the early 1970s, with the introduction of digital data recorders. The amount and quality of data provided by DFDRs, CVRs, other recorded data such as ATC radar, gave accident investigators the first real opportunity to pursue an in-depth evaluation of the facts, conditions, and circumstances surrounding an occurrence. The introduction of digital recordings also made it practical to use flight recorder data proactively.

The introduction of digital avionics and fly-by-wire technologies in the 1980s provided investigators with challenges and opportunities. This new technology eliminated some well-established investigative techniques while offering an opportunity to record and recover vast amounts of previously unattainable information. Indeed, the amount of available information overwhelmed early model DFDRs. However, the advent of solid-state recorders has solved the recorder capacity problem while improving survivability and reliability.

The future of flight recording is promising. Advances in recorder and aircraft systems will allow for the introduction of recording techniques to record video images of the cockpit and data link messages, as well as providing more opportunities for the proactive use of flight data to prevent accidents.

FUTURE VIDEO ACCIDENT RECORDER

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FOREWORD

This paper examines the viability and use of video camera systems for accident investigation. While the examples used, and the details explored, are applied to commercial aircraft, the same logic reads across to all public transportation, where safety of passengers is paramount. Specific recent interest from ferry operators, inter-city rail operators, and school bus operators shows that future accident investigations will be heavily dependent on information gathered and recorded by video means.

INTRODUCTION

In March 1999, the National Transportation Safety Board issued a Safety Recommendation, which highlighted its earlier commitment to monitoring the progress of the use of video recording in the cockpit, following an air accident in 1989. The Recommendation goes on to emphasise the work being carried out by Eurocae and ICAO FLIRECP/2 concerning video recordings, and notes the commitment of FLIRECP/2 to the introduction of video recordings in an appropriate and agreed format.

These conclusions only serve to reflect the case put by the United Kingdom Air Accidents Investigation Branch in a position paper of 14th June 1996.

As the technology has matured, trials of various systems have been carried out, but no clear mandate for a system has so far been given. This paper shows how recent developments in Digital Video Recording technology can be used in the aerospace environment to achieve the aims of air accident investigators.

A system consisting of five internal cockpit mounted cameras, and three external cameras is suggested. Using digital control methods, the update rate and recorded resolution of individual cameras can be varied to make the best use of the available recording medium.

The paper goes on to discuss the reasoning behind digital video recording, its advantages over tape based recording, and to compare various video compression techniques.

The paper goes on to suggest how such a system may be used as part of a future "Aircraft Recorder Server", in which Audio, Data and Video are all recorded in a single “Black Box”.

AIRBORNE CAMERA SYSTEMS

Fire at Manchester - August 1985. On 22nd August 1985, a British Airtours 737 was on a take off roll from Manchester Airport when an engine fire caused the pilot to abort. Not realising the extent of the fire, he followed standard procedures to exit the runway, as he did so turning the flaming wing upwind fanning the flames onto the fuselage. The resulting fire caused the deaths of 55 passengers and crew.
The Air Accidents Investigation Branch (AAIB) of the United Kingdom Department of Transport concluded in their report (AAIB 8/88) that "Research should be undertaken into methods of providing the flight deck crew with an external view of the aircraft, enabling them to assess the nature and extent of external damage and fires"

Accident at Kegworth - January 1989. On 8 January 1989, a British Midlands 737 had an engine failure during flight. As the crew, unlike the passengers, were unable to see the traces of physical damage on the engine itself, they carried out various procedures to identify which engine had a problem. For various technical and operational reasons, they throttled back the healthy engine, and made their approach to East Midlands Airport on their failed engine. The accident just short of the runway cost 47 passengers their lives.

The AAIB report on the accident (AAIB 4/90) stated that "The CAA should expedite their current research into methods of providing flight deck crews with visual information on the status of their aircraft by means of external and internal closed circuit television monitoring."

The Benefits of Improved Vision. In 1991, in Jeddah, a DC-8 had a tyre burst on take-off roll. Unaware of the fire, the pilot retracted the burning undercarriage into the wheels well, causing the total loss of the aircraft with 260 passengers and crew.
In a similar incident in 1986, a wheel well fire caused a fire warning shortly after take off from Heathrow. The pilot of the departing aircraft was warned of the extent of the fire by the pilot of an aircraft following up, allowing him to return to land with no casualties despite extensive damage to the aircraft.

CAA and Other Work. Prompted by the AAIB report, the United Kingdom Ministry of Defence Royal Aerospace Establishment, Farnborough carried out a successful "Proof of Concept" flight (March 21, 1989) to show that external cameras fitted to a BAC 1-11 would prove useful to the pilot, and would be capable of operating in the environment.

In 1989 British Airways, funded by the UK CAA, carried out a trial installation of two cameras on a Boeing 747, the results of which were published as CAA Paper 95001. This report also covered a funded study by DRA Farnborough into "A Human Factors Investigation into the Use of Airborne External Video Camera Systems", and a Safety Benefit Study carried out by the College of Aeronautics at Cranfield, now Cranfield University. While acknowledging the potential safety benefits brought by video cameras in several of the analysed categories, the CAA concluded that, given the technology at the time, they could not take steps towards mandating external viewing systems.

RECENT DEVELOPMENTS IN THE INDUSTRY

Glass Cockpits Traditionally, Air Accident investigators have been able to rely on data "stored" by instruments jammed at the point of impact, following an accident. However, modern "Glass Cockpit" displays have no such "memory" and provide the investigator with little in the way of evidence to show their status leading up to, or at the time of, an air accident. This has seriously reduced the amount of information available for post accident analysis.

FANS. Recent moves in aviation have further impeded the accident investigator. The adoption of the "Future Air Navigation System" (FANS) would mean that uplinked information from Air Traffic Controllers will in future be carried out by datalink rather than voice. While operationally there are many advantages, the adoption of FANS severely reduces the amount of useful information available to the accident investigator from the Cockpit Voice Recorder.

Cockpit Environment Recorder. It is our contention that much of the above information could be restored for post accident use by eventually replacing the Cockpit Voice Recorder with a combined cockpit voice and video camera system recording the complete "Cockpit Environment". The discussion of the structure of the combi recorder is dealt with in the section of this paper entitled "The Future Flight Recorder".

The video camera positions suggested for this system are: Captain's main instruments display, covered by camera located outboard and behind the pilot; Co-pilot's main instruments display, covered by camera located outboard and behind the pilot; General flight crew activity, covered by "fish eye" lensed camera in roof panel; External "Fin" mounted camera, showing the overall attitude of the aircraft, damage to control surfaces and engines; Underbelly forward looking, viewing the nosegear; Underbelly rearward looking, viewing the maingear. In addition it may be useful to have a further two cameras in the cockpit covering the central console, and the overhead panel. The exact locations of the cameras will be specific to the aircraft type, and must be established through trials.

TECHNOLOGY

Aerospace Standards.
To withstand the harsh aerospace environment, all components need to be designed and manufactured specifically for use in that environment. Taking standard off the shelf cameras and recorders designed for the office environment and using them in the air, while economically attractive, will result in early problems and failures. Specifically, externally mounted cameras need to be small, light, and reliable using solid state electronic shuttered light control, thermostatically controlled heaters for de-misting and de-icing, and aerodynamically shaped housings to allow the flow of air to remove water droplets.

The Video Camera.

The worldwide use of video cameras for buildings and area security is now well established, with thousands of cameras being installed weekly. This mature technology is now leading to highly reliable solid state CCD camera sensors, at ever-cheaper prices and in ever-smaller physical sizes.
Camera observation has now become an accepted part of modern life. The modern businessman uses camera technology to conduct "video conferencing" with international offices. Mostly, then, we have come to accept the presence of cameras in our daily lives, and are no longer intimidated by the idea that we are being recorded going about our business.
Indeed, most of us welcome the increased security afforded by town centre police surveillance cameras, and point of sale cameras which check that we are who we say we are, every year preventing millions of pounds in fraudulent transactions. In many instances, video tapes are used for training de-briefing (for example in line-pilot's simulators), and can also be used to confirm that the correct actions were taken by staff, for example showing that procedures were correctly followed when in dispute. Taken together, the advent and introduction of video cameras into any workplace, including the cockpit, should not be feared, but should be welcomed.

Resolution. One of the major parameters to be considered in the choice of video camera is the required resolution of the recorded image. Whilst modern image enhancement techniques can re-emphasise video data obscured by errors in lighting, and even errors in focusing, it must not replace data which was not originally captured by the video system due to poor sensor resolution. To do so would bring the reliability of the data extracted into question.
The sizes of aircraft instruments, and the text and graphics displayed on them is well defined, mostly by reference to the "Design Eye Position", which is the position of the average pilot within cockpit.

The minimum requirement of the video for accident investigation needs in the cockpit is to identify a graphical pointer (defined in ARP4103 as a minimum of 0.1 inches (2.54mm)), which could then be simulated on a representative instrument to obtain the reading. This would imply that a single "standard" 400 TV lines per picture height resolution camera could detect such a pointer over an area of 677 x 508mm.

If reading text on the instrument panel is required, this results in a far more strenuous set of criteria. The sizes of text are shown below as Table 2 (SAE ARP4102)

Experimentally it has been found that to read text, 10 TV lines are needed even in good laboratory conditions. Assuming that the camera can be located at the same distance from the instrument panel as the Design Eye Position, and given a "standard" video camera with a resolution of 400 TV lines per picture height, this means that to be able to read a 5mm high character, a single camera will be able to cover only 300 x 225 mm on the instrument panel.

Text Category	Angular Subtension at Pilots Design Eye Position
Primary	20' of arc = 0.33°
Secondary/Non	15' of arc = 0.25°

Essential	
Minor	12’ of arc = 0.20°
Fixed, Continuously Available	10’ of arc = 0.17°

Table 2

Colour. Where detection of alarm signals is concerned, colour is an essential part of the message, and the use of a colour sensor is justified. However, colour CCD sensors have considerably lower resolution than monochrome sensors, and their use must be treated with some caution.

Lighting. Modern monochrome CCD cameras are capable of operating from full moonlight (0.1 lux) to full sunlight (100,000 lux), by automatic electronic shuttering, which makes them ideal for use in the cockpit environment, where they will automatically adapt to the wide range of conditions which may prevail. However, as they react to the average light level across the scene, they are not so effective where part of their field of view might be the darkened instrument panel, and another part may be the bright windshield. Therefore careful positioning, and possibly masking of certain parts of the field of view, may be necessary.

THE VIDEO RECORDER.

Solid State Recording vs Tape. Tape based systems have traditionally been used for video recording for flight trials and other airborne work. When considered for air accident investigation uses, the medium has serious shortcomings.

Wear. In a system in use 24 hours a day, the requirement for maintenance to replace worn tapes is relatively high, resulting in high “cost of ownership” for the airline. A solid state digital system needs no such maintenance.

Quality. With a high frequency, wide bandwidth signal like video, the quality of recording on tape systems soon deteriorates with usage, most experts recommending that a VCR cassette be used no more than 10 times. A digital system, using flash memory with an expected life of 200,000 write cycles, would reduce this maintenance to a minimum.

Flexibility. Perhaps the biggest advantage of digital systems over tape based systems, however, is the ability to rapidly access a particular image or sequence of images. A tape system is essentially a serial device, where a user has to start at the beginning and progress through the recording until reaching the required sequence of images. With a digitally controlled system, a sequence of images can be accessed easily either by time, or alarm. This could mean that an alarm could be noted by the digital system, for example: on a fire alarm; pilot initiated alarm; when the aircraft altitude falls below 10,000 feet; or whatever the air accident investigators require. Then this section of recording could be easily accessed during analysis.

Further to this, uniquely in a digital recording system, the alarm action can cause a change in the way that the recorder works. For example, this could mean that as the aircraft descends prior to landing, the recorder starts to record at higher resolution or with a faster update rate.

Under normal circumstances, the recording will overwrite once the medium is full, after say half an hour of recording. Again, given a digital alarmed system, it would be simple to program the recorder to preserve the recording say one minute prior to, and one minute following an alarm, thus ensuring that vital information is not overwritten however long the flight continues after the incident.

These parameters, and others, will be discussed by Eurocae Working Group 50, prior to the publishing of the promised Minimum Operating Performance Specification (MOPS).

VIDEO MULTIPLEXING

In order to avoid multiple recorders, it is essential in any multi-camera video system to convert the various camera inputs to a single video signal. This is achieved by "Video Multiplexing", which takes one picture (field) from the first video input, and follows it with a field from the next input, a field from the third input, and so on. If one camera input is more important than another is, then more fields can be taken from that input channel, or that channel can be returned to more often. If the incoming video signals are "genlocked" that is synchronised to a single master video clock then it is possible to switch between the video channels at field rate. In an aircraft environment, running extra genlock cables to each camera position will build extra weight and therefore running cost into the system, and it is usually sufficient to "slip" a field from time to time to achieve the multiplexing of unsynchronised signals. In practice higher reliability will be expected if up to 4 fields are recorded from each channel at a time.

VIDEO COMPRESSION

Essential Parameters. To make the best use of any given volume of digital recording medium, it is essential to use one of several video compression algorithms. For accident investigation usage, it is essential that the chosen method records information which can be relied upon, and in which each picture "stands alone" containing within its data file all the information necessary for the reconstruction of the picture. Also, the chosen method must be able to operate in "real time", that is that compression rates must be able to cope with a number of pictures per second.

JPEG vs MPEG. The two most successful video compression methods suitable for real time video compression are JPEG, defined by the Joint Photographic Experts Group, and MPEG, defined by the Motion Picture Experts Group. MPEG systems are designed to be used for compression of motion pictures, and rely on the storage of moderately compressed "Intra

Pictures” every 15th frame, then Forward Predicted “P-Pictures”, storing only the change vectors of parts of the pictures, and finally Bi-directional “B-Pictures" which are generated estimation pictures averaging between the I-Pictures and the B-Pictures. This technique gives excellent compression of static scenes, generating larger files, hence using more of the available storage medium where there is movement within the picture. This is just at the moment where our interest in the picture is greatest. The reliability of these pictures is not high; for example a car moving quickly away from a traffic light will appear to take the white stop line along with it for a few frames. Discerning what happened in an accident situation with this sort of evidence would at the very best be unconvincing. Furthermore, since in subsequent pictures all that is stored is changes to the I-Picture, the possible loss of that I-Picture should there be recording medium damage in an accident, would mean that a whole stream of data is rendered meaningless. JPEG addresses each incoming video field as a separate picture, compressing with a predictable, pre-settable, compression rate, leading to a predictable file size. Overall a compression ratio of about 12:1, giving a file size for a colour picture of about 20 kB, will produce a quality of reproduced image about equal to that from an SVHS video recorder, adequate for most requirements. The incoming video signal is digitised and subjected to a 2 Dimensional Discrete Cosine function, applied to each cell of 8 x 8 pixels (picture elements). The output is quantized at the preset Q level, a higher Q leading to a smaller file size but a loss of high frequency information, hence detail. This quantization results in a data file consisting of runs of value numbers, and long runs of zero’s, and can be further compressed by merely storing the numbers of zero’s in any given run (Zero Run Length Coding). The resultant files are then further compressed by the use of a “Lookup Table” of frequently encountered patterns (Huffman Coding).

The resultant recording is effectively to turn the video sequence into a series of still pictures, showing the fine detail of the scene, more akin to using a 35mm camera with autowind, than to traditional movie film photography. It has been found in various military and commercial security systems that an update rate using this technique as slow as one frame every four seconds is adequate update to track incidents.

Given the requirements for our video compression techniques stated above, the best choice is a JPEG based algorithm.

THE FUTURE AIR ACCIDENT RECORDER

The above thinking has led to the development of a video based Accident Recorder, now in its prototype form.

Future Air Accident Recorders are likely to be ‘combi’ units, recording audio, data and video in a single “Black Box” recorder. This recorder will be digital solid state, for the reasons already discussed, and will need to satisfy the recording requirements for all air accident needs. This will mean that an installed dual redundant system will allow the total destruction of one of the recorders, without affecting the ability of the air accident investigators to do their work.

THE "AIRCRAFT RECORDER SERVER"

The last couple of years have seen an explosion in the development of information systems. Specifically the growth of the Internet has led to the sudden and dramatic development of transmittal and recording systems and techniques. This has necessitated the differences between the digital transmission of data, audio and video signals being almost eliminated.

New accident recorders will take advantage of these developments, by becoming "server" machines. Data, audio and video will be converted to digital signals at source (that is at the DAU for data, at the microphone control unit for audio, and at the camera site for video). The serial data can then be transmitted through the airframe and recorded by a "dumb" box, which merely acts as a sponge to all data, which it sees. A standard software protocol such as TCP-IP, and hardware Ethernet, which is widely used for all Internet transactions can be employed, and the community can benefit from advances and developments in the wider engineering world. The advantage of this approach is that the technology dealing with the acquisition of the original data is the same as that dealing with the digitisation, compression and transmission, leaving the technical issues with the sensing equipment manufacturer, and leaving the way open for future enhancements. The "Aircraft Recorder Server" would establish the Recorder as the Ethernet "hub". This would allow twisted pair transmission at up to 100Mb rates, and would allow any number of new "nodes" to be added, to expand the system in the future.

The use of industry standard techniques will allow the transmission of data between the "Server" and the terminal, to be used as an accident preventative just as "Quick Access Recorders" are used at present. In the future, data will be transmitted from the aircraft in flight to the ground such that maintenance issues can be addressed long before the aircraft lands.

CONCLUSION

The history of aviation accident investigation gives strong arguments for the use of cockpit and external video cameras. The component parts for the systems, video cameras, and multiplexing digital video recorders now exist, and are in everyday use in ground based security systems. The development of the combined "Aircraft Recorder Server", in conjunction with recommendations from Eurocae Working Group 50, will provide future air accident investigators with an invaluable new source of evidence.

BIOGRAPHY

Mike Horne BEng CEng MIEE is Managing Director of AD Aerospace Ltd. After qualifying from the University of Bradford with an honours degree in Electrical and Electronic Engineering, and a Student Apprenticeship with Marconi Avionics in 1983, he has worked extensively in video camera systems for a wide variety of purposes from missile guidance and fire control, to pipe inspection and commercial security. His work has included image intensified and thermal imaging systems. In 1995 he joined the successful video security systems company, Dedicated Microcomputers to form DM Aerospace, which later split off as an independent company AD Aerospace, specialising in the design and manufacture of video systems for aerospace. During his time at the company, Mike has overseen the development of the first "Digital Video Network Server" compatible with aerospace requirements. This is now being offered to the world's airlines, and a spin off product to the School Bus market. Mike has two children, Greg aged one, and Dennis aged two months.

Proactive Use of Highway Recorded Data via an Event Data Recorder (EDR) to Achieve Nationwide Seat Belt Usage in the 90th Percentile by 2002

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HIGHWAY TRANSPORTATION SAFETY TECHNOLOGIES

SYMPTOMS OF A PROBLEM

Automobiles have been in existence for over a hundred years (1898-1999). Today, we have over two hundred and fourteen million in America alone, and six hundred and ninety million worldwide. Nationwide, forty-seven million vehicles are continually in-motion during daytime usage. Within twenty years these numbers are expected to double. Last year, twenty-four million vehicles were involved in a crash or accident. Over 40,000 people died (115 daily) and the total economic cost is estimated at $150 billion annually. (Blincoe 1996) The personal, social, and economic costs of motor vehicle crashes include pain and suffering; direct costs sustained by the injured persons and their insurers; indirect costs to taxpayers for health care and public assistance; and for many victims, a lower standard of living and quality of life. During the past two decades, motor vehicles accounted for over 90 percent of all transportation fatalities, and an even larger percentage of accidents and injuries. Our increasingly mobile society exposes all age groups to the risks of crashes, as passengers, as drivers, and as pedestrians. The automobile is essential for the style of life we demand, and yet, motor vehicle crashes remain a major public health problem. In contemporary society automobiles play an indispensable role in transporting people and goods, and yet, the health care cost of motor vehicle crashes is a national financial burden that must and can be reduced. Worldwide, research and development is underway into systems that link highway infrastructure and telecommunications using emerging technologies via computers, electronics, and advanced sensing systems. While this paper will propose a highway safety counter-measure it will do so after reviewing the policy issues that created the current circumstances connected with occupant safety. Without this review it be impossible to understand the simplicity of the proposed counter-measure. This paper will identify methods for expanding the use of recorded data on highways to improve transportation safety by providing something that has yet to be achieved in the history of the automobile—a simple transportation safety technology capable of reducing fatalities of comparable magnitude. Thus, the primary objective is to technically explain this highway safety countermeasure designated Seat Belt Event Data Recorder (SB-EDR). It is noted that the author is an independent researcher with no association, alliance, or adherence to any transportation safety organization. What follows is an objective analysis of a national problem.

COMMON SENSE PRINCIPLES

The following common sense principles are well known to automobile safety designers, law enforcement personnel, and professionals in medical science and the automobile insurance industry. The sources for these principles are *The Official Driver's Handbook* (Ontario, Ministry of Transportation, 1995) and the *Presidential*

Initiative to Improve Seat Belt Usage (1997).[1] Seat belts and child safety seats reduce the risk of injury or death in collisions. Seat belts help keep you behind the wheel and in control of the vehicle in a collision. In a vehicle with airbags, a seat belt keeps you in your seat so the airbag can protect you. Seat belts keep your head and body from hitting the inside of the vehicle or another person in the vehicle. When a vehicle hits a solid object the people inside keep moving until something stops them. If you are not wearing your seat belt, the steering wheel, windshield, dashboard or another person might be what stops you. This "human collision" often causes injury. Seat belts keep you inside the vehicle in a collision. People who are thrown from a vehicle have a much lower chance of surviving a collision. Fire or sinking in water is rare in collisions. If they do happen, seat belts help keep you conscious and unhurt, giving you a chance to get out of the vehicle. In a sudden stop or swerve, no one can hold onto a child who is not in a seat belt or child seat. Infants or children who are not wearing seat belts can be thrown against the vehicle's interior, collide with other people or be thrown onto the road. The *Presidential Initiative for Increasing Seat Belt Usage* cites, "….Seat belts and child safety seats work. Yet, fewer than 40 percent of both adults and children who died in traffic crashes were properly restrained. Seat belts work. They are the most effective means of reducing fatalities and serious injuries when traffic crashes occur and are estimated to save 9,5000 lives in America each year. Research has found that lap/shoulder belts, when used properly, reduce the risk of fatal injury in front seat car occupants by 45 percent and the risk of moderate-to-critical injury by 5o percent. For light trucks occupants, seat belts reduce the risk of fatal injury by 60 percent and moderate-to critical injury by 65 percent. Every 14 seconds someone in America is injured in a traffic crash and every 12 minutes someone is killed. When a traffic crash occurs, occupants are still traveling at the vehicle's original speed at the moment of impact. Just after the vehicle rapidly comes to a complete stop, unbelted occupants slam into the steering wheel, windshield, and other parts of the vehicle's interior. Seat belts are effective in reducing fatalities and injuries caused by this second collision, or "human collision," when the vehicle's occupants hit some part of the vehicle or other occupants. Seat belts provide the greatest protection against occupant ejection. In fatal crashes in 1995, only two percent of restrained passenger car occupants were ejected, compared to 25 percent of unrestrained occupants. Ejection from a vehicle is one of the most serious injurious events that can happen to a person in a crash. Three-quarters of the occupants who are ejected from passenger cars are killed."

TRANSPORTATION SAFETY ORGANIZATION MISSION STATEMENTS

The mission statements of the NTSB, NHTSA, and NSC are all directed toward improving transportation safety. [2]The National Transportation Safety Board (NTSB) seeks to determine the "probable cause" of transportation accidents and to formulate safety recommendations to improve transportation safety. The National Safety Council (NSC), chartered by an act of Congress, is a nongovernmental, not-for-profit, public service organization devoted solely to educating and influencing society to adopt safety, health, and environmental policies, practices, and procedures that prevent and mitigate suffering and economic losses arising from preventable causes. The

[1] *Presidential Initiative for Increasing Seat Belt Use in the United States*, Executive Order 13043, The White House, Washington, DC., Filed 4-17-97; FR Doc. 97-10331.

[2] See NTSB web page at http://www.ntsb.gov/ See NHTSA web page at http://www.nhtsa.gov/ and NSC web page at http://www.nsc.org

National Highway Traffic Safety Administration (NHTSA) *Strategic Execution Plan* (June 1996) cites that it's mission is to save lives, prevent injuries and reduce traffic related health care and other economic costs. This plan also states that "Translating the concepts of the National Highway Traffic Safety Administration's (NHTSA) Strategic Plan into programs is both easy and difficult. The easy part comes from the large body of proven tactics and approaches that are used to improve traffic and vehicle safety and from the extensive library of data and research results that can support new activities. It is difficult because highway causalities are becoming more challenging. We have taken steps that have reduced motor vehicle crash losses in recent years to the lowest levels in decades and their lowest rates in history. We must know look beyond our tradition of regulating industry and overseeing state and community programs. We must increasingly look toward stimulating public demand for vehicle and traffic safety, developing and applying new technologies (particularly computers, and communications, sensors, and advanced materials) to well defined problems, and forming more creative and productive relationships with the industry and other government bodies." These remarks by the Administrator of NHTSA recognize progress but admit that new methods must be tried to a well-defined problem—traffic injuries and fatalities. The intent of this paper is to promote one such counter-measure of combining emerging technologies.

PRESIDENTIAL INITIATIVE

On January 23, 1997 President Clinton directed the Secretary of Transportation to prepare a plan to increase seat belt use nationwide. This plan became known as the "*Presidential Initiative for Increasing Seat Belt Usage*." The report states that America must set ambitious seat belt and child safety seat use goals. It cites, "the unprecedented opportunity to save lives, prevent injuries, reduce health care and other costs, and improve the lives of all Americans—simply by increasing proper seat belt and child safety use. Furthermore, in order to reach these goals requires a bold initiative reaching beyond business as usual." The overall goals are:

- Increase national seat belt use to 85% by 2000 and 90% by 2005 from 68% in 1996
- Reduce child occupancy fatalities (0-4 years) by 15% in 2000 and by 25% in 2005 from a total of 685 in 1995

This report notes that the vast majority of all fatal and non-fatal injuries in America, including traffic injuries, are not acts of faith but are predictable and preventable. Key points are:

- Injuries are a major health care problem and are the leading cause of death for people age 1 to 42.
- Fatalities, however, are only a small part of the total injury picture.
- For each injury-related death, there are 19 hospitalizations for injury and another 300 injuries that require medical attention.
- Every year, one in four Americans will have a potentially preventable injury serious enough to require medical care.
- These injuries account for almost 10 percent of all hospital emergency department visits.
- Injury patterns vary by age group, gender, and cultural group.
- Injuries pose a significant drain on the health care system, incurring huge treatment, acute care, and rehabilitation costs.

The report concludes that, "Each year, traffic crashes in the United States claim over 40,000 lives and cost Americans $150 billion in economic costs, including $17 billion in medical and emergency expenses, lost productivity, and property loss. Traffic crashes aren't "accidents." They are both predictable and preventable. The quickest, easiest, and most effective way to prevent traffic injuries is to make certain that every vehicle occupant is properly buckled up on every trip. The motor vehicle injury problem affects all Americans. The cost of personal pain and suffering, the loss of a loved one, and serious injury to a family member cannot be measured. Every person in America also bears the economic cost of motor vehicle crashes—on average, $580 a year. These include the costs of the emergency response providers, higher medical and insurance costs, and lost productivity. When individuals don't wear seat belts, these costs increase considerably because the injuries are more serious."

MEASURING IMPROVEMENT

It is debatable as to how improvement is defined--yet nobody seems content with the fatality statistics. This paper recognizes two sources for statistics. They are the National Safety Council (NSC) publication *Accident Facts* 1998 Edition and The USDOT National Highway Traffic Safety Administration (NHTSA) publication entitled *Trafiic Safety Facts in 1997.* 1997 is regarded as the safest year in highways. Safety campaigns are being credited with pushing the highway death rate to an all-time low. Traffic accidents killed 41,967 people in 1997. Since people drove a little more than 2.5 trillion miles, the death rate was 1.6 per 100 million miles traveled according to the National Highway Traffic Safety Administration (NHTSA). Although the total number of fatalities has been lower in some other years, the higher mileage held down the rate, the lowest since NHTSA started keeping statistics 30 years ago. Traffic accidents killed 42,085 people in 1996, for a rate of 1.7 deaths per 100 million miles. Of those who were killed last year, 21,989 died in passenger car crashes. An additional 10,224 died in light truck crashes, while 2,106 were killed in motorcycle crashes, 717 in large truck crashes and 17 were killed in buses. The agency listed 640 deaths as "other" or "unknown" occupants of vehicles and 154 as "other" nonoccupants. In 1997, 5,307 deaths involved pedestrians, while 813 involved cyclists. All except for light trucks, large truck and cyclist deaths represented declines from 1996. Meanwhile, there were 2.38 million people injured in car accidents last year, while another 77,000 pedestrians were injured. It has been difficult and challenging to achieve occupant vehicle safety to reduce injuries and fatalities irregardless of the combined efforts of the National Transportation Safety Board (NTSB), The U.S. Department of Transportation (USDOT), and The National Highway Traffic Safety Administration (NHTSA) and The National Safety Council (NSC).

The simple fact is that although there have been advancements and improvements in seat belts and air bags over the years **it has not been possible to get motorists to willfully wear seat belts.** This failure to use seat belts is a nationwide problem.

EVENT DATA RECORDER (EDR) INITIATIVES OFFER NEW OPPORTUNITIES

Recent emphasis towards incorporating an Event Data Recorder (EDR) in future motor vehicles may serve as the missing link between seat belt usage, air bag safety and improved occupant protection. In 1997, the National Transportation Safety Board (NTSB) issued recommendations to NHTSA, based partly on public hearing held on march 17-20, 1997, Public Forum on Air Bags and Child Passenger Safety, indicating that NHTSA should pursue crash information gathering using EDR's. In a safety recommendation letter to NHTSA on July 1, 1997, NTSB recommended:

"Develop and implement, in conjunction with the domestic and international manufacturers, a plan to gather better information on crash pulses and other crash parameters in actual crashes, utilizing current or augmented sensing and recording devices. (H-97-18)" [3]

In NHTSA's response to the Safety Board, it indicated that it was currently obtaining data from EDR's through the cooperation of the manufacturer, for use in crash investigations. This cooperation is needed since the technology to "download" data from these devices is only available to the manufacturer. NTSB added the EDR recommendation on its "*10 Most Wanted List*" in May 1997. The current status of the NTSB recommendation to NHTSA is: H-97-18 Open-Unacceptable. Currently, NTSB is reviewing NHTSA's activities in this area to determine if the status should be changed to Open---Acceptable. [4]

In 1997, NHTSA, under a joint agreement with National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) and NHTSA, contracted with JPL to:

"Evaluate air bag performance, establish the technological potential for improved air bag systems, and identify key expertise and technology within NASA that can potentially contribute significantly to the improved effectiveness of air bags."”

The JPL Executive Summary (April 1998) cites that "…This automobile system is injuring occupants because of the widely variable nature of motor vehicle crashes and the performance of current air bag systems. Crashes can happen at any speed and vary widely in character and severity. The occupants to be protected are typical of the population as a whole. They include men, women and children of all sizes and ages who may, or may not, be belted. A restraint system, such as an air bag, must respond to the highly varied and unpredictable need for protection. An inherent design feature of air bags is that they deploy rapidly toward occupants during a crash. This leads to the tendency to cause injuries. To deploy, air bags must burst through protective covers and expand in a very short time. The time from initial impact to full deployment must be on the order of 50ms."

[3] See NTSB web page at http://www.ntsb.gov/Recs/history.htm=Original

[4] See NTSB web site: http://www.ntsb.gov/recs/recording%5Fdevice.htm

The *JPL Report* [5] noted development on promising technologies to meet the air bag design challenges and forecast these intended improvements by model years 2001-2003. The following is a synopsis:

- 2001 - Improved crash sensors, belt use sensors, and seat position sensors.
- 2002 - Belt spool-out sensors and static display sensors.
- 2003 - Occupant weight and position sensors.

Regardless of these anticipated advancements, JPL noted that an un-belted out-of-position occupant would receive no protection if the air bag is suppressed or malfunctions. The importance of proper seat belt use is highly stressed as a critical issue. The JPL Report found manual restraint use (safety belts and child safety seats) to be critical to addressing the problems of air bags. Furthermore, it was noted that "if air bag designers could assume that occupants would be belted, air bags could be designed to give superior protection for far less hazard. Occupants need to be in optimal position to survive a crash; therefore people need to use seat belts."

The *JPL Report* also served as an impetus towards implementing on-board EDR's in vehicles. In the final report of this project, JPL recommended that NHTSA investigate EDR's, stating in recommendation (6):

"Study the feasibility of installing and obtaining crash data for safety analyses from crash recorders on vehicles. Crash recorders exist already on some vehicles with electronic air bag sensors, but the OEM's determines the data recorded. These recorders could be the basis for an evolving data-recording capability that could be expanded to serve other purposes, such as emergency rescues, where their information could be combined with occupant smart keys to provide critical crash and personal data to paramedics. The question of data ownership and data protection would have to be resolved, however. Where data ownership concerns arise, consultation with experts in the aviation community regarding the use of aircraft flight recorder is recommended."

Finally, the *JPL Report* noted that "Surveys of industry and NASA did not identify major new technologies or concepts. All of the technologies and concepts surveyed had been previously described in published papers, company brochure, etc., or were variations of these concepts and technologies. Improvement of restraint system safety and protectiveness is primarily one of evaluating and developing known technology options from a total systems perspective. Perhaps this report can be a catalyst for new ideas." It is the intent of the author to follow-up this suggestion by technically explaining a new idea and concept for significantly improving occupant safety via combining emerging technologies.

A Task Force was formed through the sponsorship of NHTSA and met on October 2, 1998 to address research requirements for on-vehicle event data recorders. [6] Participants included

[5] Phen, Dowdy, Ebbeler, Kim, Moore, and VanZandt; *Advanced Air Bag Technology Assessment*; JPL Publication 98-3; April 1998. The report can be found on the JPL web site- http://csmt.jpl.nasa.gov/airbag/contents.html

representatives from NHTSA, FHWA, NTSB, TRB, the major American automobile, truck, and bus manufacturers, and several other vehicle manufacturers. The Task Force members recognized issues regarding liability and privacy. The objective offered by the NHTSA for the task Force was to facilitate the collection and utilization of collision avoidance and crash worthiness data from on-vehicle event data recorders (EDR). The scope was limited to research rather than regulatory initiatives. Current EDR systems are considered to be early generation systems with enormous potential for collecting and using pre-crash, crash, and post-crash data. EDR's are defined as devices capable of gathering, storing and displaying data elements from a vehicle in motion as pre-crash, crash and post-crash. Event data elements include but are not limited to active suspension measurements, advanced systems, air bag inflation time, air bag status, airbag on/off switch position, automatic collision notification, battery voltage, belt status of each passenger, brake status-service, brake status-ABS, collision avoidance, braking, steering, etc., crash pulse-longitudinal, crash-pulse lateral, CSS presence indicator, Delta-V-longitudinal, Delta-V-lateral, electronic compass heading, engine throttle status, engine RPM, environment as ice, wet, temperature, lamination & other, fuel level, lamp status, location via GPS data, number of occupants, principle direction of force, PRNDL position, roll angle, seat position, stability control, steering wheel angle, steering wheel tilt position, steering wheel rate, time and date, traction control, traction coefficient estimated from ABS computer, transmission selection, turn signal operation, vehicle mileage, vehicle speed, VIN, wheel speeds, windshield wiper status, yaw rate, turn-key start time, vehicle movement time, location at start, velocity at crash, trip time at collision or crash, fire in cabin, water in cabin, audio-clip at air bag deployment, etc.

KEY DATA ELEMENTS

Although an EDR may ideally provide any, or all, of the data elements mentioned above the most critical data elements are:

- Location
- Time
- Velocity
- Direction
- Seat Belt usage

CRASH PULSE

Crash pulse is an important concept used in analyzing crash data. A notice in the *Federal Register* [7] regarding federal motor vehicle safety standards; occupant crash protection noted that "Crash pulse means the acceleration-time history of the occupant compartment of a vehicle during a crash. This is represented typically in terms of g's of acceleration plotted against time in milliseconds (1/1000 second). The crash pulse for a given test is a major determinant of the stringency of the test, and

[6] NHTSA, MVSRC – Subcommittee on Crashworthiness, Event Data Working Group Meeting #1, Draft Minutes of October 2, 1998, Washington, DC.

[7] Federal Register, Volume 63, No. 181 / Friday, September 18, 1998 pg. 49958.

how representative the test is of how a particular vehicle will perform in particular kinds of real world crashes. Generally speaking, the occupant undergoes greater forces due to the secondary collisions with the vehicle interior and restraint systems if the crash pulse is shorter, which would lead to higher overall g's. In a relatively "hard" crash pulse, a vehicle's occupant compartment decelerates relatively abruptly, creating a high risk of death or serious injury. In a relatively "soft" crash pulse, there is a lower rate of deceleration and proportionately lower risk of death or serious injury. The nature of the crash pulse for a vehicle in a given frontal crash is affected by a number of factors, including vehicle speed, the extent to which the struck object collapses and absorbs injury, and, in the case of non-fixed objects, the relative mass of the vehicle and the struck object. Large cars typically have relatively mild crash pulses, while small cars and utility vehicles typically have more severe crash pulses."

COMBINING EMERGING TECHNOLOGIES

By combining simple technologies and incorporating these within the Event Data Recorder (EDR) Program it would be feasible and possible to introduce a nationwide plan of implementation that can willfully increase seat belt usage and make our roads the safest in the world. It will be further argued in this paper that the EDR program and implementation plan could and should include positive incentives and reward the motorist and occupants for wearing seat belts while at the same time decreasing the annual costs of negligence to society.

OLD PROBLEMS OFFER NEW OPPORTUNITIES

Past problems connected with seat belt usage rates and simple solutions combining emerging technologies may solve present and future problems connected with air bag technology. A great effort was devoted within the auto industry to improving air bag safety but there is no method reliable enough without restraining the driver and occupants via seat belts. This is especially true regarding young children. Air bags work best when seat belts are engaged. The bottom line to safety during a crash is keeping the occupants in position. There is absolutely no question that seat belts save lives. Seat belts are the most effective safety device available today, yet, only 66 percent of Americans actually use seat belts. Federal assistance programs such as Medicaid, Medicare and Aid ultimately pay many costs of motor vehicle crashes to Families with Dependent Children. Approximately one third of the cost of motor vehicle crashes is paid by tax dollars (source NHTSA). This enormous cost burden is a national problem. In 1996, this cost was estimated at 176.1 billion dollars. Today, despite the greater number of airbags in the vehicle fleet, the number of vehicle deaths and injuries have increased for three consecutive years, and slightly decreased in 1996. Despite significant efforts by the federal government to reverse this trend, deaths and injuries continue to rise. The time has come to utilize state-of-the-art technologies to address and eliminate this national tragedy. Numbers tell the story why we should use seat belts:

- 23,900,000 motor vehicle crashes are reported by law enforcement agencies each year in the United States.
- 17 million people and 12 million vehicles are involved in these crashes.
- About 43,200 deaths result in these crashes; that's an average of 115 deaths per day (similar to a major airline crash every day of the year).

- 21,989 passenger car occupants die every year (that's about 2,000 more than the total number of homicides that occur in the US each year).
- Motor vehicle crashes are the leading cause of death for persons between 6 and 33 years old.
- In 1989, if every front seat occupant had buckled up, an estimated 15,500 deaths and several hundred thousand serious injuries could have been prevented.
- Seat belts could save about half of the motorists who die unbelted in crashes each year, and prevent about half of the serious injuries unbelted motorists suffer.

SHORT HISTORY OF SEAT BELT USAGE IN THE UNITED STATES

The *Presidential Initiative for Improving Seat Belt Usage* states "…while automobile manufacturers installed the first seat belts in the 1950's, seat belt use was very low—only 10-15 percent nationwide—until the early 1980s. From 1984 through 1987, belt use increased from 14 to 42 percent as a result of the passage of seat belt use laws in 31 states. Then, from 1990 through 1992, belt use increased from 49 percent to 62 percent as a result of a national effort of highly visible enforcement and public education. Since then, belt use has risen slowly and some states have struggled to maintain seat belt use at current levels. In 1996, belt use nationwide was 68 percent, and ranged across the states from a high of 87 percent in California, to a low of 43 percent in North Dakota. Currently, 49 states, the District of Columbia, Puerto Rico and all the U.S. Territories have seat belt laws. New Hampshire is the only exception. (New Hampshire requires seat belt use up to age 12). In 37 states, the law provides only for "secondary" enforcement of seat belt violations, requiring an officer to stop a violator for another infraction before issuing a citation for failure to buckle up. Under primary enforcement, a citation can be written whenever a law enforcement officer observes an unbelted driver or passenger. Currently, 12 states, the U.S. territories, Puerto Rico, and the District of Columbia, all have primary (or standard) enforcement laws. California, Georgia, Louisiana, Maryland, the Virgin Islands, and the District of Columbia have a seat belt law that assesses driver license penalty points. Seat belt use in the 12 states with primary (standard) seat belt laws currently averages 15 percentage points higher than states with secondary laws."

AUDIBLE AND VISUAL SEAT BELT WARNING SIGNAL LAWS

There is federal law that permits and regulates audible and visual seat belt warning devices. There is a specific length of time after start-up that devices are permitted to perform. Afterwards, they are generally useless when a vehicle is in motion. No audible or visual signal reminds occupants that seat belts have been disconnected after a vehicle is moving. In one example, it is possible to buckle-up at start-up then un-buckle and drive unprotected without any warning or reminder. Therefore, lacking is the ability to constantly monitor seat belt usage. A public opinion poll conducted by Louis Harris for Advocates for Highway & Auto Safety, May 1996 surveys attitudes. [8] Despite conventional wisdom that the public wants less government involvement in regulatory matters, decisive majorities of Americans feel it is important for the government to play a strong role in highway and automobile safety regulations. Among the key findings in this are that 94% say it is

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[8] Harris, Louis. (1998). "*A Survey of the Attitudes of the American People on Highway and Auto Safety*" A Public Opinion Poll conducted by Louis Harris for Advocates for Highway and Auto Safety, April, 1998.

important to have federal regulations of car safety standards, with 77% stating such a presence is important. 80% feel a federal presence is important in passing laws that mandate seat belt use, with 61% saying federal involvement in this area is very important.

SEAT BELT DEFENSE CLAIMS AND ACCIDENT FRAUD

In 17 states (Alaska, Arizona, California, Colorado, Florida, Iowa, Kentucky, Michigan, Missouri, Nebraska, New Jersey, New York, North Dakota, Ohio, Oregon, West Virginia, and Wisconsin) safety belt defense is allowed. Damages collected by someone involved in a crash may be reduced if a person failed to use a belt. The reduction is permitted only for injuries caused by nonuse of belts, and in some cases the reduction may not exceed a fixed percentage for the damages. The Insurance research Council (IRC) [9] estimates that between $5.2 and $6.3 billion is added each year to the bill of American auto insurance policyholders because of outright fraud and/or injury claim padding. A SB-EDR system that determines the number of occupants and other crash behavior would help reduce insurance fraud.

LEGAL IMPLICATIONS OF CRASH RECORDER DATA

The Office of Technology (OTA) assessment (1975) "*Automobile Collision Data: An Assessment of Needs and Methods of Acquisition*" [10] 1975 at cites the following:

"…On the question of whether crash recorder data should be admitted, the main point is whether the recorder is reliable, properly read out, and provides a record of the particular event in question. The data of itself is not dispositive of liability, but merely serves as certain evidence of the event. As indicated earlier in this report, there is good correlation between crash severity a recorder might measure and the extent of crash deformation to the vehicle in which it was installed; and it would be difficult to refuse evidence on the crash severity magnitude as interpreted from vehicle deformation. Thus if the recorder provides good evidence of the event, it seems appropriate that the evidence should be admitted. It may be possible to restrict through legislation the admissibility of crash recorder evidence, particularly if the recorders are government-owned and the records are retrieved and interpreted by government employees. Consider, however, the objective of a very simple and widely used integrating accelerometer that is conveniently and readily read by any police accident investigator without special training. It would appear difficult to prevent testimony by a layman – say a tow-truck operator or an auto mechanic—as to what he saw immediately after the accident. In summary, we believe that (1) the data from a crash recorder would be admissible, if it meets necessary qualifications, in a court of law; 2) the data should be admitted if it is good evidence; (3) it will be difficult to prevent admitting crash recorder data, even by Federal law, if the record can be easily read by an untrained person…"

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[9] Underwriters' Report : Wire Report at http://www.uwreport.com/wire/news1296/1212aut.htm

[10] Office of Technology Assessment. Washington, DC. 1975. *Automobile Collision Data: An Assessment of Needs and Methods of Acquisition*

RESPECT FOR OWNERSHIP OF THE DATA

Privacy is the most important issue regarding the success or failure of implementing the SB/EDR. In a position paper presented to the NHTSA EDR Working Group entitled *Information Privacy Principles for Event Data Recorder (EDR's) Technologies* (Kowalick) 1998 noted individual motorists or others within motor vehicles have an explicit right to privacy. Although this right to privacy is not explicitly granted in the Constitution, it has been recognized that individual privacy is a basic prerequisite for the functioning of a democratic society. Indeed an individual's sense of freedom and identity depends a great deal on governmental respect for privacy. Therefore all efforts associated with introducing future EDR technologies must recognize and respect the individuals interests in privacy and information use. Thus, it is imperative to respect the individual's expectation of privacy and the opportunity to express choice. This requires disclosure and the opportunity for individuals to express choice, especially in regards to after-market products. OEM EDR technology limits an individual's expression of both privacy and choice. After-market value added EDR products permit free market competition and sense of ownership. Several stand-alone after market technologies can easily be combined to produce an after-market EDR virtually independent of the vehicle architecture thereby readily permitting a common standard for retrofitting to a vehicle fleet. Since individuals will operate and occupy vehicles equipped with EDR's that record data elements, subsequently it follows that information is created regarding both individuals and vehicles. Individuals should have the means of discovering how the data flows. A visible means of the type of data collected, how it is collected, what its uses are, and how it will be distributed is basic to consumer acceptance. Consumers should also have a choice in making this data available for post-crash analysis. Numerous studies cite the number one central concern of the public as understanding the reason they are being subjected to technology up-front, candidly and directly. Responsibility for disclosure should be high priority and may be achieved through methodologies via print-material formats, etc. Disclosure must be constant and consistent. Any data collected via EDR technologies should comply with state and federal laws governing privacy and information use. All data collected and stored should make use of data security technology and audit procedures appropriate to the sensitivity of the information. EDR technology data storage should include protocols that call for the purging of individual identifier information respectful of the individual's interest in privacy. Information collected should be relevant to the purpose and mission statement associated with the EDR disclosure statement. Consumers should have the reasonable assumption that they will not be ambushed by information they are providing. Information derived from EDR technologies absent personal identifiers may be used for other purposes clearly stated in the disclosure statement. Information including personal identifiers may be permissible if individuals receive effective disclosure and have a friendly means of opting out. Personal information should only be provided to organizations that agree to abide by the privacy principles stipulated in the disclosure statement. Should the EDR technologies be maintained in a government database Federal and State freedom of Information Act (FOIA) obligations require disclosure. Such databases should balance the individual's interest in privacy and the public's right to know. Permanent or temporary storage of data should preclude the possibility of identifying or tracking either individual citizens or private firms and should follow the principles suggested to the EDR Working group. A position paper presented at the Second World Congress of Intelligent Transport Systems (1995 Yokohama) entitled *Positioning Systems and Privacy* by C.R. Drane and C.A. Scott cites, "…We put forward for discussion a stronger version of the respect for ownership principle. The stronger version holds that the driver puts time, energy, and money into moving along the road network. Accordingly, the driver has ownership of the trajectory of this movement…The idea that movement data is owned by the person who exerts effort in generating the data is a rather abstract concept." A paper presented to the NHTSA EDR Working Group entitled *Privacy Concerns for the National Highway Traffic Safety Administration* by Sharon Y. Vaughn (NHTSA/OCC) concludes: "Following the same procedures that NHTSA implements with respect to operating the NASS, SCI and FARS programs, NHTSA would require a release from the owner of the vehicle in order to gain access to the data from an EDR. NHTSA would assure the owner of the vehicle that all personal information would be withheld from disclosure."

SOLUTION TO THE ISSUE OF WHO OWNS THE DATA

There are many problems and concerns connected with the question of ownership of the EDR and the data that is generated. It has been argued that vehicles are sold to consumers without any vestigial interests retained by manufacturers and thus the vehicle owner would presumably own the data as well. If this is true then the ability of public authorities to access the data is greatly reduced and may be impossible since the owner can withhold the data if they felt it would not serve self-interest. Another problem results when a supplier rather than a motor vehicle manufacturer retains ownership of the data and controls access by utilizing proprietary protocols that essentially prevent anyone else from accessing the data. However, suppliers may report the result of the data extraction. It has been suggested that these problems might be overcome if the manufacturer retained ownership or if an agreement allowing access to the data could be arranged with the owner of the vehicle. The complexity of these solutions would hamper implementation of a SB/EDR system. The simple solution is to design a system that transmits the data from the vehicle to a secure archive for post-crash analysis. By transmitting data through a secure encrypted digital cell link to an archive problems associated with permission from the owner and access to the vehicle are overcome. A simple release from the owner when the vehicle is registered is all that is legally required. Positive incentives for the owner could include reduced registration fees and a disclaimer that personal identifiers will not be collected and privacy will be preserved. An example reads:

THIS VEHICLE CONTAINS A SYSTEM TO TRANSMIT CRASH DATA ELEMENTS TO A SECURE ARCHIVE FOR POST-CRASH ANALYSIS. THE OWNER OF THIS VEHICLE MAY ACCESS THE DATA.

The infrastructure for such a system currently exists. The U.S. is linked with wireless cells (cell sectors) for cell phone communications. Cellular telephones are actually in operation more than most users think (if the phone is turned on, but not actually being used). To monitor the state of the network and be able to respond quickly when calls are made, the main cellular controlling switch periodically "pings" all cellular telephones. This pinging lets the switch know what users are in the area and where in the network the telephone is located. This information is used to give location. See *Wireless Technologies and the National Information Infrastructure* (see OTA –ITC-622). The Office of Technology Assessment has done several studies of aspects of telecommunications privacy and security. See U.S. Congress, Office of Technology *Assessment Security and Privacy in Network Environments*, OTA-TCT-606 (Washington, DC: U.S. Government Printing Office, September 1994). The next millennium will see a marriage between cell phone technologies and GPS location technologies. Inexpensive single chip embedded receivers are currently used in cell telephones. It would be feasible and practical to combine these emerging technologies to create a low cost SB-EDR. Another benefit of transmitting crash data is that it simplified the process of storing data and responding to requests for information. It also enables the U.S. Government to collect and store a large volume of crash data that can be accessed through chain-of-custody agreements for research. There are many emerging technologies that permit transfer of high-speed data. Basically, the point here is that when a vehicle crashes it collects data elements such as location, time, velocity, direction, number of occupants, seat belt usage, etc., and then stores these for extraction either via wireless Infrared or wireless RF. A wireless IR extraction can be utilized on-site without entering a vehicle if the on-board SB-EDR is located in the vicinity of the rearview mirror / front windshield.

RECENT DISSERTATION CITING A SHORT HISTORY OF EDR INITIATIVES

A recent dissertation provides a review of the worldwide initiatives to implement EDR's. Entitled "*Validity and Reliability of Vehicle Collision Data: Crash Pulse Recorders for Impact Severity and Injury Risk Assessments in Real-Life Frontal Impacts*" it was written by Andres Kullgren as a thesis for a degree of Doctor in Medical Sciences, Department of Clinical Neuroscience, Section for Personal Injury Prevention, Karolinska Institute, Stockholm, Sweden in December of 1999. Included within is a section that details a short history of crash recorder techniques (p14-15). The dissertation cites verbatim, "To be able to use adequate impact severity parameters and thus increase the accuracy of the impact severity; calculations in studies with traditional retrospective accident reconstruction techniques should be complemented by severity measurements recorded by on-board measurement devices. Several attempts to do this have already been introduced as described below. The first attempt to measure acceleration time history in real-life impacts with the aim of increasing the accuracy of impact severity measurements was carried out in 1971, when NHTSA started a project called Disc recorder Pilot Project (Hackbarth 1972), where 1050 crash recorders were installed in a fleet of vehicles in the U.S. In 1974 Teel et al (1974) presented results from recordings of 23 real-life impacts. The Disc Recorder measured acceleration in three dimensions in the crash phase with accelerometers based on a spring-mass-system, where the movements of the mass in the impact were recorded. The mass displacements were recorded on a rotating magnetic disc. The measurement range was +-50g, the accuracy was =-8 and the threshold was +-5g. In 1972 the U.S. Department of Transport started a project where a simple and low cost crash recorder was developed (Hudson 1972). Acceleration measurements in the impact phase were based on a photographic film by a light-emitting diode. The light from the diode was reflected in a mirror located on the mass, and then recorded on the film. A prototype of a crash recorder was built and tested, but with disappointing results. The measurement accuracy of the acceleration levels was too low. In 1979, on request from NHTSA, Sherwin and Kerr presented a new crash recorder, where longitudinal and lateral accelerations were measured with a range of +- and with an accuracy of +-8%. This recorder was purely electronic with no moving mechanical parts. The accelerations were measured with piezo-electrical sensors during 0.512 seconds, with a sampling rate of 500Hz and with a frequency response of 80 Hz. The cost per unit was in 1979 calculated to be approximately 50 USD. These recorders, and other simple and relatively inexpensive crash recorders presented before 1980, have been listed and analyzed by Meinton and Smith (1980). Since 1980 several other crash recorders for measuring the acceleration time history have been presented, see Wilkie et al (1989), Salomonsson and Kock (1991), Fincham et al. (1991), Barth et. Al (1994), Kullgren et al. (1995). And Norin (1995). The crash recorder by Wilkie et al. (1989) was intended for recording longitudinal and lateral accelerations and impact speeds. This electronic crash recorder measured acceleration with a sensor using piezoelectric film. In 1989, the cost per unit was calculated to be below 140 USD. One prototype was built and tested. The DRACO recorder proposed by Finchman et al. (1991) and the UDS recorder presented by Salomonsson and Kock (1991) and Barth et al. (1994) were intended to be used also for legal purposes. They can measure many parameters in the pre-crash, crash and post-crash phases. Accelerations and rotational accelerations in three dimensions are measured in the crash phase with a sampling frequency of 500Hz. 25 UDS recorders were fitted in police cars in London as a part of a wider study of vehicle recorders and driver behavior carried out by the European Union's DRIVE initiative on information technology applied to road transport (Fincham 1995). The UDS has been installed in a large fleet of vehicles but the accident information has not yet been presented or used in research projects. The crash recorder from the Swedish insurance company FOLKSAM measures the acceleration time history in one direction with a sampling frequency of 1000 Hz and with a threshold of approximately 2g. The measurements are based on recordings of the movements of a mass in a spring-mass-system in the impact phase. The recordings are done on a photographic film by means of a light emitting diode located on the mass. In 1995 the cost per unit was approximately 5 USD. The crash recorder used by Volvo (DARR) and presented by Norin (1995), records the signal from the airbag sensor for 105 ms with a sampling frequency of 600 Hz, and is activated when the airbag is deployed. A later version of the DARR measures the acceleration for 167 ms but with a lower sampling frequency (Broden and Olsson 1996). In validation tests the standard deviation of ∇V measurements has been found to be 1.1 km/h (2.5%) (Broden and Olsson 1996). Less costly crash recorders have been proposed by Warner et al. (1974) and Aldman and Tingvall (1987): the former measuring the change of velocity in two directions and the latter for measuring an impact severity parameter related to the change of velocity during part of the impact phase.

OTA ASSESSMENT

The Office of Technology Assessment (Washington, DC) issued a report in February of 1975 entitled "*Automobile Collision Data: An Assessment of Needs and Methods of Acquisition.*" The study was requested as an evaluation of the automotive crash recorder program proposed by the National Highway Traffic Safety Administration (NHTSA). Although this assessment is dated a close reading will reveal that many of the problems and concerns expressed within are still relevant. The assessment addressed the following issues:

- How much is NHTSA spending to gather accident data?
- Is that data sufficient, or is further data on the characteristics of automobile collision necessary for effective NHTSA standards setting?
- An evaluation of the type of data being produced by existing crash recorders and an explanation of how this data is being used by NHTSA.
- If a database is inadequated, how might an adequate database be obtained and what are the consequences associated with obtaining the data in different ways?
- What are the legal questions associated with the existence of actual physical data from an accident?

The final report divided into the following areas:

- The Need for More and Better Crash Data
- Characteristics of an Adequate data Collection Program
- Alternatives for Adequate Data Collection Program
- Federal Responsibility and Expenditures for Collision Data Gathering

Premises specific to crash data analysis in 1999 are:

- The conclusion that the current national accident database is inadequate to resolve the uncertainties in NHTSA's current and proposed motor vehicle safety programs.
- The major deficiency in data relating collision forces and actual fatalities and injuries.
- That a comprehensive accident data program must be designed with great care that is representative and avoid inherent biases to answer outstanding critical safety questions and provide uniformity in reporting and format.
- That the federal Government, not States, manufacturers or insurance companies, should support the central data collection activities whereby this is a national problem and that Motor Vehicle Safety Standards are promulgated by the federal government.
- Crash recorders provide data that may be admissible in a court of law.

AIR BAGS

The introduction of air bags has not solved the problems associated with occupant protection. Air bags have been installed in millions of cars and light trucks. As of the end of the model year 1996, driver air bags had been installed in over 56,000,000 vehicles and passenger air bags in over 27,000,000 vehicles. When occupants properly use seatbelts, air bags increase the chances of survival in severe frontal crashes. But air bags may pose dangers for some occupants in certain situations. About 35 million cars currently on the road are equipped with passenger-side air bags and each month approximately one million new cars equipped with air bags are manufactured. Between 1993 and mid-1998, 61 children died because they were struck by an air bag in what would otherwise have been a survivable crash. These occupants were in the danger zone when the air bag inflated. Forty-four adults were also killed by their air bags in crashes they could have survived. In 1996, the Safety Board completed a study on the performance and use of child restraint systems, seatbelts, and air bags for children in passenger vehicles. The study analyzed data from 120 crashes that occurred between 1994 and 1996. Vehicle occupants included 207 children under age 11. Of the 120 accidents, air bags deployed in 13 accidents in which a child was seated in the front passenger seat. The study focused on the dangers that passengers-side air bag pose to children; factors affecting injury severity; adequacy of federal standards regarding the design and installation of child restraint systems; need to improve seatbelt fit for children; adequacy of public information and education on child passenger protection; and adequacy of state child restraint use laws. The Safety Board also convened a public forum in March 1997 to discuss concerns related to the effectiveness of air bags and ways to increase seatbelt and child restraint use. Other issues discussed included air bag-induced injuries; role of air bags as a primary or secondary restraint system; deployment thresholds; complexity of implementing depowered air bags; switches, and suppression devices; advanced air bag technology; experience with air bags in other countries; evaluating the effectiveness of air bags; enforcement of restraint laws; design of child-friendly seats; and design of child restraints.

THE SEAT BELT EVENT DATA RECORDER (EDR) SYSTEM WOULD CONSTITUTE ONE OF THE MOST POWERFUL AND COST-EFFECTIVE AUTO SAFETY DEVICES EVER CONCEIVED.

A device combining occupant sensing technologies to encourage and monitor seat belt usage within an Event Data Recorder (EDR) is what is required to produce a large change in United States and worldwide auto fatalities. Such a device would do so by achieving something that has eluded motorists to date-- the widespread use of seat belts twenty-four hours a day. There is no question that if seat belts were used twenty-four hours a day, then there would be a substantial reduction in the number of fatalities and serious injuries. The insurance industry, health professionals, Law enforcement and the civil and criminal courts would applaud such a scenario. Paradoxically, the need to further reduce auto fatalities comes at a time when the United States mileage death rate is already at an all time low--the lowest in the world. Yet, the actual death rate is still considered a very unacceptable number. Worldwide, only one country, Sweden has an initiative to reduce traffic fatalities to zero. If a comprehensive Event Data Recorder (EDR) incorporating occupant sensing and restraint usage data elements is adapted and utilized then the mileage death rate will decrease even lower. A major, rapid shift in fatality trends will occur. Three times over the years fatalities have increased by 5,000 or more deaths in a relatively short time, and, conversely, four times deaths have fallen by 7,000 or more in a short time. B.J.Campbell [11] notes, "It is interesting to speculate on the reasons for these massive changes. By the 1930's automobile accidents were already a considerable problem in the United States, and by 1937 deaths reached 39,643. The death rate per hundred million miles was more than five times greater than in 1986 (14.68 vs. 2.58). There was a large decrease (-7000) in 1937-38, seemingly not related to changes in exposure, for the mileage exposure before and after the decrease appears to have stayed virtually the same. This change is puzzling since it happened more or less in the middle of the Great Depression. On the other hand, it appears more likely that the up swing in deaths just before WW II reflects the economic expansion on the eve of the war with a consequent increase in exposure. There was an increase of 10% in mileage during the same period, but fatalities went up even more (up 5,000). The largest downswing in our nation's history, a decrease of 16,000 lives over a single year period, happened early in WW II, when mileage exposure dropped by more than one third. Gas rationing, tire rationing, a 35-mph speed limit, and millions of young men in armed services and off the highways all coincided with this period; all these factors presumably contributed. Actually, fatalities per unit exposure were about the same, as earlier, thus this improvement appears to have been almost entirely exposure driven. After the war, there was an increase of 9,000 traffic fatalities within two years at the time of de-mobilization. The reduced mileage exposure seen during the war was reduced. As with the previous large decline, the increase in fatalities was largely exposure driven, but fatalities actually increased somewhat less than exposure would have indicated, suggesting the simultaneous influence of other factors. The next upswing was very large, though spread over a longer period--an increase of nearly 15,000 in fatalities from 1961 to 1966. In 1961, the actual number of deaths in the U.S. was 38,091, fewer than the 39,643 recorded 24 years earlier in 1937. Thus, despite the growth in population and cars from the 1930;s to 1961, the death rate per hundred million miles had fallen so much that the raw number of fatalities remained relatively constant. Within the next five years, however, the rate soared such that in 1966 the

[11] Campbell, B.J., et al, *Seat Belt Law Experience in Four Foreign Countries Compared to the United States*, B.J. Campbell, & Frances A. Campbell, University of North Carolina, December 1986.

raw number of deaths was 53,041.This rate is described by two phenomena: first, a great increase in cars and mileage exposure, and second, by a plateau in the improvement in mileage death rate. For approximately nine years the mileage death rate did not fall. In 1961, the death rate per hundred million vehicle miles was 5.16. In 1969, it was 5.21. This long-term stagnation in the death rate was unique to that point in history--a time when car ownership was soaring, speed limits were high, and powerful cars were a central fact of car marketing and owner preference. It was probably no coincidence that during this period calls for an increased Federal role in highway safety were growing more urgent, finally culminating in the activation of the National Highway Safety Board in 1967. The downswing in 1973-75 reflected a combination of the oil embargo, the related severe recession, and the 55-mph speed limit enacted in response. In that time, deaths dropped by about 9,000 despite the fact that exposure did not decrease proportionately. Likewise, during the recession of 1981-83, a drop in fatalities of 9,000 occurred though exposure remained much the same."

The point of the forgoing is that the occasional very large changes in United States highway fatalities have been "powered" by major societal forces--wars, recessions, or periods of great economic growth." B.J. Campbell and Francis A. Campbell come to the conclusion that *"It has not yet been possible to produce fatality changes of comparable magnitude by imposition of any specific highway safety countermeasure."* They are absolutely correct. The historical record confirms their beliefs.

TIME FOR A NEW IDEA TO PROMOTE SEAT BELT USAGE

Thus, the time has come for a new impetus, a new idea. It is time to reward the motorist for seat belt usage by positive incentives. An EDR tied to seat belt usage would make this possible. This would be a new innovation in auto safety with great potential towards reducing injuries and fatalities. Once available to motorists worldwide this device will provide the specific highway safety countermeasure required assuring that motorists are adequately protected. It is feasible to forecast a dramatic reduction in United States traffic fatalities due to the fact that motorists' will be reminded when the seat belts are engaged. Externally the existing and future-pending seat belt laws can now be adequately enforced twenty-four hours a day--all year long. This would help to achieve a major goal of the NTSB that of getting the states to pass and enforce primary seat belt laws. A conservative forecast is that approximately 10,000-20,000 fatalities can be avoided within one year of implementation nationwide and perhaps a quarter million motorists injuries worldwide can be prevented. This device has the potential of literally saving millions and millions of motorists as we enter the 21st Century. An EDR system tied to seat belt usage has tremendous value for society. This idea for a SB-EDR can be reduced to a tangible form. Perhaps, the simplest way to determine is such a device would be an asset to society is to observe motorists--any where and at any time. Ask yourself how many of these motorists are actually wearing seat belts and how you know this to be true? Observe the various traffic flows, the ever changing lighting and visibility conditions and the seeminglessly endless number of motorists who for whatever reason fail to buckle-up. Remind yourself that seatbelts have been around for a long time, that they do save lives, and yet that for odds-and-ends reasons motorists avoid them. Doesn't it make sense to install an economical, carefree, user-friendly safety device to eliminate all the odds-and-ends excuses of non-usage and make everyone's highway safer? By promoting usage of the Seat Belt Event Data Recorder (SB-EDR) System through positive incentives such as a reduction in automobile insurance and a nationwide uniform and reduced penalty for motor vehicle violations, the SB-EDR device would make the world motorways safer and save thousands of lives.

DESCRIPTION OF THE TECHNOLOGY

Reduced to a tangible form the SB-EDR is a system to:

- Record, in real time, seat belt usage, vehicle speed, trip duration, and direction of travel using Global Positioning System (GPS) technology;
- Detect seat belt usage using infrared (IR) technology, making it difficult or impossible for the driver or vehicle occupants to fool the seat belt usage detection system; and
- Display lights indicating seat belt usage through the front and/or rear windshield from the location of the rearview mirror.

The SB-EDR system consists of the following basic components:

- IR seat belt detection system;
- Seat belt usage display system;
- Data recording system;
- Data transfer via wireless IR or RF

The IR seat belt usage detection system consists of a wide-angle IR emitter, retroreflective material on the seat and seat belt webbing, and a wide-angle IR detector. Mounted in the rearview mirror assembly, the emitter continually irradiates the seat area with a wide beam of infrared radiation whenever the vehicle is on. IR retroreflectors on the seats and/or seat belt webbing reflect some radiation back to the wide-angle IR detector, which is mounted next to the emitter. The detector determines if the seat is occupied and if the seat belt is in use by calculating the proper angles expected to be reflected back to the detector. Additional detection systems can be mounted on the ceiling to monitor seat belt usage in the rear seats. The display system consists of forward and/or rearward indicator lights that are illuminated when the system concludes that all mounted occupants are using seat belts. The forward light, preferably blue neon, is mounted flush against the windshield and intensity-adjusted by coupling it with a photovoltaic cell. The rearward indicator light, preferably a red laser or light-emitting diode, is mounted adjacent to the rearview mirror. An illuminated forward light indicates proper seat belt use, while the rearward light indicates at least one seat belt that is not in proper use. An override button could be provided to turn off the rear indicator light to avoid alerting others, including law enforcement personnel, that the seats are not in proper use. Although the indicator may be turned off, the system continues to monitor and record seat belt usage. Occupants will be reminded to buckle up as they see the oncoming cars' seat belt indicator lights. Furthermore, it is anticipated that when the SB-EDR system is widely implemented, oncoming drivers will flash their headlights to remind forgetful occupants to fasten their seat belts. The data recording system consists of GPS circuitry, a microprocessor, and a removable memory module that contains "at least one Meg" of encodable, erasable, programmable memory. The microprocessor controls the IR seat belt usage detection and display systems and receives and records data. Four GPS antennae receive satellite signals—two antennae mount the system housing to the windshield and two house interfaces. GPS circuitry provides the microprocessor with vehicle velocity, longitude, latitude, travel duration, direction, and time information. This information as well as data on occupant seating, seat belt use, and override button are stored in memory. Law enforcement may remove the memory unit for use during crash investigation. The memory unit may be secured with a special lock accessible only to appropriate personnel to prevent tampering with the crucial data for determining liability. The system housing would be ruggedized to survive vehicle crash. Another functionality is the ability to transmit stored data elements to a secure archive by utilizing digital wireless IR transfer or wireless RF transfer.

The seat belt monitoring system would be implemented in partnership with insurance companies, who will benefit in several ways. By increasing seat belt usage, the system decreases the costs associated with vehicle crashes. By providing information on occupancy and travel direction/speed/duration, the system may reduce the costs associated with insurance fraud. Insurance companies may be able to reduce costs by denying claims when the system indicates that an occupant was not wearing a seat belt at the time of the crash. Law enforcement would also benefit because the system enables easier identification of seat belt infractions. The judicial system would benefit from having additional data on which to base decisions.

CONCEPT OF THE SB/EDR SYSTEM COUNTER MEASURE

The objective of the SB-EDR System is to increase seat belt usage worldwide within the six hundred and ninety million vehicles on the planet earth by getting people to willfully wear seat belts. The SB-EDR is essentially a real-time vehicle event data recorder similar in concept to a flight recorder utilized in air travel. The device consists of passive safety apparatus that will display an interior and exterior visual signal that indicates whether seat belts are being used. This interior/exterior visual signal (telltale light) will be seen by the motorist and also by traffic. On interstate highways a motorist may face hundreds of cars for each mile traveled. This unique light source will become an icon for vehicle occupant safety. This visual signal will serve to advise others to buckle up, much in the same manner, as when other motorists turn on their headlights, eventually all motorists do. Oncoming traffic flow varies from 1 to 200 vehicles per mile. Each vehicle would serve to advise and remind motorists to buckle-up. Once, one motorist notices that the other motorists have engaged their seat belts, perhaps, he/she will engage seat belts. This would have to be a completely voluntary act, not subject to fine or punishment. The major inducement to buckle up would occur from the reminder of others who have done so, and through positive incentives for doing so. Positive incentives will encourage motorists to buckle-up. Currently, there are no positive incentives to have motorists buckle-up other than the message that seat belts save lives and reduce injuries. Although this message is rather common sense it has been ineffective and usage rates have not reached potential level.

Positive incentives would include reduced automobile insurance rates endorsed by such organizations as Private Citizen and The Insurance Institute for Highway Safety. Private Citizen is a coalition of consumer, health, safety, law enforcement and insurance companies, organizations and agents working together to support the adoption of laws and programs to reduce deaths and injuries on our highways. The Insurance Institute for Highway Safety is an independent, nonprofit, scientific and educational organization. It is dedicated to reducing the losses--deaths, injuries, and property damage--resulting from crashes on the nation's highways. Another initiative for encouraging positive incentives for seat belt usage would be a nationwide reduction in motor vehicle violation fines for those motorists who were cited and who happened to be buckled-up. The motorist would be rewarded, not penalized and would thus willfully wear seat belts which is the overall objective of the SB-EDR.

Motorists' usage of seat belts would increase thereby saving lives and reducing injury and related medical costs. Highway travel would become safer. This device would receive support, approval, and endorsement of all. The device could be installed as a simple after-market retrofit verifiable within the states that enforce the annual inspection of vehicles. Usage of this device would provide added protection and reduced insurance rates for motorists. Theoretically, seat belt usage will increase worldwide, and the nations' highways would become safer. Motorists will be aware of when they have engaged seat belts and motorists nationwide, during daylight and evening hours, will be constantly reminded to buckle up without law enforcement intervening. Law enforcement would be greatly aided in the responsibility of enforcing seat belt laws in those states that choose to penalize non-usage rather than reward usage. The SB-EDR device would also permit monitoring of seat belt usage at night, during a time when a large percentage of accidents occur. To date, it has been impractical, if not impossible to either monitor usage or enforce the primary seat belt laws at night. Such a device could be installed in the general location of the windshield mirror in such a manner that it would not interfere with vision or conveyances. It could emit a light signal inside the vehicle that would also be visible to rear traffic, and simultaneously emit a visual signal that would be noticeable to on-coming traffic.

HOW THE SB-EDR WORKS

When the automobile is parked and the ignition is turned-off the SB-EDR is non-operational. When the driver enters the vehicle and is seated behind the steering wheel, and when he/she starts the ignition the SB-EDR becomes operational. The SB-EDR becomes operational when the automobile is started and electrical power reaches the unit. A small, LED light emits a red signal from the unit located within the rearview mirror housing that is clearly visible to the motorist and other occupants of the vehicle. At this point, any and all audio or visual reminders or warning devices to buckle-up, which were initially designed by the manufacturer within the vehicle, will be engaged as usual. Thus, at this point the driver has the choice or buckling the seat belt as required by law or not buckling-up before driving the vehicle. If the driver chose to engage the seat belt then an interior reminder light, located near the mirror on the windshield will turn-off. Simultaneously, a second exterior light, emitting a stable blue neon light, located in the same vicinity, but radiating outward toward the front of the vehicle in the direction of on-coming traffic flow will be lit. But, if the driver intentionally chose not to engage the seat belt or unintentionally forget to do so, then the initial interior red light would continue to stay lit as a constant reminder to buckle-up. Should the light become a constant irritant to the driver or passengers they have the option of turning it off by a lit push switch. This option preserves privacy and prevents any abuse of civil liberties or self-incrimination. However, the decision to by-pass buckling-up will be recorded on the microprocessor for future post-crash analysis. Simultaneously, at the point where the SB-EDR becomes operational it begins to receive a data signal from a series of Global Positioning System satellites (GPS). The GPS is a constellation of 24 satellites operated by the Department of Defense, providing travelers with a constant fix on their location. Thus, it is possible to provide the following data time, position in longitude and latitude, velocity, direction, and seat belts engaged on disengaged.

Once the vehicle moves the SB-EDR will continue to monitor and begins to record real time data. This real time data is recorded on a microprocessor attached to the GPS unit. While the vehicle is moving the following real-time data cited above is being monitored. Seat-belt usage is monitored via an infrared light transmitter and detector and recorded in real time data. The SB-EDR is self-contained in a small compact unit that is capable of surviving a crash. It is reliable, tamper-proof, environmentally suitable, maintenance free, and is designed to record real time data for analysis before, during, or after usage of the vehicle. This real time data would be invaluable following a collision or crash. The data could be retrieved on-site by IR extraction without entering the vehicle. Or, accessing a secure archive where it was forwarded via a cell link transmission could retrieve the data. Either way the data is secure and encrypted in digital format. Under normal operational conditions (other than a crash or collision) once the vehicle is stopped and the ignition is turned-off the SB-EDR becomes non-operational. The driver has the option to erase the data stored in the microprocessor by pushing an erase button. If the data is not erased it will be saved. This functionality further preserves civil liberties, protects privacy and eliminates self-incrimination, etc. Finally, if the driver or occupants disengage seat belts during normal operation of the vehicle then the SB-EDR would stop emitting the forward lighting and begin emitting the interior lighting which designated that seat belts are disengaged. This feature would help parents keep young children properly in position throughout the trip and especially at the time of a crash or collision.

ENDORSEMENTS

A SB-EDR encouraging seat belt usage would receive endorsement from the following:

- NTSB & NHTSA interested in achieving nationwide seat belt usage and finding it very difficult to convince the state legislatures to pass primary seat belt laws.
- State legislatures interested in passing and enforcing primary seat belt laws. Prior to incorporation of such a device there was no accurate accountability, especially after dark when ½ of all accidents occur.
- State legislatures interested in enforcing time curfew for teen age drivers to reduce fatality rates. As example, North Carolina has a graduated license system that prohibits teen-age drivers from driving after 9:00 p.m.
- Automobile Insurance Industry which is harassed by insurance fraud. There is a growing trend in America in the area of staged accidents that result in enormous medical claims and increased insurance costs for everyone.
- Legal profession connected with accident reconstruction and liability claims.
- The medical professions connected with Emergency Medical Services (EMS, EMT) etc.
- Auto manufacturers interested in safer vehicle occupant protection.
- Automobile, truck and trailer rental, and leasing companies.
- Vehicle fleets such as FedEx & UPS, etc.
- Consumer and advocacy groups interested in automobile safety.
- Law enforcement community.
- Professional societies.
- Public Health and Injury Control Organizations/Associations.
- State Highway Safety Offices

Last but not least—The American public, which is paying for auto insurance and suffering too much from traffic injuries and fatalities.

RECOMMENDATION: INTRODUCE THE SB-EDR AS A FMVSS

Clearly, if seat belts were used thousands of lives would be saved, as would billions of dollars of social and economic costs of these collisions. And yet, seat belts are not adequately used. An Event Data Recorder (EDR) incorporating and combining occupant sensing and restraint usage as data elements will correct this problem. Such a device could be introduced to vehicles in a manner similar to the Center High-Mounted Stop Lights. As early as 1975, the Safety Board recommended that automobile brake lights be mounted high enough to separate the function of brake lights from tail lights so that a following driver could see the lights of at least two vehicles directly ahead. Center high-mounted stop lights have been required on all new passenger cars sold in the United States since the 1986 model year and all new light trucks since the 1994 model year.

In March 1998, NHTSA issued a report on their effectiveness. The study concluded that center brake lights prevent 92,000 to 137,000 police-reported crashes, 58,000 to 70,000 nonfatal injuries, and $655 million in property damage a year. It also estimates that the lamps save $3.18 in property damage for every dollar they cost. The point here is that this safety device has been extremely effective because it was introduced nationwide via a Federal Motor Vehicle Highway Safety Standard. It is the strong suggestion and recommendation that SB-EDR's be introduced in a similar fashion. If these EDR's include a module for encouraging, monitoring, and recording seat belt usage then this initiative will greatly improve seat belt usage rates nationwide. It will also be possible to increase and monitor seat belt usage twenty-four hours a day globally.

VALUE OF THE SYSTEM

- Encourage seat belt usage and provide monitoring and accountability at all times of day and night worldwide.
- Increase nationwide seat belt usage by positive incentives and consumer acceptance.
- Permit agencies and manufactures to analyze crashes and collisions with real time data similar to those utilized in Aviation as in-flight recorders.
- Provide insurance companies with required accountability to rebate motorists who utilize this passive auto safety apparatus to enhance vehicle occupant safety.

RAMIFICATIONS AND SCOPE

- Accordingly, the SB-EDR will increase the number of motorists that will use seat belts from the approximate sixty-eight percent at present. 37,221 fatal motor vehicles crashes occurred in the United States in 1995 and 41,789 deaths occurred in these crashes--up from 40,676 deaths in 36,223 crashes in 1994. From 1994 to 1995 motor-vehicle deaths increased three percent, thus there were 43,900 deaths, 2,300,000 disabling injuries and a cost of $170.6 billion dollars to society. The 1996 statistics reflect 43,330 deaths associated with motor vehicles and a cost to society of 176.1 billion dollars.

- ❖ The SB-EDR System will support and encourage State Legislatures to pass and enforce primary seat belt laws by providing real time accountability with a simple, efficient, non-obtrusive method of determining which motorists are wearing seat belts. Currently, belt use laws in only 12 jurisdictions (California, Connecticut, Georgia, Hawaii, Iowa, Louisiana, Maryland, New Mexico, North Carolina, Oregon, and Texas) are "primary," meaning police that may stop vehicles solely for seat belt violations.

- ❖ The SB-EDR System will encourage seat belt usage during nighttime hours when many accidents occur in which occupants are not wearing seat belts. Prior to this system, it was not feasible to encourage use of or enforce the seat belt laws after dark. About half of all motor-vehicle deaths occur during the day and thus the other half occur at night.

- ❖ The SB-EDR System will decrease the number of serious injuries and fatalities in traffic accidents associated with not wearing seat belts. The estimated motor-vehicle accident costs reported in *Accident Facts* (1995) cite comprehensive costs in 1994 on a per person basis as $2,890,00 (death), $193,000 (incapacitating injury), $44,000 (non-incapacitating evident injury), $23,000 (possible injury) and $2,600 (no injury). Disabling injuries in motor-vehicle accidents totaled $2,100,000 in 1994, and total motor-vehicle costs were estimated at $176.5 million.

- ❖ The SB-EDR System will provide a visible reminder and motivation seen by millions of motorists thousands of times throughout the day and night. It will become a national icon--a symbol of auto safety. It will reinforce the habit of wearing seat belts amongst adults and will encourage young children and future motorists of the inherent value of wearing seat belts.

- ❖ The SB-EDR System will provide new impetus and added opportunities to local, state, national, and international organizations to promote highway safety and especially seat belt usage. The SB-EDR System would permit the possibilities of providing positive incentives to motorists who use seat belts by encouraging insurance companies to offer reduced automobile insurance rates due to the reduction in medical claims and to permit Legislatures to reduce traffic citation fines. These common sense, doable, positive initiatives combined with the utilization of the system will promote and improve highway safety.

- ❖ The SB-EDR System would provide a means whereby law enforcement agencies and insurance companies could verify if the motorists and other occupants of the motor-vehicle had seat belts engaged or disengaged at the time of the traffic accident. To date, no such method exists. Such data would be extremely useful in deterring hazardous locations, and reducing accident fraud.

- ❖ This system will do something that has not yet been possible: To produce fatality changes of comparable magnitude by imposition of a highway safety countermeasure. The SB-EDR System would achieve this goal if the National Highway Traffic Safety Administration (NHTSA) designated the device a Federal Motor Vehicle Safety Standard. It is recommended that this transpires in a manner similar to when the NHTSA amended Safety Standard No. 103 which thereby required all vehicles to utilize a single-center, high-mounted stoplamp on passenger cars, in addition to the stoplamps presently required. The system would serve as the missing link in the long history of auto safety devices and will enhance all existing devices thereby promoting the general welfare of motorists.

CONCLUSIONS

Unconventional ideas are likeliest to pop up in dis-establishment places. This paper is a classic example of a genuinely good idea expressed by a concerned independent researcher with a vision for "unlimited impossibilities" towards improving occupant safety. Few technical papers possess the power to leave the reader with that feeling of awareness that we call a sense of revelation. This is one of those papers. In this brief work a series of insights and perceptions provide compelling rationale to the objective of improving occupant safety via combining emerging technologies. The overall paper expresses social conscience based on human need. The 20th Century will be remembered as a time of tremendous technological advancements. It will also be recalled as the time when moral barriers were crossed permitting endless carnage on the highways of the world. Perhaps historians will refer to this period in transportation history as an "autocaust" and if so, the time has come to reverse this trend. Implementation of the safety counter measure (SB-EDR) identified in this paper will result in increased nationwide seat belt usage and improve vehicle transportation safety.

REFERENCES

1. American Civil Liberties Union (ACLU). (1999). Washington, DC. *Legislative Briefing Kit on Electronic Monitoring* at http://www.aclu.org/library/pbr2.html
2. ____. ACLU White Paper: *Big Brother in the Wires; Wiretapping in the Digital Age*. March 1998.
3. Blincoe, L.J. 1996. *The Economic Cost of Motor Vehicle Crashes*. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.
4. Campbell, B.J., et al (1986). *Seat Belt Law Experience in Four Foreign Countries Compared to the United States* (Falls Church, Va.: University of North Carolina: AAA Foundation for Traffic Safety).
5. Clinton, William J (1997). Executive Order 13043 – *Increasing Seat Belt Use in the United States*, Presidential Documents, FR Doc. 97-10331 Filed 4-17-97, The White House, Washington, DC.
6. C. R. Drane and C. A. Scott, "Positioning Systems and Privacy," *2nd International Congress on Intelligent Transport Systems* Yokohama, Japan, November 1995.
7. Volvo Technical Report: (1997) *DARR- Applying Digital Technology to Accident Research* at http://www.volvo.se/rt/trmag/vtr972/article2/a2no297.html
8. Evans, L., *Traffic Safety and the Driver*. New York, NY: Van Nostrand Reinhold, 1991.
9. *Background Information About Crash Data* at http://www.nhtsa.gov/people/ncsa/codes/Mindata/Background.html
10. Federal Register, Volume 63, No. 181 / / *Proposed Rules*. Pg. 49958. Washington, DC. Friday, September 18, 1998.
11. *Highway Occupant Protection* at http://www.ntsb.gov/Recs/highway_occupant_protection.htm#SafetyIssue
12. Harris, Louis., "*A Survey of the Attitudes of the American People on Highway and Auto Safety,*" April 1998.
13. Insurance Institute for Highway Safety (IIHS). Q *& A: Speed Limits*. 1998. Available at http://www.hwysafety.org/
14. ITS America. 1999. Washington, DC. ITS *Fair Information and Privacy Principles* at http://www.itsa.org
15. ____. *Archived Data User Server Addendum to the ITS Program Plan.* September 1999.

16. Kullgren, Andrews., *Validity and Reliability of Vehicle Collision Data: Crash Pulse Recorders for Impact Severity and Injury Risk Assessments in Real-Life Frontal Impacts*, Thesis for Doctor in Medical Science, Karolinska Institute, Stockholm, Sweden, 1998.
17. National Highway Traffic Safety Administration web page at http://www.nhtsa.gov
18. *National Information Infrastructure: An Overview* at http://www.brint.com/papers/nii/overview.htm
19. National Transportation Safety Board web page at http://www.ntsb.gov
20. National Safety Council. (1998). *Accident Facts,* 1998 Edition. Itasca, IL NSC web page at http://www.nsc.org
21. Phen, Dowdy, Ebbeler, Kim, Moore, and Van Zandt; *Advanced Air Bag Technology Assessment*; JPL Publication 98-3; April 1998. The report can be found on the JPL web site – http://csmt.jpl.nasa.gov/airbag/contents.html
22. Office of Technology Assessment. Washington, DC. 1975. *Automobile Collision Data: An Assessment of Needs and Methods of Acquisition.*
23. Office of Technology Assessment. Washington, DC. 1982. *Mandatory Passive Restraint Systems in Automobiles: Issues and Evidence.*
24. Office of Technology Assessment. Washington, DC. 1986. *Electronic Record Systems and Individual Privacy*
25. Office of Technology Assessment. Washington, DC. 1995. *Electronic Surveillance in a Digital Age*
26. Office of Technology Assessment. Washington, DC. 1993. *Advanced Network Technology*.
27. Office of Technology Assessment. Washington, DC. 1993. *Data Format Standards for Civilian Remote Sensing Satellites.*
28. Office of Technology Assessment. Washington, DC. 1995. *Advanced Automotive Technology: Visions of a Super-Efficient Family Car.*
29. Office of Technology Assessment. Washington, DC. 1995. *Wireless Technologies and the National Information Infrastructure.*
30. *Presidential Initiative for Increasing Seat Belt Usage* (1997) at http://www.nhtsa.dot.gov/people/injury/airbags/presbelt/
31. Society of Automotive Engineers. (1999) *Intelligent Vehicle Technologies* at http://www.sae.org
32. Telestrategies, Inc. (1996). *The Emerging Market for Wireless Location-Based Products and Services* (Washington, D.C.: Telestrategies, Inc.).
33. *Transportation Statistics Annual Report* 1998. Washington, DC.
34. UR WWW: Wire Report 1212e: *Claim Fraud in One-Third of Auto BI Claims* at http://www.uwreport.com/wire/news1296/1212aut.htm
35. U.S. Department of Transportation (USDOT), 1997. *Strategic Plan 1997-2002*. 30 September.
36. U.S. Department of Transportation (USDOT), Bureau of Transportation Statistics (BTS). 1998. *National Transportation Statistics 1998.* Available at http://www.bts.gov/ntda/nts
37. U.S. Department of Transportation (USDOT), National Highway Traffic Safety Administration (NHTSA). 1997. *Traffic Safety Facts 1996.* Washington, DC.
38. ____. *Report to the Congress on the National Highway Traffic Safety Administration ITS Program: Program Progress During 1992-1996 and Strategic Plan for 1997-2002*. January 1997.
39. ____. *Motor Vehicle Crashes as a Leading Cause of Death in the U.S*., 1994, Technical Report DOT H5 808 687. Washington, DC.
40. ____. Intelligent Vehicle Initiative Business Plan at http://www.its.dot.gov/ivi/bp114b.htm
41. ____. Federal Motor Vehicle Safety Standards; *Occupant Crash Protection*, 49 CFR Part 571, Docket No. 74-14; Notice 113 at http://www.nhtsa.dot.gov/cars/rules/rulings/OccCProt.html
42. U.S. Government Printing Office. Washington, DC. *The Privacy Act of 1974, Government in the Sunshine Act, Freedom of Information Act (FOIA), and Drivers Privacy Protection Act.*

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MAIB

MARINE ACCIDENT INVESTIGATION BRANCH

VOYAGE DATA RECORDERS IN MARINE ACCIDENT INVESTIGATIONS

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KEYWORDS

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INTRODUCTION

Data recorders are now commonplace in many forms of transport and have made a substantial contribution to the understanding of accident causes and the improvement of safety. Recorded data has enabled accident investigators to reconstruct events to identify precisely what went wrong and to ensure that effective, rather than convenient, recommendations can be made to prevent the same thing happening again. While many transport modes recognize the value of such devices, sections of the marine community have yet to be convinced. This reluctance to accept the value of data recorders and take positive measures to fit them in merchant vessels is, in the opinion of the authors of this paper, a contributory factor to the poor safety record of some ship owners today.

This paper not only argues the case for Voyage Data Recorders (VDRs) but gives examples of rudimentary data recordings that have made significant differences to the quality of United Kingdom marine accident investigations. There is no doubt that they have not only led to a much greater understanding of what actually occurred in each case but have done much to, arguably, ensure that the correct lessons are being learned.

THE CASE FOR VOYAGE DATA RECORDERS

BACKGROUND

The air transport industry has led the way with data recorders. The mandatory fitting of flight deck recorders and cockpit voice recorders in most commercial aircraft has made a major impact to the improvement of safety in the air. This paper makes no attempt to rehearse the benefits; the results are clear to all and, when something goes wrong, the air accident investigator's task is made much easier.

Although there are some features that are common to both the air and sea transport industries, there are significant differences. Flights are measured in hours, voyages in days or even weeks. A ship can sink without anyone being aware of it for several days. Integrating a data recorder in the compact environment of an aircraft is one thing, fitting it into a merchant vessel is something entirely different, and the costs of so doing can be great. In a very competitive and loosely structured international industry there are many who see little or no commercial advantage to fitting them.

The safety record of some ship owners and flag states is far from satisfactory. In the past ten years about 1000 merchant ships have been lost and many more have been involved in lesser accidents to varying degrees. The human toll has been equally horrifying. Shipping, perhaps more than any other industry, is influenced by the realities of the market place with well run, properly manned, modern vessels having to compete with badly maintained, poorly managed, indifferently crewed vessels of excessive age. The well run ship with its greater investment in training and safety is often at a commercial disadvantage when compared with a vessel at the other end of the spectrum where such matters are barely a consideration and the operating costs are consequently less.

Accidents can, and do, occur to vessels in any category and sailing under any flag. Leading flag states go to great lengths to establish the causes by fully investigating the circumstances and promulgating the findings for the benefit of all. States with independent accident investigation organizations are recognized as being the most effective in view of their impartiality and the trend towards making marine accident reports public. Many nations, despite having large parts of the world's fleet sailing under their flags, do little to fulfill the international requirement to investigate marine accidents when they occur. If an investigation is carried out there is, too often, little or no attempt to publish the report and any contribution to improving safety at sea is lost.

Marine accident investigation is all about reconstructing events. Unlike aviation where access to data recorders can provide answers to complex questions and establish patterns of human behaviour, the marine accident investigator has to rely much more on physical evidence and, crucially, the recollections of those involved. Occasions arise when there is nobody alive to tell the tale and the process of reconstruction becomes even more difficult. Ships sink, sometimes without trace.

This paper makes no attempt to argue for more independent and open marine accident investigations but it does advocate the early introduction of data recorders. Such devices will ensure that a true account of what occurred in an accident can be obtained. that appropriate recommendations are made and important lessons can be learned. They will also add greatly to an understanding of human factors at sea.

THE CURRENT POSITION

The case for fitting VDRs in ships has been made. In July 1997 the Safety of Navigation Sub-Committee of the International Maritime Organization (IMO) approved draft standards for shipborne VDRs although, crucially, agreement has yet to be reached on which ships must carry the recorders and when. The European Community has acted ahead of the IMO requirements to ensure that all passenger ferries operating in Europe are equipped with VDRs to IMO standards.

This is just a start but, if in future, VDRs are to be carried by substantially more ships, agreement must be reached in the IMO on carriage requirements and on the text of a suitable amendment to the International Safety of Life at Sea (SOLAS) Convention.

Within the IMO there is disagreement at present. Some flag states do not want VDRs at all while others argue that a trial period is needed. This latter position is seen as a delaying tactic and an excuse to have the entire idea put to one side for the foreseeable future. On the other hand, there are others, mostly North American, Western European and Australasian flag states, that want their rapid and complete introduction to increase safety and environmental protection around their coasts.

There are also disagreements among shipowners. A small minority need no convincing of their value and have voluntarily fitted VDRs to their vessels. Others recognize their potential as a safety tool but are concerned that having borne the high cost of installation there will be no commercial benefit while a third group, probably the majority, will resist their introduction whatever the circumstances. Those in the third category will raise various arguments to prevent their introduction and frequently cite the lack of any clear evidence that they will improve safety or offer a competitive advantage. Vessels fitted with VDRs have, arguably, a better safety awareness and record but this seemingly does not attract any commercial benefit

The United Kingdom's Marine Accident Investigation Branch (MAIB) knows there are significant advantages to having access to data recorders both onboard and ashore. There is growing evidence to show that events can be reconstructed far more accurately than is ever possible without them. It has also meant that the primary and underlying causes of accidents can be identified with far greater certainty, and with less argument from anyone wishing to protect their own, or client's, interests.

MARINE ACCIDENT INVESTIGATION LIMITATIONS

Specialist marine accident investigation is still a relatively new science. It relies extensively on being able to interview witnesses and the gathering of evidence on a slightly ad hoc basis.

Despite substantial improvements with interviewing techniques, the human memory is fallible. Even the most co-operative of witnesses will forget crucial events and will have difficulty in recalling precise times. Most witnesses do their best to remember events but there will be many gaps in the information they can provide. They also tend to be more cautious with what they reveal if company lawyers are present during the interview.

As witness statements are often the most important factors in the collection of evidence, conclusions invariably have to be drawn from what they say even though the information derived is often incomplete and in conflict with that derived from other sources. Although it is possible to carry out a good investigation using traditional techniques, there are too many occasions when the conclusions lack robustness or those with vested interests may exercise whatever influence they can to have their point of view presented in a more favourable light. It is not unknown for the true causes and underlying factors to be ignored in a final report and the blame for whatever occurred to be conveniently placed on anyone who has died in the accident.

Whenever the evidence is inconclusive the issues will be clouded. Too often in the past the causes of the accident have not been accurately identified and too little has been done to improve matters. The practice can lead to unsafe practices being condoned or remedial measures not being introduced for want of firm evidence. An officer or a pilot is conveniently "found" to have been at fault with "human error" cited as the reason, but the lack of hard evidence allows for neither a robust criticism nor an effective defence of the finding. This is very unsatisfactory for all concerned. The lessons from such accidents are frequently ignored and the underlying causes, often involving those not directly involved in the actual incident, are never promulgated.

EXAMPLES OF UK ACCIDENTS WHERE DATA RECORDING WAS NOT AVAILABLE

Zulfica/Wilhelmina J

In 1991 the Cypriot registered cargo ship *Zulfika* collided with the British fishing vessel *Wilhelmina J* causing the capsize and loss of the fishing vessel with the lives of all six of her crew. The MAIB's investigation into this tragedy found that because there had been no survivors from *Wilhelmina J,* a degree of supposition had been necessary concerning her precise movements. The inspectors had, nonetheless, concluded that among other things the master on *Zulfica* had been seriously at fault in the management of his vessel by not stopping and reporting the accident to the coastal authorities until some two hours after the event. The master was subsequently tried in a Cypriot court of law on charges arising from the accident. Although he was acquitted on all counts, his reputation was tarnished and suspicion still surrounds his actions.

Had either vessel been fitted with a VDR, a more reliable reconstruction of events would have been possible and enabled a safe conclusion to be reached.

Flag Theofano

In 1990 the Greek registered bulk carrier *Flag Theofano* sank in 20 metres water depth with the loss of all nineteen persons on board. She was carrying a cargo of 3920 tonne of cement and was only three miles from her intended destination anchorage when the accident occurred. It was blowing force 8 and a rough sea was running at the time.

The investigation concluded that she probably capsized following a cargo shift. The precise cause could not be ascertained but a judgement was made that heavy rolling had been induced by a possible propulsion break down or a steering failure. With no survivors or witnesses it was impossible to be more precise. As forty nine other cement carriers had foundered in the previous ten years, the IMO took swift and effective action to limit the size of cement cargoes and their ability to shift. However, with the families' of the lost crew members demanding someone to blame, criticism was inevitably directed at the master for sailing from the loading port when severe weather was forecast.

A VDR would have enabled a far more accurate, not to say fairer, means of investigating the accident.

Hero/Larrissa

In 1994 the Maltese registered cargo ship *Hero* collided with, and sank, the British fishing vessel *Larrissa*. All six crew of the *Larissa* were lost and accident investigators were unable to recreate the circumstances leading up to the collision. The only source of information on *Larrissa's* movements was that provided by the crew of the cargo ship and their evidence was scarcely credible. Had she been fitted with a VDR capable of recording radar information and the voices of those on the bridge, the actions of those involved would have been judged on fact rather than supposition.

Derbyshire

One of the world's largest vessels, the UK registered 170,500dwt bulk carrier *Derbyshire* sank with the loss of all 44 hands in the north west Pacific in September 1980. Nobody knew where she had gone down and speculation grew as to the reasons for her loss. Much of this focused on circumstantial evidence that she had foundered due to structural failure.

Pressure from the families of those who had lost their lives in the accident eventually led to an underwater search being carried out by the International Transport Workers' Federation in 1994. This found her lying in many pieces on the seabed at a depth of 4100 metres and prompted the British Government to carry out a more comprehensive survey and analyze the findings. This has now been done and the matter is being referred to a re-opened Formal (Public) Inquiry in the UK. Leaving aside the arguments about what caused the Derbyshire to sink, the lengths to which it has proved necessary to establish the cause of loss, and the costs of so doing, have been, and are continuing to be, extensive. The provision of a VDR capable of floating free, or one capable of being recovered from the seabed, would have transformed the process of trying to establish the cause of her loss with savings in money, time and effort. Above all, it would have ensured that any lessons to emerge would have been known far more rapidly.

MAIB EXPERIENCE WITH RECORDED EVIDENCE

A better system of being able to record events has long been advocated. A VDR records what actually happened, removes argument, and ensures that appropriate corrective measures can be taken. It is among the most valuable tools available to the marine accident investigator.

Data recorders are not necessarily confined to 'black boxes' on vessels. Most ships now carry a range of computer operated equipment. Much of it will have accessible memories or a means of recording data. The knowledgeable marine accident investigator is able to extract a wide range of information from onboard computers and can often reconstruct many events with the benefit of a common time standard.

Additionally, and increasingly, other sources of recorded data are becoming available including recorded radio channels, vessel traffic system (VTS) shore radars, closed circuit television and privately operated video cameras.

In recent years MAIB Inspectors have investigated accidents where some form of electronic system has independently recorded events as they have occurred. These have not only been very revealing but have clearly shown up the inadequacies of existing methods.

Without exception these electronic systems have shown up the limitations of the human's ability to accurately recall events. There have been a number of occasions where the 'evidence' of an apparently honest and reliable witness has been totally contradicted by a recording of a shore radar, vhf radio or, on one occasion, the ship's VDR and its ability to replay everything that was said on the bridge.

EXAMPLES OF UK ACCIDENTS WHERE DATA WAS RECORDED

In 1998 a vessel was holed while on passage in the River Thames. The vessel sank as a result of the grounding but all on board survived. When interviewed after the event both master and second officer were convinced they had been in mid channel when the accident occurred and had struck some floating debris. They were genuinely astonished to discover from the recording of the port authority's radar that their vessel had been outside the fairway for some time prior to grounding. Without this incontrovertible evidence doubt about the vessel's actual track would have remained in doubt.

In 1994 a VDR fitted cruise ship lost all propulsion and main electrical power seven miles off a lee shore. The wind was gusting force 8 and the vessel began to drift rapidly towards the nearest land. When interviewed after the event the master was sure he had been fully aware of the direction of the vessel's drift towards the shore and had reported this accurately to the coastguard. When the accident was investigated it transpired that he had actually informed the coastguard the vessel was drifting clear of the coast which led them to believe the risks involved were not great and that there was no need to activate the local area emergency plan. When faced with this 'fact' after the accident the master refused to believe it. It wasn't until he listened to the VDR bridge audio recording that he discovered his memory was at fault.

This incident gave MAIB inspectors their first experience investigating an accident in which a VDR had featured. Quite apart from providing a true record of what had occurred it was also their first real opportunity to compare evidence gathered in the traditional manner with accurate evidence from a recorder. The results were not only surprising but demonstrated the very real shortcomings of traditional techniques.

It also provided a further insight into what actually happened on the bridge during the incident. The VDR's recorded radar information gave an accurate indication of the vessel's drift rate and direction. Interestingly it bore little resemblance to the positions plotted on the chart. It was then found that a single error in chartwork had initiated a chain of events that only became evident when listening to the VDR voice recordings of those on the bridge. The master had been given incorrect wind and tide information by his bridge team which explained why his report to the coastguard was inaccurate.

It would be unwise to draw too much from this one incident but the potential advantages of having a VDR were marked. What, in other circumstances might have been considered reliable evidence was shown to be inaccurate. It also became clear that evidence derived from a VDR can lead to a far better understanding of human factors at sea. This is still an area where much work needs to be done.

It is widely accepted that over 80% of all accidents can be attributed to human factors. These include fatigue, sleep deprivation, poor onboard communication, inadequate training, incompetence or inexperience, perceptual abilities, lack of teamwork, high workload, health, drugs and personal worries arising from domestic difficulties. Many sections of the marine industry have recognized this and are beginning to take action to improve matters. A growing understanding of the human factor element has enabled investigators to gain a clearer insight into the causes of human error but their efforts are often hampered by a lack of firm evidence and good information.

There have been several other recent incidents where electronically recorded data has played an important role in either the reconstruction of events or the drawing out of lessons to be learned. There is at least one very embarrassed fisherman in Britain who was dismayed to discover that a dockside security camera had faithfully recorded his boat capsizing while it was alongside, thus demonstrating the inadequacies of his stability calculations. The pictures have made a telling impact on the fishing industry.

A cruise liner was leaving port with the pilot embarked, somewhat unusually, in a launch that proceeded her. An amateur cameraman videod the departure and managed to capture the moment the liner went aground in vivid Technicolor. The interesting thing from the accident investigator's viewpoint was that the video camera also recorded everything the pilot said. Or to be more accurate it recorded what he didn't say. According to the information on the sound track the pilot had no idea the ship was just about to hit the only rock near the main channel!

Except when there has been a deliberate attempt to suppress, or distort evidence, such revelations are generally welcomed by those involved even though they may cause acute embarrassment. There is a natural reluctance of people to be so exposed but, providing a form of confidentiality or protection can be provided, and the results are used for the purpose of identifying causes, most people accept that such devices have the potential to lead to genuine improvements in safety.

CONCLUSIONS

Marine accident investigators in the United Kingdom need no convincing of the importance of data recorders in ships and will argue for their introduction as soon as possible. They believe they will remove the many ambiguities and uncertainties that currently exist in accident investigations and will argue that their introduction will make a major contribution to marine safety.

The authors of this paper also believe that despite the undisputed benefits that arise from being able to investigate accidents more thoroughly, many in the marine community will continue to find little to persuade them that fitting VDRs will personally benefit them.

For VDRs to find universal favour there must be financial benefits from their carriage. A reduction in the costs of insurance or other charges for VDR fitted vessels would do more for their introduction than any amount of domestic or international regulations.

MONITORING AND MANAGING WHEEL CONDITION AND LOADING

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KEYWORDS

Rail, Wheel, Defect, Weighbridge

INTRODUCTION

Damaged wheels, hot bearings and bad loading practices are increasingly recognized as major contributors to the hazards and costs of the rail industry.

To improve both safety and economy, rail operators need vehicle condition data. A combination of wheel, bearing and load monitoring integrated by an effective database application can present the necessary information in a way that can be used productively.

Teknis has developed a system that provides accurate in-motion weighing and comprehensive analysis of load distribution plus defect detection and classification at wheel, bogie, wagon and train levels.

Teknis' Wheel Impact Load Detector (WILD) is designed to allow track & structure owners to monitor the vehicles running on their rails and rolling stock owners to optimize their maintenance scheduling. The system is low-cost, quick to install and maintain and requires no modification to the track.

This paper presents an overview of the technology and operational results reported by National Rail.

SYSTEM OVERVIEW

The basic components of the WILD system are the track mounted sensor array, on-site processing rack (CSU) and control PC.

The WILD system is modular. All configurations use the same software. The system dynamically senses the configuration so increased capability can be added by plugging in the appropriate hardware. Power can be AC or DC (including solar). All sensor units perform a range of self-test functions and return status in real-time to the control PC.

Sensors are mounted in pairs, one on each rail, between the sleepers. Depending on requirements a WILD array may contain:

- 10 -12 Accelerometers
- 4 -12 Load Gauges
- 2 - 4 Temperature Sensors
- 4 Wheel Flange Detectors
- Automatic Vehicle Identification Tag Reader
- Hot-Box/Hot-Wheel Detector
- Out-of-Gauge/Dragging-Equipment Detector
- Lateral Tracking Sensors

Accelerometers and load gauges measure impact and axle load respectively. Temperature sensors measure rail temperature. The wheel flange detectors sense the direction and speed of the train passing over the array. The AVI tag reader allows defects and data to be associated with particular vehicles, independent of consist.

Lateral tracking sensors quantify sideways movement of wheelsets to detect problems such as faulty side bearers and 'warped' bogies.

Hot-box/hot-wheel detectors use thermal data to target faulty bearings and brakes. Out-of-gauge/dragging-equipment detectors look for shifted or badly arranged loads and other objects that project outside of the nominal cross-section of railway vehicles. WILD can integrate the output from these sensors via a direct interface module at the CSU or through networked data files at the control PC.

Defect measurement and classification are independent of speed and load. This makes artificial normalization techniques such as 'Impact Factor' redundant.

Load measurement comes in two levels. Level 1 uses 4 load gauges and provides measurement accuracy of +/-5%[8]. Level 2 load measurement uses 12 load gauges to give +/-1%[8]. All load measurement is independent of speed up to 130km/h[8].

The upper speed limit is set at 130km/h because there has, as yet, been no opportunity to test at higher speeds. The system itself is capable of operating at speeds in excess of 250km/h[11].

SENSOR ARRAY AND PROCESSING RACK

Standard defect and load sensors are placed between the sleepers in 6 pairs as shown in Figure 1. The wheel flange detectors are then positioned at either end of the array. This makes 10 sleeper spans, or about 7 meters, for the full array. This excludes the AVI, lateral, hot-box and out-of-gauge sensors which tend to be located adjacent to the array. Sensors are clamped to the track using specialized mounting blocks designed for ease of installation and maintenance. This provides solid connection to the rail without drilling, welding, or as required in some cases, replacing entire sections of track. This method of attachment has proven absolutely reliable.

There have been no signs of any loosening or slippage shown by any mounting block on any WILD array over the full operational life of all existing sites.

The CSU contains interface boards for each group of sensors in a standard 19" rack. Signals from the array are processed by the CSU. Combined with the further processing in the database, this removes variations due to track modulus, wagon suspension, speed and static load.

Data is organized into messages, then sent to the control PC. The CSU and control PC use a secure HDLC link to transfer data, operator commands and system status. The communications medium can be dialup PSTN, leased line or radio link. If required, data can also be transferred via LAN, WAN, intranet or Internet. In the event of communications failure the CSU has sufficient battery backed memory to store full data on 64,000 wheels for up to 3 months[11].

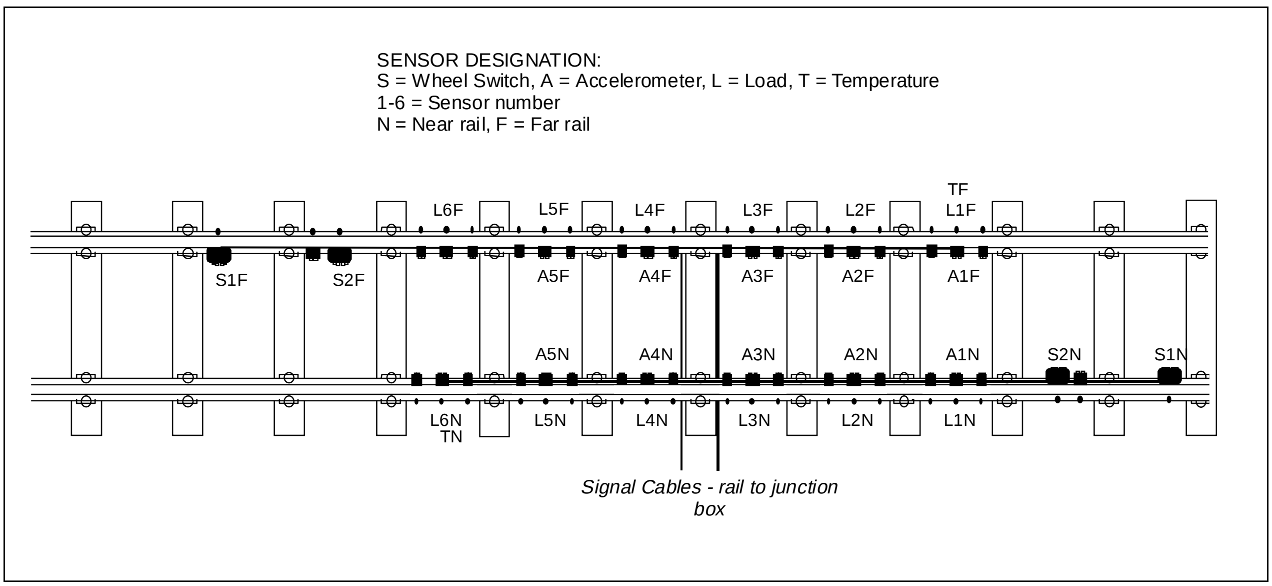


FIGURE 1: Schematic of Array Sensor Positions

CONTROL PC AND DATABASE

Data sent to the control PC is kept in the WILDDB database application. This can be networked to other PCs to automatically forward selected data. In order to cater for the wide variety of requirements characteristic of railway operations WILDDB has been designed to allow extensive user-configuration. Once data for a train has been received it is processed collectively to classify defects and analyze loading patterns. Consequent actions, such as automatically printing a report or sounding an alarm, are user-definable. Processing algorithms are fully parameterized so that changes can be made without rewriting any software. All data can be reprocessed at a later time to verify improved algorithms and/or alter parameters.

None of the original information is lost or changed at any stage of the processing. This data can be reprocessed in part or whole at a later date. If any aspect of the analysis is enhanced or if fine-tuning of the system is desired, it is not necessary to wait for a valid statistical sample of trains in order to verify improvements.

LOAD MEASUREMENT AND PATTERN ANALYSIS

Figure 2 shows measurements of total train mass. Figure 3 shows fully loaded, 50% loaded and empty (TARE) wagon masses. The data is taken from a calibration trial of a new WILD system with Level 1 (+/- 5% rated accuracy) load measurement[1]. The maximum line speed for the site was 80km/h. The reference train mass was given as 412.1 tonne. The mean of the data below is 412.3

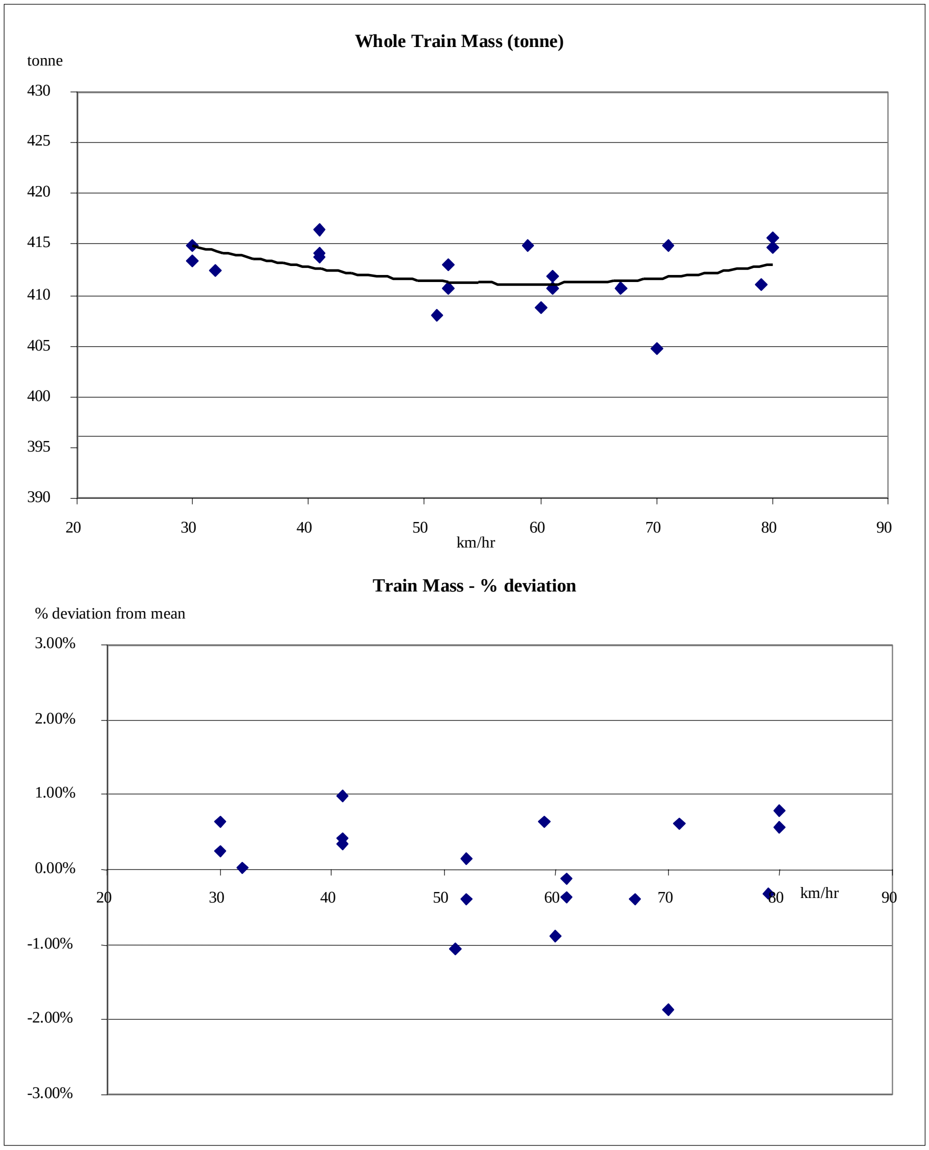


FIGURE 2: Total train mass and percentage deviation with Level 1 load measurement

The following series of graphs show data for three load reference vehicles. The graphs on the left show mass as measured verses speed. Those on the right show deviation from measured mean as a percentage. The x axis on all graphs is km/h. Dotted lines represent weights obtained from a quasi-static reference weigh-bridge.

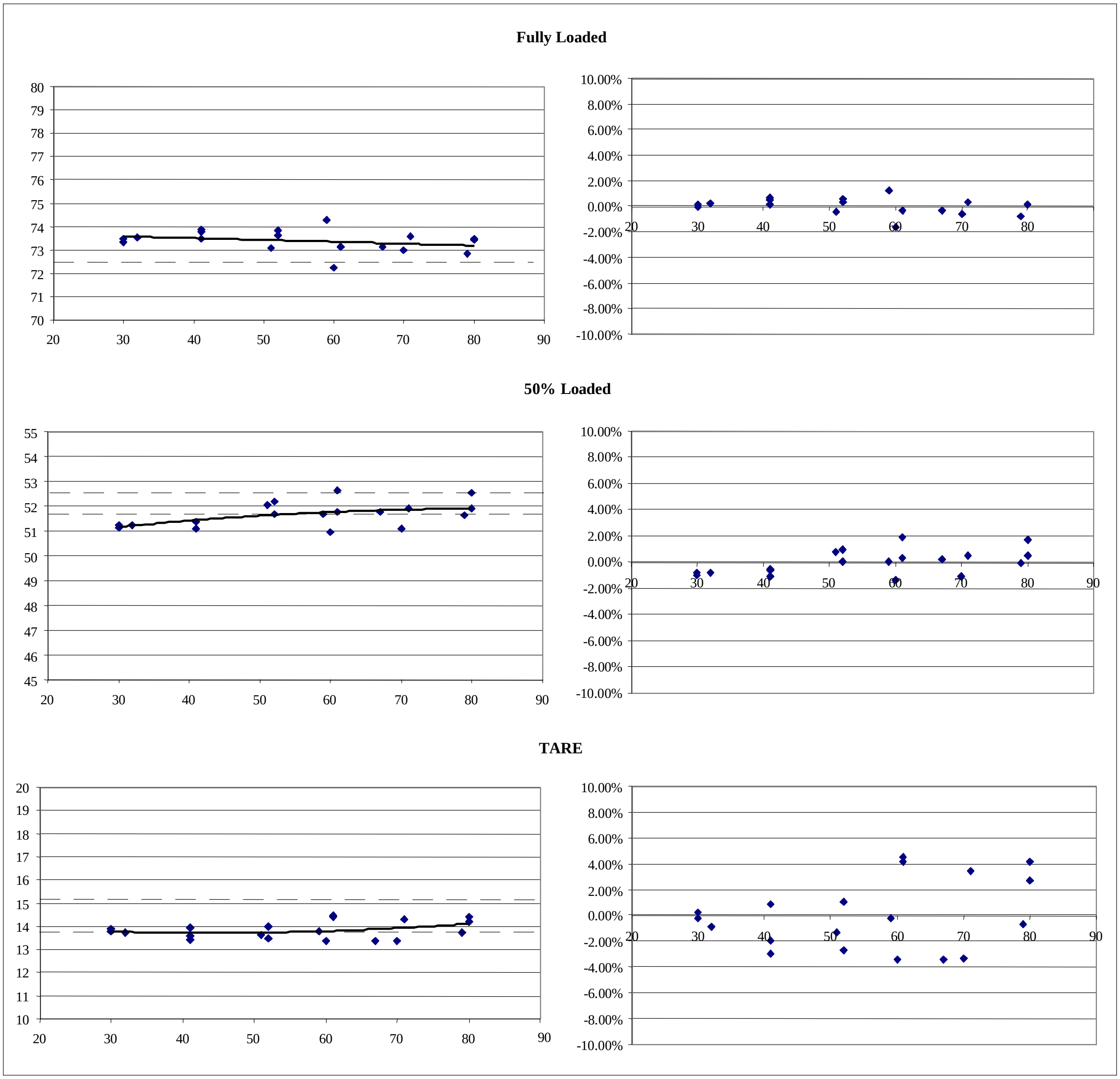


FIGURE 3: Wagon mass and percentage deviation for fully loaded, half loaded and empty reference wagons with Level 1 load measurement

The deviation on the TARE vehicle, when specified as a percentage, is noticeably greater. However, the deviation in terms of tonne is comparable and better than the variance of the reference weigh-bridge. Table 1 lists mass and deviation data for these test runs. At the bottom of the table are summary measures including standard deviation, mean, minimum, maximum, the reference value and the mean difference from the reference value. All values are measured in tonnes.

km/hr	**Full**	**50%**	**TARE**
30	73.3	51.1	13.8
30	73.5	51.2	13.9
32	73.6	51.2	13.7
41	73.5	51.1	14.0
41	73.9	51.3	13.4
41	73.8	51.4	13.6
51	73.1	52.0	13.7
52	73.8	51.7	13.5
52	73.6	52.2	14.0
59	74.3	51.7	13.8
60	72.2	51.0	13.4
61	73.1	51.8	14.5
61	73.1	52.6	14.4
67	73.2	51.8	13.4
70	73.0	51.1	13.4
71	73.6	51.9	14.3
79	72.8	51.6	13.7
80	73.5	51.9	14.4
80	73.5	52.5	14.2
mean	**73.4**	**51.6**	**13.8**
std dev	0.45	0.49	0.38
min	72.3	51.0	13.4
max	74.3	52.6	14.5
reference	**72.4**	**52.3**	**14.5**
delta mean	1.0	-0.7	-0.7

TABLE 1: Level 1 load measurement data for calibration trials

LOAD ACCURACY

Results of these trials showed typical vehicles with nominal wheels displayed +/-2.5% variance over 25 tonne and +/-900 kg under 25 tonne[1].

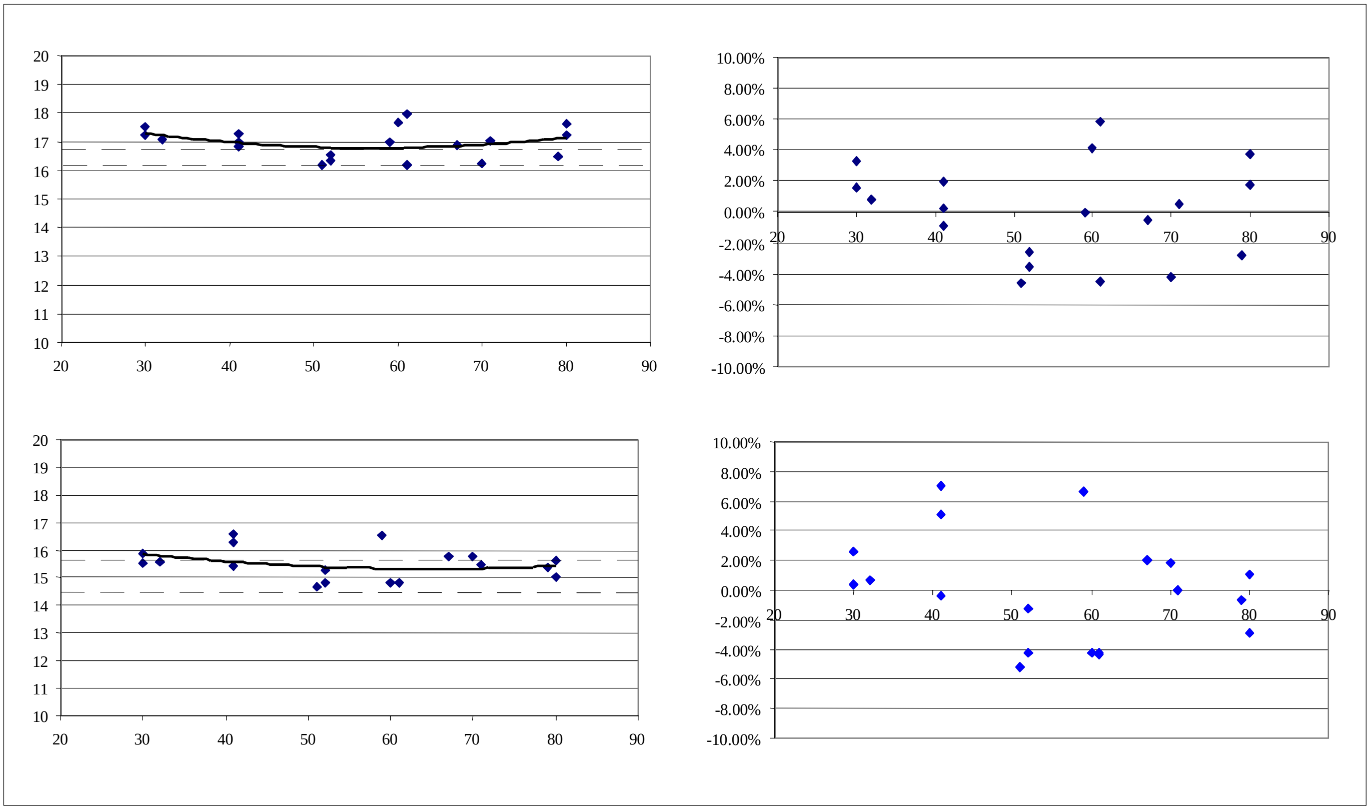
As shown in Table 1, the standard deviation does not increase with load. The variability is not a function of mass or speed and system performance actually improves with load. In other words, variability can be defined as +/- kg instead of as a percentage. This translates into the following performance:

		Full	50%	TARE
	mean	73.4	51.6	13.8
	Std dev	0.45	0.49	0.38
4 Confidence Level				
95%	**Low**	72.5	50.6	13.1
	High	74.3	52.6	14.5
	+/- kg	882 kg	960 kg	745 kg
	+/- %	1.2%	1.9%	5.4%
98%	**Low**	72.4	50.5	12.9
	High	74.4	52.7	14.7
	+/- kg	1049 kg	1142 kg	885 kg
	+/- %	1.4%	2.2%	6.4%
99%	**Low**	72.2	50.3	12.8
	High	74.6	52.9	14.8
	+/- kg	1161 kg	1264 kg	980 kg
	+/- %	1.6%	2.4%	6.7%

1. *95 % level of confidence = mean mass as measured +/- 1.96 sigma*
2. *98 % level of confidence = mean mass as measured +/- 2.33 sigma*
3. *99 % level of confidence = mean mass as measured +/- 2.58 sigma*
4. *all figures are in tonne unless otherwise denoted*

TABLE 2: Level 1 load variance expressed in kg rather than percentage

Measuring the mass of axles that have significant defects decreases accuracy by a few percent. Figure 4 shows load data for vehicles with moderate-high level defects.



<u>FIGURE 4: Level 1 load measurement on wagons with defective wheels</u>

In addition to in-motion weighing, the WILD system analyzes load balance in wagons and load distribution over an entire train. This can be further refined to include overload limits based on wagon type or even individual wagons within the fleet that require special attention. Speed can also be factored in. For example, the system can be configured to automatically generate an alarm and print a report when a particular type of wagon with a certain type of bearing is detected with a combination of load and speed above certain limits. The system can also alarm on hazardous conditions such as empty vehicles within a heavy consist.

WHEEL DEFECT CHARACTERIZATION

WILD can detect and classify defects from a few millimeters in size up to large (>10cm) skids[10]. Standard defects such as skids, built-up treads, cracks and spalling can be differentiated and graded. The system is also capable of detecting long-period defects such as out-of-round wheels, sub-surface defects and collapsed wheel tread due to cracking[7, 10]. The system can discriminate multiple defects on the same wheel and can provide separate classifications and relative positions of each. Defect measurement is reported in terms of impact force in kiloNewtons (kN). While all raw data is stored, reporting tends to be on the basis of 'normalized' values that have had the effects of speed and load removed. Normalized magnitudes are repeatable to within +/-5%[10] independent of speed (30-130km/h) and load (empty up to 38tonne axle load).

The normalizing reference function is based on the smooth tread of a new or freshly machined wheel, fully loaded and traveling at 80km/h. It has been repeatedly shown that this process results in the consistent and repeatable grading of wheel defects[10, 15].

It is very important that the system reports the same wheel defect at the same level regardless of axle load. Otherwise a wagon with a defective wheel might pass over the site without incident when empty only to cause an alarm and require change-out when loaded.

Figure 5 shows both tabular and graphical representation of normalized data from multiple runs of the same defect at different load levels. This data was obtained during normal operations at a heavy-haul WILD site in Western Australia. Speed is effectively constant. The only variables are direction and load. Direction alternates for each successive data point and load varies from 22 tonne to 130 tonne. The left-hand graph plots impact against speed. The graph on the right shows the impact level at each run. This is a good example of a skid that is 'freshened' or renewed occasionally.

Below is a list of column headings for the table in Figure 5.

Car ID	-	AVI tag ID for vehicle
Car#	-	The position of the wagon in the consist
Dir	-	Direction of travel. User-defined designation.
Date	-	The date the train crossed the array
Time	-	The time the train crossed the array
km/h	-	The average train speed over the array in km/h
Load	-	Wagon mass in tonnes
Index	-	Estimated track damage potential of the defect
Axle1 kN – Axle4 kN	-	Normalized kN impact data for axles 1 to 4

Carr ID	Carr #	Dir	Date	Time	km/h	Load	Index	Axle 1 kN	Axle 2 kN	Axle 3 kN	Axle 4 kN
551	102	N	25-Aug	0:54	73	22	24			238	
551	102	H	25-Aug	21:57	74	131	24			250	190
551	102	N	27-Aug	10:35	71	21	18			246	
551	102	H	28-Aug	1:22	73	134	23			262	
551	102	N	28-Aug	12:05	73	21	20			267	
551	102	H	29-Aug	5:40	73	129	22			257	
551	102	N	29-Aug	12:46	75	20	17			246	
551	102	H	31-Aug	10:54	73	126	23			242	
551	103	N	31-Aug	18:48	72	21	20			242	198
551	103	H	01-Sep	9:21	74	130	23			234	
551	103	N	01-Sep	17:30	73	22	20			234	
551	103	H	02-Sep	8:28	74	133	24			248	
551	103	N	02-Sep	18:20	75	23	20			245	
551	103	H	03-Sep	8:49	67	129	19			234	
551	103	N	03-Sep	18:36	74	22	19			234	
551	103	H	04-Sep	8:48	73	134	22			246	190
551	103	N	04-Sep	20:13	76	21	16			256	
551	22	H	05-Sep	14:34	71	127	25			240	
551	23	N	06-Sep	1:57	73	22	16			238	
551	23	H	06-Sep	16:44	71	130	17			230	194
551	102	N	08-Sep	7:21	72	21	24			242	
551	102	H	09-Sep	6:10	71	132	21			230	

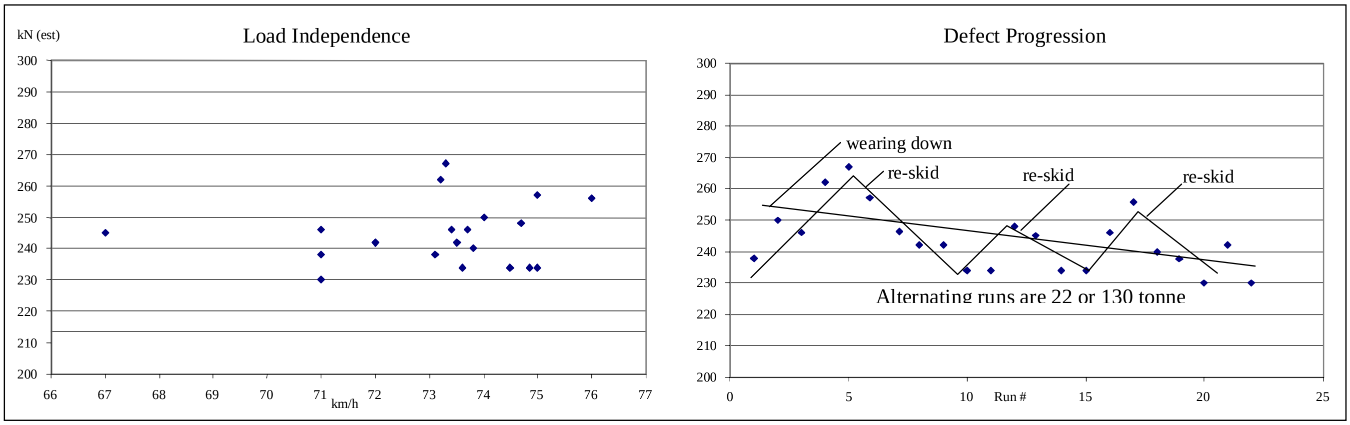


FIGURE 5: Defect data showing load independence and skid progression

Figure 6 shows normalized data from a 75mm flat at different speeds. The data was obtained during standard calibration trials run as part of the commissioning of a new WILD system.

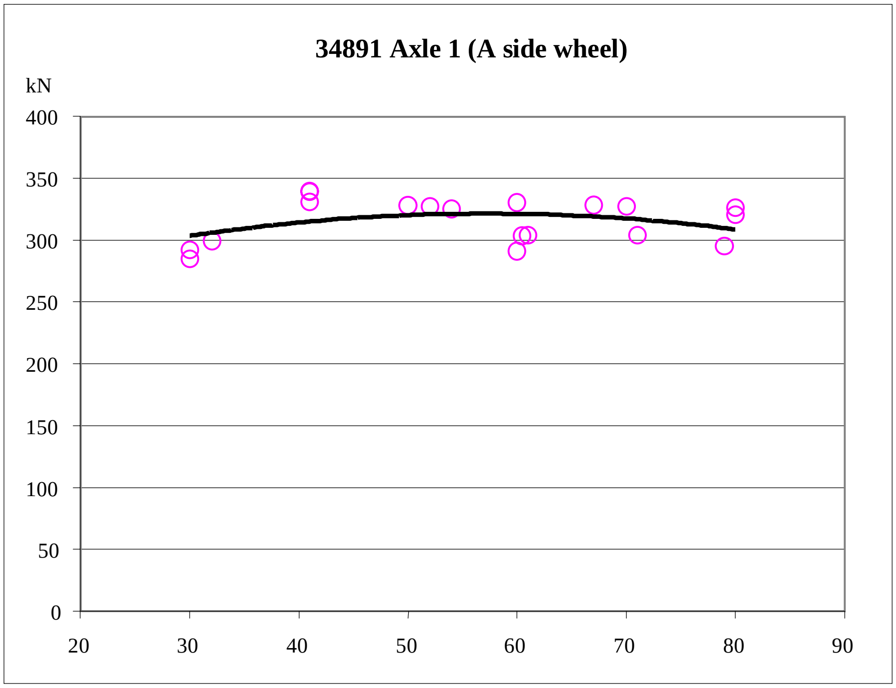


FIGURE 6: Impact data from 75 mm flat

In addition to the basic defect classification, the severity of a WILD alarm can take into account other factors such as combined number/severity of defects on any/all wheels in a wagon, vehicle type, tag or the owner of the train.

DEFECT PROGRESSION AND VARIABILITY

Detection of wheel defects requires that the defect be running on the rail/wheel contact surface when the wheel crosses the array. A defect that is very small or not on the normal running area of the wheel can sometimes evade detection.

Variation in readings from one pass to the next is usually caused by:

1. Normal defect progression or creation of a new defect
2. Sharp edged, very small defects near the edge of the normal rail/wheel contact area
3. Particularly narrow rail/wheel contact area
4. Defects with a ‘resonant’ speed. At this speed, usually well over 80km/h, wheel/rail contact at the defect is momentarily zero. In this situation the data is effected by the way the wheel ‘lands’.
5. Reversal of wheel rotation, when a vehicle is turned around or a train reverses over a WILD array. This becomes more apparent in highly complex or asymmetric defects.

WILD sites with vehicle tag identification have allowed study of long term trends in defect progression. These suggest that:

- Spalls remain stable and constant but increase the chance of skid formation at that point on the wheel[10]
- Skids (or flats) periodically ‘freshen’ or sharpen, then wear at the edges, then sharpen again at the next heavy braking, etc (see Figure 5). Such flat spots tend to skid more easily. This is especially apparent on locomotives. Skids can also degenerate into long period defects through sub-surface heat damage[7, 9, 13, 14]
- Long-period defects are stable if caused by machining but tend to increase steadily when formed under a skid[7, 9, 13, 14] (see above)
- Cracks increase exponentially[7]

DEFECT ISOLATION – WHEELS ADJACENT TO IMPACTS

Association of defects with specific wheels is very strong. Severe impacts on one wheel are isolated to one or two zones on a wheel (wheels are divided into 5 zones). However, such high-impact cases can cause a small amount of 'bleed through' to other wheels in the same bogie. Figure 7 shows all zone readings for the wheel adjacent to (and in the same bogie with) a wheel exhibiting a severe impact.

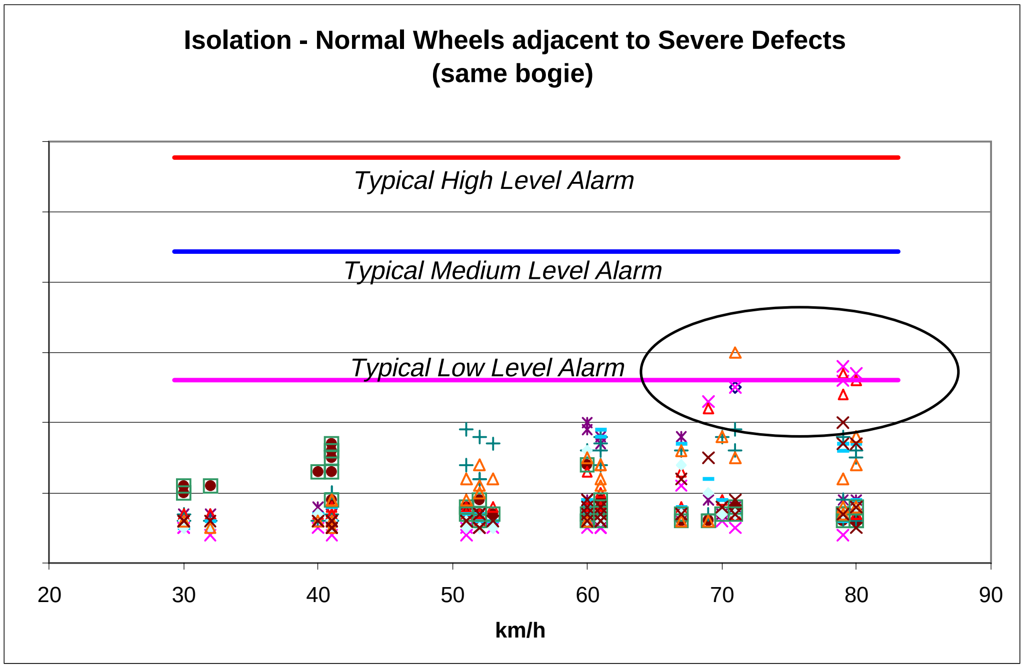


FIGURE 7: Examination of impact levels registered on one wheel from a high impact on the adjacent wheel in the same bogie

Note that there are some readings, which are elevated to the point where they will register low level alarms. This is not considered to be a problem because the adjacent wheel has already caused a high level alarm on the train.

OTHER DATA

The system provides other data that can be of particular interest to operators. Rail and ambient temperatures are measured for each train to provide additional environmental and structure related data.

Speed measurement is accurate to 0.3%[1, 10]. Inter-bogie spacing is measured in millimeters and total train length can be measured to within 0.1%[1,10]. Figure 8 shows trial data for the measurement of a locomotive wheelbase. Figure 9 shows total train length measured while the train coasted across the site and then again when the train was accelerating in reverse (i.e. under compression). In some operations train length must be below a specified maximum for certain turn-outs or unloaders. The WILD system can be configured to alarm on trains exceeding a user-specified length restriction.

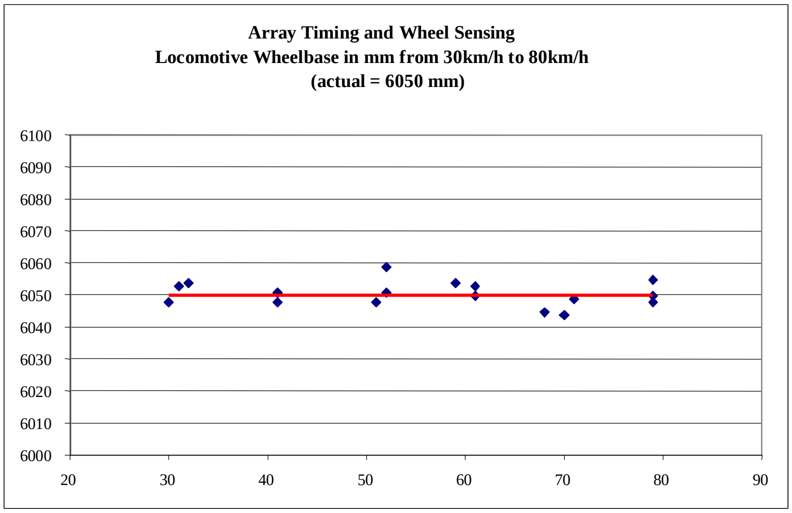


FIGURE 8: Axle spacing measurements for a locomotive wheelbase

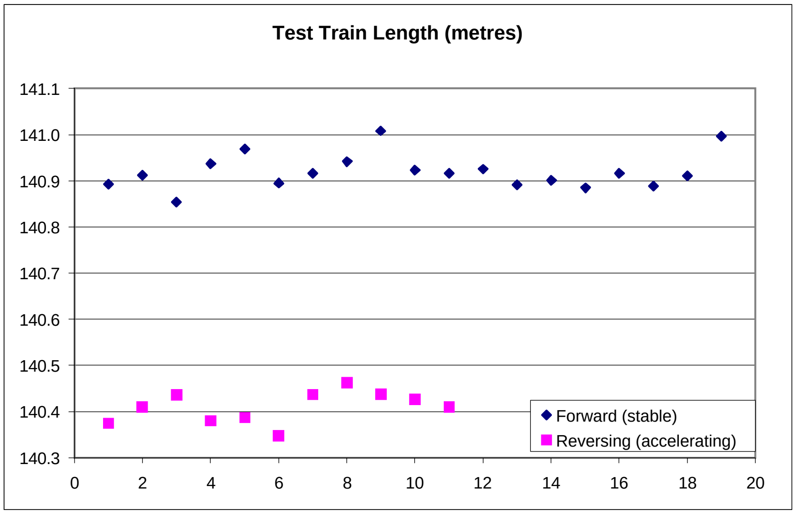


FIGURE 9: Total train length during coasting and compression

SYSTEM PERFORMANCE ISSUES - ENVIRONMENTAL NOISE

Railway lines are not noted for being benign environments, particularly from an electronics point of view. Electromagnetic noise, up to and including lightning strikes, is a common fact of life.

The connection from the on-track array to the processing rack passes through a bulkhead of transorbs and gas arrestors to protect against transient surges. WILD installations have been functioning for several years in some of the worst lightning areas in Australia.

Also important is the ability to function with high levels of non-destructive day-to-day noise. All array sensors are separately grounded back to a single-point earth that serves as the reference for all equipment.

One installation in particular serves as a proving ground. Located in tropical Queensland, the CSU processor rack sits between two 50,000Volt step-down transformers. In addition to overhead electrification the rail carries a return current fluctuating between 0 and 300 Amps depending on train location and traction. Figure 9 shows both raw and filtered wheel switch signals from this site.

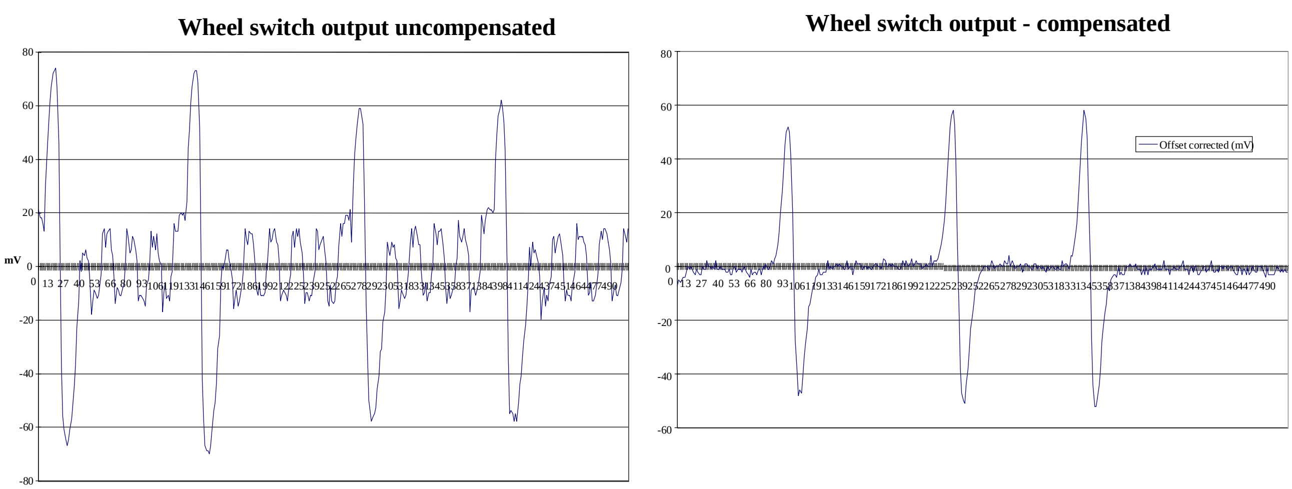


FIGURE 9: Raw and filtered wheelswitch signals

NATIONAL RAIL - SYSTEM AS INSTALLED

WILD systems are in use around Australia: in New South Wales, Queensland, Western Australia and South Australia.

National Rail (NR) is an Australian rail carrier. The NR WILD system is located near Port Germein, approximately 300km north of Adelaide, South Australia. In addition to the basic defect sensors the system includes full Level2 load measurement, AVI tag reader and lateral sensor array. Figure 10 shows a photo of the site.

The CSU processor rack is housed in a standard equipment hut with two PSTN phone lines. One line is used by the WILD to automatically dial out to the control PC on detection of a train. The other line provides a dial-in interface to the maintenance PC. This PC is permanently connected to the CSU as a secondary interface to the WILD.

Due to data privacy issues among the various operators that run traffic over the site, the control PC is housed at Teknis. Once the ownership of a train is established the control PC dials out to download the data to the specified recipient (either National Rail or Australian Rail Track Corporation).

FIGURE 10: Photo of National Rail WILD site

DESCRIPTION OF TRIALS

Calibration trials are performed as part of commissioning for every WILD site. Known consists, specially assembled to provide a mixture of good wheels, defective wheels and vehicle loads are run over the WILD array at speeds from 30 up to 130km/h (or the maximum line speed). This provides specific data concerning the structural response so that normalizing reference functions can be fine tuned.

OPERATIONAL METHODS

As with other systems, the effectiveness of the WILD depends on two things; what it can do and how it is used.

The National Rail fleet is made up of approximately 4,500 vehicles with a total of approximately 27,000 wheelsets. NR purchased a WILD system in August 1998. Since then they have worked closely with Teknis in order to gain the most out of the system.

As a joint effort Teknis and National Rail have undertaken an ongoing research and development program, looking at both the technical and operational aspects of the system.

The main areas of study to date are:

1. Wheel defects and their effect on bearings
2. Analysis of lateral tracking data to discriminate between types of tracking defects such as misaligned (or 'warped') bogies and faulty side bearers.

Other areas of interest include:

1. Wheel defects and loading related to safety
2. Affect of wheel and bearing defects on fuel consumption
3. Evaluating wheel defects and lateral ‘hunting’ as causes of load shifting
4. Average distance traveled between occurrence of a wheel defect and failure of the bearing
5. Relationship between wheel defect severity and average distance to failure (as described above)
6. The characteristics of different bearing types in response to similar wheel defects

The most important issues emphasized by National Rail have been:

1. Identification of vehicles by AVI tag enabling defect tracking and trend analysis over extended periods.
2. The ability to configure the system to raise alarms on serious defects that, by nature, do not have significant impact levels.
3. Separating vehicle data from different owners to safeguard confidentiality.
4. The ability to reprocess all original data in a separate database and so not risk losing current settings or results.
5. Reliability, accuracy and robustness.

In the first month after commissioning of the WILD, National Rail implemented an operational structure for managing the system. The current structure, refined over the 8 months since, is shown in Figure 11. The results of this approach are described in the following sections.

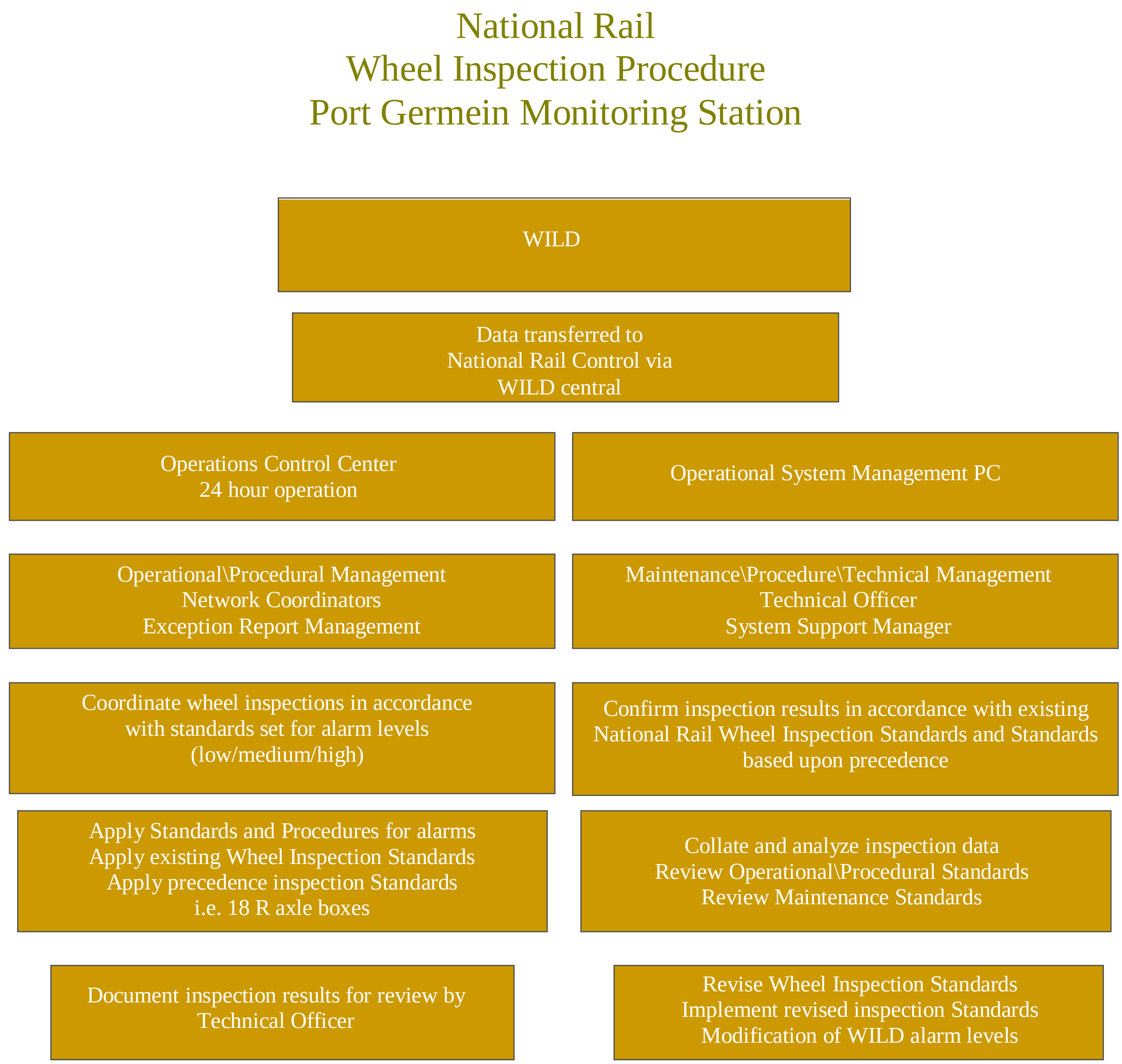


FIGURE 11: National Rail - WILD system management schematic

METHODS OF EVALUATION

WILD is a preventative system. Evaluating such a system, whose effect is the absence of something (e.g. bearing failures), is inherently less direct than evaluating a system that directly produces an output.

To quantify the effectiveness of the NR WILD we looked at:

1. Number of bearing failures before and after the system became operational.
2. Number of defects reported by the system
3. Comparison of reported defects with inspection results and proportion of defects so reported that result in a wheelset change-out.

NATIONAL RAIL - OPERATIONAL RESULTS

National Rail maintains a continual regimen of wheel inspection using accepted, industry standard techniques. This accounts for most serious wheel defects. However, the inherent limitations of visual and aural (or 'roll-by') inspections are well known.

Before the WILD system came into operational use National Rail had a highly seasonal bearing failure rate. In the cooler months (May to September) the rate would peak to 1 or more per week[4, 6]. During summer, the frequency was far lower. Averaged over an entire year, there would be approximately 2 bearing failures per month. Of these, approximately 75% were associated with 18R type bearings. It was thought that the great majority of these failures could be attributed to one of two causes; loss of bearing grease, or damage to bearings due to wheel defects. To combat the first, NR introduced a concerted program of preventative maintenance involving re-greasing all bearings. This began in June of 1998 and was completed in the first half of September. At the same time (August) the WILD system was commissioned. In the 8 months since there have been a total of 3 failures. All 3 were detected by WILD. As described later, these failures came about due to procedural issues characteristic of any new operation, rather than technical deficiency. Out of all defects detected by the system, the only three that were not reported caused derailments within weeks of first alarm. This, along with the number of defects reported, strongly suggests that re-greasing did not target the major cause of bearing failures.

The total number of incidents each month, reported by the WILD system, are shown in Figure 12. An 'incident' in this context represents a medium or high level alarm. In summary this graph represents a real reduction in serious defects of 90% over 6 months[4]. In January of this year the alarm criteria were changed to include lower level defects. This appears as a jump in the number of reported defects for February and March. There have been no defects reported by WILD that have been regarded as false alarms. All defects reported are inspected in accordance with current NR defect standards. These standards are, at present, in accordance with worlds best practice. National Rail plan to update these standards to take advantage of the new information generated through WILD. A reported defect that meets the NR inspection criteria for 'condemnable' is removed immediately. All high alarms, and about 35-40% of medium level alarms, fall into this category. Other wheels reported by WILD that do not conform to the standard are generally marked for continued observation to gather data on defect progression. Increasingly, the WILD data has been used to override the inspection results. Because of the relative newness of the system, this has only been done when it was felt that the defect presented a serious hazard even though it did not meet the standard for removal. In the case of 18R bearings the standard procedures have already been changed to adopt the WILD system as primary indication of a condemnable wheel defect[2, 3, 4] (see Table 4).

Table 3 is taken directly from an NR report[4]. It shows the comparison between defect data and visual inspection for the 23 wheelsets reported by WILD during September 1998, one month after the system was commissioned. Table 4 shows a similar excerpt, this time from January 1999. In many cases, the WILD defect classification matches closely with the observed defects. Where the defect data and inspection do not agree, the growing trend (as seen in Table 4) is for WILD to override the inspection results. This is due to the repeatability of the data from one pass to the next plus the fact that trains that produce alarms have been inspected and confirmed as OK only to derail soon afterward (see Table 5 and Figure 13). This strongly supports the system's ability to detect defects that cannot be detected by visual inspection methods.

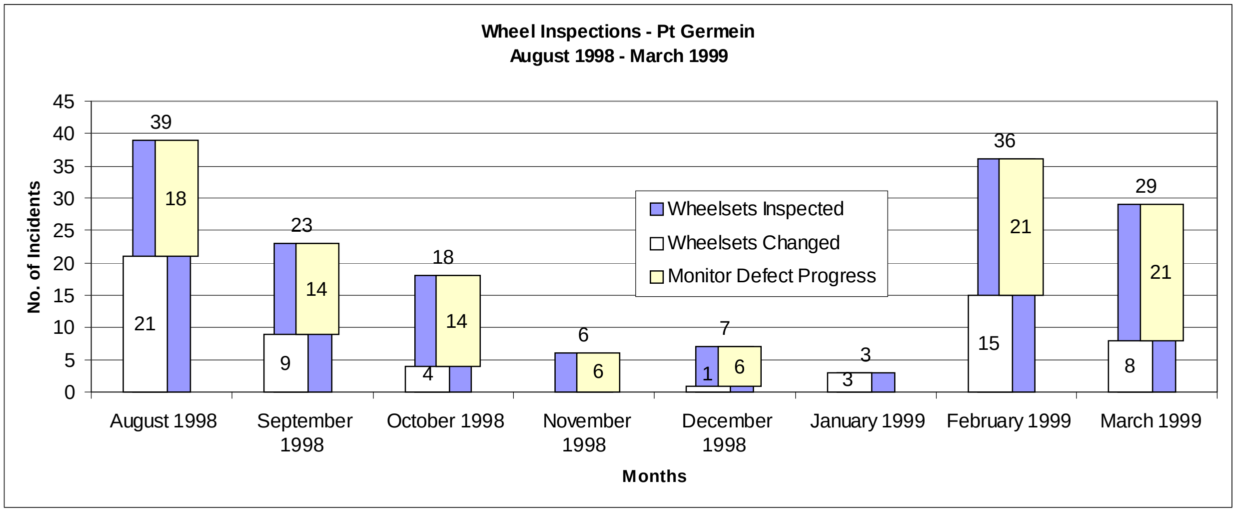


FIGURE 12: Defects reported and action taken for each month since commissioning

Defect Measurement and Classification	Action Taken	Description from examination
371kN Spall	Change	Wheelset impact for 18 R box over 300kN, change out wheelset. Wheel pitting approx. 3 mm in depth thermal cracking approx. 30 mm in length propagating from pits.
321kN Skid	Change	Shift Diary item refers to wagon having handbrake released at Bowmans, wagon detached and reattached at AFT, handbrake most likely left on at this location. Extensive skidding on wheels.
270kN Skid	Monitor	Morandoo Flying Gang to monitor wheelset condition.
264kN Skid	Change	Inspection of wheelsets indicated wheels pitted to approx. 3mm and thermals to approx. 30 mm in length. Wagon to be deployed to maintenance for wheelset change.
350kN Spall	Change	AFT Maintainers inspected wagon and advised hole the size of 20 cent piece approx 2 - 3 mm in depth, relatively thin wheel, wheelset changed out.
264kN Skid	Monitor	AEI tag on 'B' end repaired, no defects observed on wheelset, monitor wagon.
323kN Spall	Change	Hole in tread 80 mm x 40 mm 1.5 - 2 mm in depth. Network Coordinators notified requested to remarshall wagon to front of consist as safety precaution, red card on arrival into Sydney for wheelset change.
293kN Skid.	Change	Examination indicated extensive skidding over half wheel diameter, wagon carded to Whyalla for wheelset change.
315kN Skid	Monitor	G. Thorogood to determine condition of wheelset and advise course of action taken. Data to be obtained for loco's, table to possibly introduced to WILD system for loco alarm levels.
275kN Skid	Change	Wagon due for PM, deploy to maintenance for PM and wheelset change.
267kN Skid	Change	Wagon identified as being in the o\due category >50 000 km for PM, B. Benbow advised to remove wagon for wheelset change and PM.
285kN Skid	Monitor	Chullora Maintainers arranged wagon to be inspected by TO's at Cooks River, wagon deployed to Melbourne for inspection by WMC Flying Gang, no defect located on wagon, monitor wagon.
277kN Skid	Monitor	TX. Alice Springs to inspect wagon upon arrival.
285kN Skid	Monitor	Perth Maintainers advised to inspect wagon, inspection has indicated no fault with wheelsets on this wagon, monitor next time over site.
269 kN Skid	Monitor	Advised G. Thorogood, inspection to be arranged in Perth by Graham.
293kN Skid	Monitor	Advised TraileRail Perth to inspect wheelset on arrival into Perth and advise outcome of inspection.
266kN Skid	Monitor	Advised TraileRail Perth to inspect wheelset on arrival into Perth and advise outcome of inspection.
264 kN Skid	Monitor	AFT Maintainers to inspect on arrival into Adelaide, monitor over site to determine if magnitude of defect increasing.
264kN Skid	Monitor	Mick C to arrange inspection of wagon in Melbourne.
268kN Skid	Monitor	Crossing inspection indicated potential fault with consist, train speed reduced to 80 km\hr. Subsequent roll-by and visual inspections indicated no problem with wheelset. Monitor wheelset over site.
270kN Skid	Monitor	Wheel to be checked on arrival into ACR to confirm magnitude of defect on wheelset.
286kN Skid	Change	Wagon due PM, inspect Perth and confirm condition 'ok' to travel back to WMC for PM.
267kN Skid	Monitor	Wagon inspection arranged by Network Coordinators at Pt Augusta, wheel condition confirmed as 'ok'. Monitor next time over site.
315kN Skid	Monitor	Forwarded 'e' mail to T\Rail Perth to inspect bogie on arrival into Perth and advise condition of wheelset.
294kN Skid	Monitor	Forwarded 'e' mail to Maintainers Perth to inspect bogie on arrival into Perth and advise condition of wheelset.

TABLE 3: National Rail WILD inspection report - September 1998

Defect Measurement and Classification	Action Taken	Description from examination
382kN	Change	Wheelset changed on arrival into AFT due to 18 R box > 300 Kn. Two skids approx 50 mm in diameter noted and minor spalling. Wagon checked over site upon repair 16/1/99, 6AL7, wheel condition 'ok'.
277kN	Change	Perth Maintainers advise wheel displayed minimum spalling, no greater than ten cent piece. Wheelset changed due to high impact reading over site & 18 R box.
310kN	Change	Perth Maintainers to inspect\change wheelset also advise nature of wheel defect. Minimal visual spalling, normal inspection standards would not have changed wheelset.

TABLE 4: National Rail WILD inspection report - January 1999

Another NR report, this time from February 1999, is summarized as follows:

1. 36 wheelsets inspected, increased from 4 inspected in January due to reviewing inspection standards as a result of characteristics displayed (via WILD) by wheelset/hot-box failures at Tottenham and Port Augusta in early January (1999)
2. 15 (or 42%) of wheelsets inspected were replaced. Of these 12 were 18R bearings, 2 were 50t bearings and one was a 70t bearing
3. *Most, if not all, were not picked up during train examination*
4. Most were changed out in accordance with NR standards
5. All displayed similar impact characteristics

Point 3 from the summary above bears special mention. Regardless of the diligence of the train examiners, manual examinations, both aural and visual, are prone to letting through significant numbers of defective wheels. Some of the main reasons for this include:

1. The large number of wheels to be inspected necessitate a quick examination
2. Often wheels are partially obscured by brakes, bogie etc so that the examiners cannot clearly observe significant portions of the circumference
3. Some defect types cannot be seen when stationary nor heard when the train is moving at normal roll-by inspection speeds. This is especially true of sub-surface and long-period defects[10].
4. The severity of many defects is not proportional to the sound produced. Long-period defects especially, can hit the rail with extreme force while only dissipating a small fraction as sound[10].

LEARNING FROM FAILURES

As mentioned above there have been 3 instances where the data from the WILD system did not prevent a serious bearing failure. While unfortunate, this has allowed us to collect a small amount of data on the distance traveled between occurrence of a wheel defect and resultant bearing failure. On each occasion the failed bearing was of the type 18R.

The first such event occurred shortly after the WILD was commissioned. Because the operational framework was not in place the wagon proceeded for roughly 2000km before derailing.

In the second instance the wagon passed over the array 12 times prior to failure and 4 times after being repaired[2]. The data from each pass is shown in Table 5. On two occasions prior to failure the WILD system reported a medium level alarm (requiring immediate inspection at the next depot). The wheelset was inspected twice in accordance with National Rail standards. Results of the first inspection found ‘minimal spalling’. On both occasions the vehicle was deemed safe to proceed. On the third occasion that an alarm would have been generated, the vehicle crossed the array during a system upgrade that delayed the incident report. After the final array crossing the vehicle traveled a further 2000km before the bearing failed and the vehicle derailed. The data from the final pass again indicated a moderate alarm level but, due to the upgrade, the report was not printed until after the failure and derailment. It is unknown whether a third inspection would have resulted in removal of the wheelset. The data shows a distinct trend; Figure 13 shows kN impact values for all passes. The total distance traveled by the vehicle from first defect alarm to eventual failure was more than 7,000 km. However, the data shows clearly the presence of the defect 2 months earlier.

The data in Table 5 also demonstrates defect measurement consistency at various loads and speeds. The column headings are listed below. It is worth noting that this level of analysis would not be possible without AVI tagging to identify individual vehicles over time.

Dir	-	Direction of train travel. Defined as Up (U) and Down (D)
Date	-	The date the train crossed the array
Speed	-	The average train speed over the array
Car#	-	The position of the wagon in the consist
Load	-	Wagon mass in tonnes
Dam	-	Estimated track damage potential of the defect
A1k – A4k	-	Normalized kN impact data for axles 1 to 4

The inspection results indicated a small amount of tread build up on the first axle in the wagon. This would account for the low-level data shown on Axle 1 of the wagon[2].

Dir	Date	Speed	Car#	Load	Dam	A1k	A2k	A3k	A4k
U	16 Aug	101	29	64.8	6		142		
D	22 Aug	83	64	46.1	9		162		
U	30 Aug	106	34	59.2	8		174		
U	13 Sep	109	28	69.7	17	140	213		
U	01 Nov	91	23	88.3	29	144	267		
D	07 Nov	93	55	45.7	35	146	290		
U	12 Nov	104	25	74.5	43	150	323		
D	10 Dec	78	56	54.1	40	141	325		
U	13 Dec	102	27	59.3	45	138	331		
D	16 Dec	93	11	76.0	39	146	336		
18/12/98 Wagon Inspected – "Minimal Spalling"									
U	20 Dec	99	20	56.3	49	149	354		
22/12/98 Wagon Inspected – "Deemed OK to travel"									
U	31 Dec	104	31	52.8	56	144	373		
06/01/99 Bearing collapse									
D	24 Jan	98	66	51.8	0				
U	28 Jan	107	18	42.3	0				
D	06 Feb	90	51	52.7	0				
U	12 Feb	106	14	76.5	0				

TABLE 5: Defect history for wagon RQPW 60078

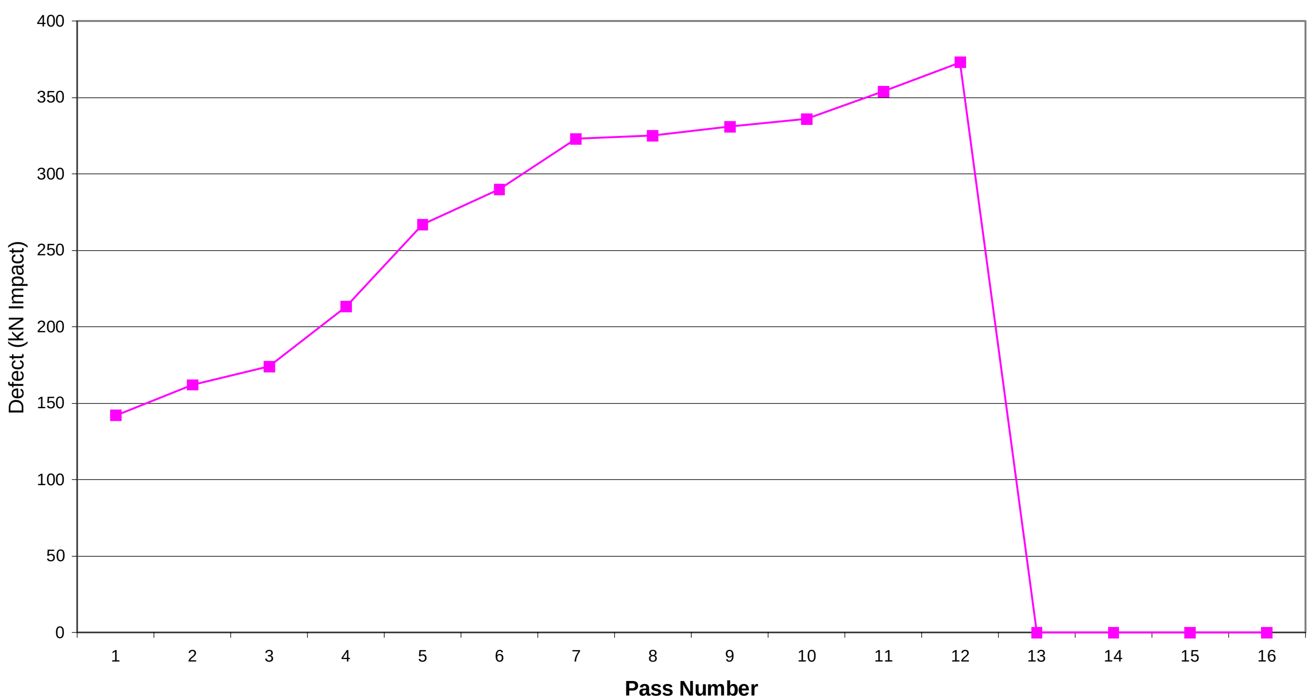


FIGURE 13: Plot of defect data for each pass of wagon RQPW 60078 over the array

The third failure occurred due to a missed tag that prevented the vehicle from being identified correctly[3]. Missed tags are rare. By chance, of all the vehicles in that consist this was the only one not to record tag information. Again, the distance traveled by the defective wheelset was several thousand kilometers.

In response to these incidents, National Rail has instigated systemic changes.

1. Alarm criteria have been lowered to encompass lesser defects.
2. Alarm levels for 18R bearings are lower than general levels to take into account the demonstrated higher susceptibility to wheel defects.
3. A second PC has been configured as backup to the main control PC so that real-time alarms are not interrupted.
4. Defect standards have been reviewed with regard to 18R bearings to incorporate the information gained from the WILD as primary indication of a condemnable wheel defect. A general review of defect inspection standards is also planned[4].

While these 3 cases by no means constitute a valid statistical sample, they do suggest that distance-to-failure may be as large as several thousand kilometers, depending on the severity of the defect. This is also supported by the practical elimination of failures with only one WILD system in place. An average train travels more than 2000 km between one pass over the WILD array and the next. If the distance-to-failure were orders of magnitude less than the distance between passes then there would still be a significant number of failures that occurred ‘between passes’.

In contrast, the distance from onset of detectable temperature increase (i.e. hot-box) to bearing burn-off can be less than 20km[12]. This means that, for bearing failures where the ultimate cause is a wheel defect, the detection of the wheel defect may provide far earlier indication of eventual bearing failure than standard hot bearing detectors.

ANALYSIS OF COST PER FAILURE AND CORRESPONDING SAVINGS

In purely economic terms, to translate these results into dollars requires an average total cost per failure. To be at all realistic, this must include both direct and indirect costs. Examples from both categories are listed below.

Direct Costs	Indirect Costs
Increased fuel consumption	Loss of business through increased costs
Part replacement, Vehicle damage	Labor, Transport, Equipment (i.e. cranes)
Track and structure damage	Schedule delays and loss of revenue
Damage to private property and freight	Compensation, Litigation

Data for such a cost analysis is difficult to obtain and estimates vary widely. Ironically, a true assessment of these costs has the potential to generate substantial savings through improvements in management targeting. A first pass would require only that all work relating to a particular incident be grouped under a separate project or job number.

As a starting point, the cost of removing and servicing a wheelset during routine maintenance is approximately US$7,000[4, 5, 6]. At the other end of the scale, a catastrophic derailment can range up to and beyond several million dollars. The average cost of a derailment has been estimated in a Canadian paper, at US$160,000[12]. National Rail however, believe that this does not take sufficient account of structure damage. The NR routes covered by the WILD system are all concrete sleepered. When a vehicle derails it will often be dragged for several kilometers, causing damage to a large number of sleepers etc. In terms of structure repair alone, NR estimates an average of US$190,000 per kilometer of track damage[6]. Recently, the Times of India newspaper reported a vehicle with a severe wheel defect causing "around 100 fractures" along more than 100 miles of track between Delhi and Ambala.

Although admittedly simplified, an approximate distribution of failures based on inverse proportionality between cost and frequency seems to agree reasonably well with available data[2, 3, 4, 5, 6]. This is shown in Figure 14 with failures divided up into 4 'classes'. The classes are described below.

Class1	-	Minor incident (e.g. bearing failure near depot) involving little collateral damage or associated costs
Class2	-	Moderate failure - some delays and or incidental costs incurred (e.g. crane, transport)
Class3	-	Major incident involving extensive damage to rolling stock and structure. Corresponding delays and indirect costs.
Class4	-	Catastrophic failure. Extensive damage to a large amount of rolling-stock and structure, possible injuries or loss of life

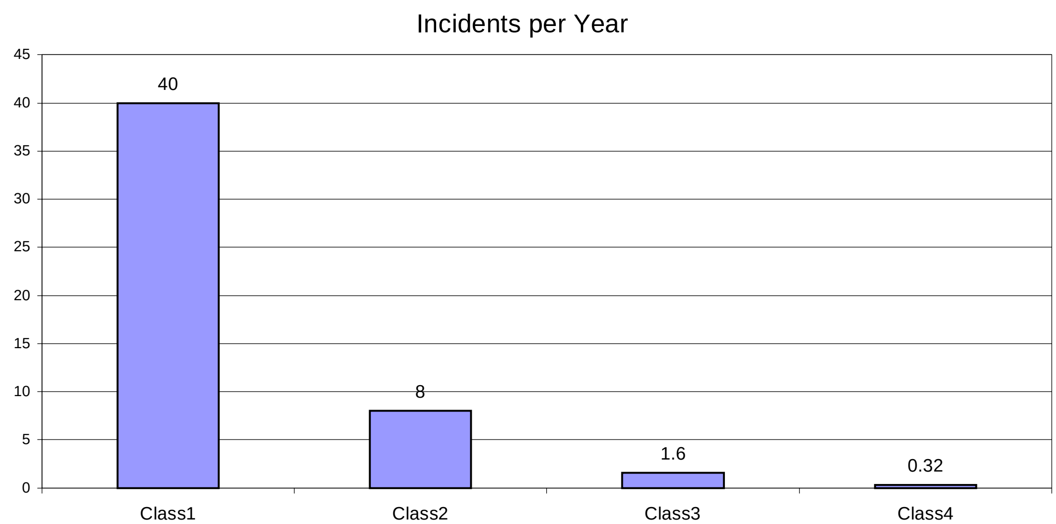


FIGURE 14: Estimated distribution of failures by class

Table 6 shows average cost per failure versus dollar value assigned to each class if we assume this distribution of failures.

	Average cost of failure in class (US$)				
	Class1 'minor'	Class2 'moderate'	Class3 'major'	Class4 'catastrophic'	Average cost per failure (US$)
Lower boundary estimate	$7,500	$37,500	$187,500	$937,500	$24,000
Middle level (NR) estimate	$12,500	$62,500	$312,500	$1,562,500	$36,000
Upper boundary estimate	$17,500	$87,500	$437,500	$2,187,500	$48,000

TABLE 6: Average cost per failure for various cost-of-failure-in-class values

If we subtract a base cost per wheelset of US$7,000 that would be spent on replacement regardless, then we are left with the difference in cost between detecting and preventing the failure and allowing the failure to occur.

The number of defects detected each month, that resulted in wheelset change-out, are shown in Figure 12. Aggregate totals for the first 6 months are listed below.

- 96 defects reported by WILD at or near the level reported for vehicles prior to recorded derailments
- 38 wheelsets changed out in accordance with NR standards or as a result of WILD data
- 3 derailments as a result of early procedural problems or delayed reporting as described above

From this large number of total defects and the decline in defects detected per month it would seem that the system was not only detecting potential failures for that 6 month period, it was also culling out wheels that would have failed later, say in 12 months or more.

Having calculated the average cost per failure we are faced with deciding how to use this to estimate savings. We could look at the question from the point of view of failure prevention. Effectively, this model translates into; "we usually get this many failures per six months. How much do we save if we prevent them from happening?" However, this becomes complicated when trying to deal with variations over time. Another way to express the problem would be, "I have 'x' defective wheels that will fail some time within the next 12 months or more, and new defects are being produced to replace the old ones that have been 'removed' through failure. How much do I save if I can stop the defective wheels currently in the system from failing *and* keep detecting the new ones before they have a chance to fail?"

This second model provides the simplest method and makes best use of the real data we have. In this model we can look at the early phase, just after installation of a defect detection system. We can also estimate the savings generated in the long term once the existing defects have been culled from the fleet. As mentioned previously, National Rail used to average approximately 2 failures per month[4, 6]. For such a 'steady state' system this also represents the rate of new defects appearing. This agrees well with Figure 12. Therefore, a reasonable estimate of the savings generated can be obtained by multiplying the number of defective wheelsets removed by the average cost per failure minus the base cost of repair. The results of this are shown in Table 7

	Savings			
Average cost per failure – base repair cost (US$7000)	First 3 months (34 wheelsets changed)	First 6 months (38 wheelsets changed)	First 12 months (70 wheelsets changed*)	'Steady state' annual (24 wheelsets per year)
$17,000 (low)	$578,000	$646,000	$1,190,000	$408,000
$29,000 (NR)	$986,000	$1,102,000	$2,030,000	$696,000
$41,000 (high)	$1,394,000	$1,558,000	$2,870,000	$984,000

* Number of wheelsets for 12 months projected from 61 at 8 months

TABLE 7: Estimate of savings for various intervals and average-cost-per-failure values

Of course, this does not take into account that some defective wheelsets were not changed out because they did not fit the NR defect inspection standards.

Using this model with the mid-level cost-per-failure assumed for NR operations, the estimated saving generated in 6 months amounts to US$1,102,000. Table 7 also shows the savings using higher and lower estimates of average cost per failure.

It is relevant to note that even the lowest savings figure (US$646,000) is several times the maximum (i.e. fully optioned) cost of a WILD system.

It should also be noted that these figures only relate to basic defect detection. They do not include benefits from load measurement or lateral tracking, neither of which has yet been modeled or quantified.

SAVINGS AS RELATED TO FLEET COVERAGE

National Rail currently has one WILD site, located so as to give maximum coverage. They estimate that this site sees approximately 60% of their fleet. Placed appropriately, an additional site could increase fleet coverage to 95%[6]. If the failure rates for traffic on different tracks were consistent then the total savings could be multiplied by a factor of 1.6 resulting in an increase in projected savings from US$2,030,000 to US$3,248,000 for the first 12 months. Steady-state annual savings would increase from US$696,000 to US$1,113,600. However, the routes up and down the eastern seaboard do not produce anywhere near the number of failures that occur on the east-west routes across the country. As to why this should be the case, there are several factors that seem relevant.

On the east-west lines:
1. Average line speed is higher (100km/h against 80km/h)
2. The structure is more rigid (concrete sleepers)
3. Runs are dryer, dustier and far longer between stops (the Nullabor plain)

Normally vehicles stay on one or the other section of the network. When vehicles do move from the eastern seaboard to the cross-country lines they are just as prone to failures and show similar defects to the vehicles that normally run on those lines.

This is not to say that the savings would not increase with greater fleet coverage. It is just not possible to use bearing failures to estimate benefits in the way we have done for the existing site.

CONCLUSIONS

The WILD system provides integrated data encompassing in-motion weighing, load pattern analysis and a range of wheel defect classifications.

Operational results show that this can provide rail operators with accurate, reliable condition monitoring information in a way that can be used productively.

By actively looking for and implementing improvements, both technical and procedural, National Rail have gained a significant improvement in fleet wheel condition plus a return on investment estimated at several times the cost of the WILD system within the first 6 months of operation. Because the system has displayed consistent ability to detect serious defects that cannot be found via normal inspection National Rail is using the WILD system as the basis for an enhancement of their defect inspection standards.

The data obtained suggests a strong connection between bearing failure and wheel defects. There is also clear indication that wheel defect detection may provide a far earlier warning of potential bearing failure than thermal ‘hot-box’ systems.

REFERENCES

1. K. Bladon (1999), Teknis Electronics WILD Trials Report - Contract CE.T.131.
2. C. Hunt (1999) National Rail Report on Collapsed Bearing - RQPW 60078
3. C. Hunt (1999) National Rail Report on Collapsed Bearing - RQJW 21970 K
4. C. Hunt (1998, 1999) various National Rail Port Germein Impact Site Reports
5. Private communications (1998 - 1999) Due to the commercially sensitive nature of the data, details of the data and sources must remain confidential.
6. P. Milton (1998, 1999) Private communications at National Rail
7. K. Bladon (1998) "Forecasting Crack Progression using the WILD System", Teknis Electronics Report No.327.
8. K. Bladon (1998) "Load Calibration for Level 1 and Level 2 WILD Systems", Teknis Electronics Report No.325.
9. J. Jergeus (1997) "Martensite Formation and Damage around Railway Wheel Flats"
10. S. Lechowicz (1997) "Defect Classification in the WILD", Teknis Electronics Report No.306.
11. Teknis Electronics (1997) - data on file
12. Surface Group - Railway Safety Directorate of Transport Canada (1996) "Hot Bearing Detector Study".
13. J. Jergeus (1995) "Martensite Formation around Railway Wheel Flats"
14. J. Jergeus (1994) "Martensite Formation in Railway Wheel Flats"
15. P. Bartle, R. Boelen, G. Chitty, T. Jeffs (1989-1991) "Wheel Tread Defect Detection" - Trails carried out for Australian National, BHP Iron Ore, Mass Transit Railway Corporation (Hong Kong), PTC of Victoria (Frankston Line), PTC of Victoria (Melbourne Underground Rail Loop), Queensland Railways, SRA of NSW (Freightrail), SRA of NSW (Cityrail). Various BHPR-ML reports. Report circulation is restricted to BHP and the relevant Authority. However, permission should be sought from other Authorities to make information available if required.

UNITS OF MEASUREMENT

Throughout this report there are several areas where measurements are quoted. The units used, along with conversion to imperial measures where applicable, are listed below.

Unit of Measure	Abbreviation	Description	Conversion
kiloNewton	kN	Metric unit of force	1 kN = 0.225 kips
kip	kip	Rail industry unit of force	1 kip = 4.448 kN
tonne	tonne	Metric mass	1 tonne = 2205 lbs
kilometer	km	Metric distance	1 km = 0.62 miles
meter	m	Metric distance	1 m = 39.4 inches
millimeter	mm	Metric distance	1 mm = 0.039 inches
U.S. dollar	US$	U.S. currency	1 US$ = 1.59 A$ at 3/99
Australian dollar	A$	Australian currency	1 A$ = 0.63 US$ at 3/99

GLOSSARY OF TERMS

18R bearing	A type of bearing used by NR highly susceptible to wheel defects
50t bearing	A type of bearing used by NR
70t bearing	A type of bearing used by NR
Accelerometer	A sensor unit used to measure force
AEI	See Automatic Vehicle Identification
Ambient temperature	Temperature of the surrounding air
Array	See sensor array
ARTC	Abbreviation of Australian Rail Track Corporation
Australian Rail Track Corporation	Australian owner of track structure
Automatic Equipment Identification	See Automatic Vehicle Identification
Automatic Vehicle Identification	In this context a combination of UHF tag sensor and radio reflective tags. The tags are attached to individual vehicles and are read as the train passes the radar tag sensor in order to uniquely identify a vehicle in a consist
AVI	See Automatic Vehicle Identification
Axle	Either the solid axle joining the wheels in a wheelset or another term for the entire wheelset
Bogie	Usually two or three wheelsets integrated with bearings, suspension, brakes etc to form a support platform for a rail vehicle.
Bulkhead	Electronic assembly designed to separate and protect sensitive equipment from potentially damaging environments
Burn-off	Describes a situation where a bearing has over-heated to the point of failure
Change-out	Refers to a defective wheelset being removed from a bogie for repairs
Class	See failure class
Collapsed wheel tread	Formed when the surface of a wheel is not sufficiently supported by the underlying metal due to cracking or cavities
Condemnable defect	A defect that requires the wheelset be removed and repaired or scrapped
Consist	A combination of motive stock and rolling stock that makes up a train
Contact patch	See rail/wheel contact surface
Control PC	The PC that contains the software required to control the WILD processor rack
Crack	A fracture in a wheel
CSU	Control Status Unit - a term used to refer to the WILD processing rack
Defect progression	The changes that occur over time to alter a defects characteristics from those of the original defect
Dialup	A communications link formed by a modem automatically dialing a pre-defined number. Also another term for PSTN.
Distance-to-failure	The distance a wheel travels between occurrence of the defect and eventual failure
Dragging Equipment	Anything attached to a train that is dragging along. Often, parts of the train that have broken but not fallen off completely
Failure	A situation where a wheelset is damaged so that it must be removed from the bogie. Often causes other damage
Failure class	A grouping of failures based on a defined average total cost per failure in the group
Flat	See skid
Gas Arrestor	High power shunt for excessive voltages
HDLC	High-Level Data Link Control. A robust synchronous communications protocol
High level defect	A defect which presents a high risk of derailment if the vehicle is not stopped immediately
Hot-box	Term used to refer to a railway wheel bearing that has over-heated due to internal friction caused by some fault in the bearing
Hot-wheel	Term used to describe a wheel that has had the brakes left on or dragging while travelling and so become hot. Used to detect sticking brakes.
Hunting	A vehicle moving from side to side until its wheels contact the gauge face of the rail. See tracking defect

Impact factor	Ratio of a measured impact value over the mass in an attempt to remove the variation in impacts produced by different masses
Impact force	The vertical force that occurs when a wheel that has a defect rolls along the rail
Incident	A defect or condition detected by the WILD system that warrants immediate attention
Incident report	Report generated automatically that describes a serious wheel defect or other serious alarm condition
In-motion weighing	In the context of the WILD this refers to weighing rail vehicles at normal line speeds
kiloNewton	Metric unit of force.
kN	Abbreviation of kiloNewton.
LAN	Local Area Network
Lateral tracking	The measurement of horizontal force designed to detect train wheels hitting the inner edge of the rail as they run along it
Leased line	A dedicated PSTN line
Level 1 load measurement	Basic in-motion weighing option in the WILD system. Uses 4 load gauges to provide +/-5% accuracy.
Level 2 load measurement	Full in-motion weighing option in the WILD system. Uses 12 load gauges to provide +/-1% accuracy.
Load balance	See load distribution
Load distribution	The balance of mass in a rail wagon from front to rear or side to side. Also, the weight of vehicles at various positions in a consist.
Load gauge	A sensor unit used to measure mass
Load pattern analysis	Examines load distribution to detect bad loading practices or shifted loads
Load shifting	A movement of load being carried in a wagon. Can be caused by wheel or bearing defects or warped bogies. Can damage freight and, in extreme cases, cause a derailment
Low level defect	A small defect with little damage potential. Important for analysis of defect progression.
Medium level defect	See moderate level defect
Moderate level defect	A larger defect often associated with wheels that have just become condemnable
National Rail	Short for National Rail Corporation Ltd
Normalization	Mathematical technique of removing the effects of variables so that data values can be directly compared
Normalizing reference function	A function applied to normalized data to some specific criteria
NR	Abbreviation of National Rail
Out-of-gauge	Anything attached to a train that projects outside a specified cross-section
Out-of-round	A defective wheel that is not circular. Can be caused by bad machining or by collapse of the wheel surface due to sub-surface defects
Overload	A vehicle carrying weight over the specified limit for the line or for its type
Processing rack	The signal processing hardware that converts sensor array signals into data to be sent to the control PC
PSTN	Short for Public Switched Telephone Network. Refers to the international telephone system based on copper wires carrying analog voice data.
Rail temperature	Temperature of the rail
Rail/wheel contact surface	The line that runs along the rail and around the circumference of a wheel that defines the normal points of contact between the two surfaces.
Return current	The current flowing through the rail that completes the circuit formed by overhead electrification and an electrically powered locomotive
Roll-by inspection	An inspection method whereby a train rolls slowly past a train examiner who listens for defects
Sensor array	The various sensors attached to the rails at a WILD installation
Severe defect	See high level defect
Side-bearer	Provides lateral stabilizing between carriage body and bogie frame
Single-point earth	Radial grounding scheme where every return line is physically connected to the same point

Skid	A flat spot on a wheel caused when the brakes lock up and the wheel slides along the rail
Spall	A defect produced when a part of the wheel surface breaks away forming a depression
Step-down transformer	Equipment used to convert a higher voltage to a lower one
Sub-surface defect	Cavities or cracks under the surface of the wheel
Tag	A radio reflective identification badge attached to a vehicle
Tag reader	UHF sensor placed at the side of a track, used to read AVI tags as vehicles pass
Teknis	Short for Teknis Electronics Pty Ltd
Total cost per failure	The total of direct and indirect costs associated with a failure
Tracking defect	A defect that causes a bogie not to run straight with respect to the track
Traction	An electric locomotive applying power to increase speed
Transient surge	A sudden change in current and/or voltage
Transorb	High speed semi-conductor device that shunts excessive voltages to ground
Unloader	Refers mainly to the machinery used to automatically unload coal or minerals from a wagon
WAN	Wide Area Network
Warped bogie	A bogie in which the wheelsets are not properly aligned
Wheel condition	General term encompassing all aspects of wheel quality esp. to do with wheel defects
Wheel defect severity	The magnitude of risk associated with a wheel defect
Wheel flange detector	A sensor unit used to detect a train wheel passing
Wheel Impact Load Detector	A system designed to measure rail vehicle loading and wheel defects
Wheel switch	See wheel flange detector
Wheel zone	See zone
Wheelbase	The distance between the center of the inner wheels of two adjacent bogies on the same vehicle
Wheelset	Comprises two train wheels joined by a solid axle
WILD	Wheel Impact Load Detector manufactured by Teknis Electronics
WILD array	See sensor array
WILDDB	The WILD database application
Zone	Roughly equivalent to dividing a wheel into 5 equal segments. For purposes of detecting wheels with multiple defects

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The <u>R</u>emote <u>A</u>ircraft <u>F</u>light Recorder and Advisory <u>T</u>elemetry System, <u>RAFT</u> (Patented)**, And It's Ability to Reduce fatal Air Accidents By 78%**
While Enhancing Air Space Capacity, Operational Efficiency and Aircraft Security

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1. INTRODUCTION

RAFT is a worldwide, real-time aircraft remote monitoring and recording system that takes an aircraft's Digital Flight Data Recorder, DFDR, monitoring parameters out of an archival data base and plugs them into a safe, readily available, usable accident prevention system. RAFT combines the DFDR sensor data with the data from the Air Traffic Management/Control (ATM/C) system along with GPS/GLONASS, Map, Terrain and Weather information to actively anticipate and prevent accidents. It ends the information vacuum created by the aircraft and the ATM/C where presently each of them, acting independently, don't have sensors that directly measure the necessary parameters required to prevent a crash. By the sharing of the digital data, all of the necessary crash prevention parameters become visible and usable to actively anticipate and prevent problems from turning into fatal accidents. It opens the whole field of commercial aviation to the use of expert systems to minimize fatal accidents. Privileged non-safety related data is ciphered at the aircraft to insure air carrier confidentiality. In addition, the global telemetry of the DFDR parameters allows aircraft monitored data to be simply and safely stored on the ground. Thus making it readily available for aircraft statistical analysis programs that enhance air carrier efficiency and safety. Also, in the advent of a crash, it provides a timely accurate global estimate of the downed aircraft's location for search, recovery and hopefully rescue operations. It establishes an aircraft global data super highway that uses high bandwidth satellite and ground Internet communication links to supply the aircraft advisories necessary to enhance air space capacity, operational efficiency, security and reduce fatal accidents by seventy-eight percent.

RAFT brings to aviation what the Internet brought to data visibility and utilization. It unifies the National Airspace System (NAS) and fills the information vacuum that has been responsible for twenty years of a stagnant air carrier fatal accident rate. This information vacuum has seriously compromised the safety net and is the major cause of the stagnant air carrier fatal accident rate. It has also led to a situation where **currently air travel is over nine times more lethal than bus travel[1], over three times more lethal than car travel and over fifteen times more lethal than space shuttle travel.** RAFT makes all of the necessary safety data visible and readily available to the people who need to solve problems. It does this in a timely and cost effective manner, before they become fatal accidents. This is accomplished by reducing workloads while unambiguously enhancing the situation awareness. The present overly dependent verbal system, that is prone to fatal misinterpretations, is supplemented with visual safety emergency icons and physical synthetic vision representations of the situation. RAFT also provides functional redundancy, simplifies the communication system and enhances the safety and timely availability of the recorded data. It is the only system capable of meeting the national goal of reducing the fatal accident rate by a factor of five in ten years and provides the necessary safety net that should be put in place prior to any transition to free flight.

2. MAIN SECTION

2.1 BACKGROUND

More accidents can be attributed to aircraft data utilization than to stress and fatigue failures of the airframe. **The present federated airspace system is failing[1] to reduce the accident rate mainly because it presents the data too late, is prone to single thread failures, difficult to modify, costly and doesn't meet the needs of the new millennium.** On 9/26/97 there was a 234-fatality, Garuda Indonesia Airlines A-300 accident. The plane went into a mountain because the air traffic controller and pilot's verbal left right heading rotational instructions were confusing and misinterpreted. Other verbal errors also may have contributed to the accident. The information was being displayed via the air traffic control (ATC) radar blip or dot. At the instant time of the crash the dot disappeared from the screen. A screen dot contains no information as to the direction\rotation of an aircraft. Yet the direction of the aircraft is a DFDR parameter provided by the inertial navigation system (INS). If the aircraft along with the terrain had been depicted to the ATC, in a simple synthetic vision display that showed the actual aircraft correctly rotating, this accident wouldn't have occurred. This accident highlighted two basic problems with our present safety systems. The first being that the system is too dependent on voice communications, that can easily be misinterpreted or unintentionally given out erroneously. The second is that the system displays depend on inferences and are abstract. They don't utilize all of the data available to make them human friendly. Fortunately in this information age we can supplement the voice and radar blip displays with synthetic vision, human friendly presentations that increase the situation awareness and substantially reduce fatal accidents.

In the 1960s there was a very successful infusion of technology into the NAS —placement of the INS into commercial aircraft. The initial INS was inserted on the B-707 by Pan American Airlines. In order to prevent a single-thread failure and provide redundancies of this critical function, two INS were installed. The FAA required that two INS units be functional prior to takeoff. To mitigate the risk of a delay, if one of the INS experienced a problem prior to take off, a third INS was installed on the B-747. In a similar fashion the autopilot, like the INS, is now functionally redundant. These units now have a very high functional availability. For enhanced safety it is desirable to eliminate other single-thread functional failures by having at least dual redundancy for fatal accident prevention.

An example of single-thread failure is the 228-fatality crash of the Korean Airlines B-747 Flight 801 that occurred on 8/6/97 at Agana Guam. At the time of the accident the ATC tracking radar was working, but the glide slope unit was inoperative. With the loss of the glide slope radar, the plane's altitude was low resulting in a crash into a hill. The altimeter on the aircraft was working. In this instance, if the aircraft's altitude data had been cooperatively shared with the ATC tracking radar data and used in an integrated display, it could have provided a backup for the malfunctioning glide slope unit. The aircraft's glide slope display can be made transparent to the failed microwave system so that the pilot would not require a different presentation. Thus, by the cooperative sharing of the DFDR and ATC data in real-time, accidents like this can be avoided. Because of the major advancements in computers, memory and communications bandwidth and technology it is now possible to provide safety function redundancy at a fraction of the present federated system cost.

The present DFDR system is analogous to having a patient in intensive care being monitored. However few people look at the data until the patient dies or after release from the hospital. The DFDR is so important that in the advent of an ocean crash we risk lives and expend vast amounts of time and money searching for it. Even with these Herculean efforts the recovered DFDR's recorded data may be unreadable. After recovery of a readable DFDR, we utilize its data in a playback mode to perform a post-flight animation and analysis to determine the root cause of a crash. This is necessary to take a corrective action that will prevent the future reoccurrence of the accident. The DFDR data is also routinely collected for post-flight statistical analysis. With six real-time programs that cooperatively share the DFDR and ATC data, about 78 percent of the fatal US air carrier crashes can be prevented. Post-flight analysis of non-crash data is still a reactive approach to flight safety, although some may marginally call it proactive. This important post-flight safety work, which can save up to 5 percent of the fatal accidents, is presently being carried out in the Flight Operational Quality Assurance (FOQA) program. **The big pay back in flight safety, as well as cost savings, does not come from post flight analysis but only comes from using this data in real-time application programs that are targeted at accident prevention. These real time programs that share safety data will result in a dramatic increases in air capacity, safety, security and operational efficiency.**

The present safety data vacuum, created by not sharing all of the sensors required in real-time to solve safety related problems, has been the major cause of the lack of reducing the air carrier fatal accident rate in over twenty years[1]. This period represents two-thirds of the time that the NTSB has been in existence. With the growing use of air travel this translates to an ever-increasing number of unnecessary and presently preventable air fatalities. By the real time sharing of the digital safety data, all of the necessary crash prevention parameters become visible and usable to actively anticipate and prevent accidents. The flight crew is responsible for control of the aircraft and ATC is responsible for the airspace and airport areas. The flight crew and the controllers are in a codependent symbiotic cooperative relationship for the safety and economic benefit of the public. It is this relationship that brought radars to both the pilot and the air traffic controller's utilization. Therefore the system should aid in minimizing misunderstanding and expedite communication to minimize fatalities. Thus air travel is a cooperative synergistic enterprise between the flight operation centers, pilots and the air controllers that requires precise communication for safe transportation. Simple shared safety advisory icons, warning of problems, only inserted into displays when there are potential and existing problems, will significantly improve safety and situation awareness while decreasing work loads. These safety icons/alarms would only come on during potential and existing problems and thus would not clutter or distract from the normal ATC displays. At present, once alarms come on in a plane there is a lot of voice communication that takes place, between the flight crew and the traffic controllers, that can easily be misunderstood. It also puts stress on both the pilot and controller, depletes precious reaction time and increases their workloads. The 1/25/90 Avionca crash, that had 73 fatalities, is just one case of where communication problems under stressful conditions have led to fatalities. The Avionca plane ran out of fuel while in a ATC directed holding pattern over JFK Airport. The crew reported to the ATC that they were running out of fuel but did not use the word emergency. The FAA listed the cause of this fatal crash as pilot error. This syntactical mistake is no reason for people to die since a simple emergency low fuel safety icon can automatically be displayed on the ATC monitor, similar to the low fuel warning light on automobiles, to alert the controller of the dangerous low fuel status. The low fuel warning light or oil pressure warning lights in an automobile doesn't increase the driver's workload but simply increases the situation awareness and prevents catastrophic failures. Once a controller receives a low fuel warning light he can then set the landing priorities to expedite a safe landing. The fuel supply is another one of the DFDR parameters whose data is presently locked in the aircraft DFDR and thus the ATC doesn't have any visibility other than with voice communication with the aircraft that the fuel is low. The problem was not the crews voice communication, pilot error or the air controller but the present unforgiving system that shares its safety data begrudgingly and has been willing to sacrifice innocent people for simple and normal human errors. The lack of automatically sharing of cooperative safety data did not permit the controller to have an unambiguous situation awareness of the pre-crash emergency. The 8/6/97 Korean B-747 crash is also another case of the failure in the single thread, verbal communication system. The ATC could have continually verbally requested the aircraft's altitude from the flight crew and together with his radar range information successfully verbally guided the plane down to a safe landing. Also if the aircraft's DFDR altitude data going to the DFDR was readily and automatically available to the ATC, it in combination with the ground radar could have easily provided an automatic back up for the malfunctioning glide slope radar. In the future, after RAFT is operational, and a 6/8/95 ValuJet type fire occurs, the fire and smoke sensors added to the plane and recorded in the DFDR, will light icons and sound alerts not only on the flight deck's displays but also on the air traffic controller's console. It is the controller's responsibility to assure that a plane that is or may be experiencing a critical flight problem on the ground is not cleared for a takeoff. Also that a plane experiencing a critical flight problem in the sky, is cleared for a safe landing in the shortest possible time. It is also important to alert the necessary ground support people to care for the passengers and flight crew so as to minimize further disasters. The present system is too verbally dependent in communication for the next millennium. Just as the internet is moving from just printed data to printed, graphics and acoustics; RAFT will permit the migration of the shared aviation system's safety information to move from essentially verbal communications to acoustic, graphic and printed. With the use of commonly shared visual icons as well as acoustic alerts the situation awareness of potential problems will be raised so as to prevent fatal accidents.

Another crash that could have been avoided with the RAFT system was the 9/2/98 Swissair, MD-11, flight 111 crash that killed 229 people. The plane left JFK Airport in NY and headed over the Atlantic towards Geneva, Switzerland. The pilot calmly made a "Pan, Pan, Pan" call telling the controllers that there was "smoke in the cockpit" and asking for a landing deviation "to a convenient place, I guess Boston." The controllers in Canada's Moncton Center suggested Halifax. In order to accomplish this the aircraft had to descend steeply. Although, the smoke in the cockpit wasn't bad enough to prevent this from occurring and the aircraft was capable of a steep descent the pilot decided to pass Halifax and circle back. After passing Halifax, while circling back, the plane went out of control and crashed at a high speed into the ocean. The pilot, in the present obsolete and antiquated system, is on his own. Many experts asked "Why didn't they pull the plug and bring the heavy laden trijet down quickly to a safe landing on the runway?" The flight recorders weren't working during the last six minutes of the flight, after it passed Halifax. There is some evidence that a fire existed in the entertainment wiring, but no one knows for sure what happened.

The RAFT real-time expert system would have prevented this fatal accident. It is no different than what we do for our astronauts in the space shuttle program. RAFT transmits the DFDR data in real-time to the ground, so that experts equipped with an aircraft simulation capability can provide the pilot with the safest way to handle this situation. Like the ValuJet debacle, there was plenty of time to bring the MD-11 down to land in Halifax. The vehicle had the capability to descend quicker and there was sufficient time to provide experts located on the ground to advise the pilot as to how best to handle the situation. The lack of a RAFT expert system hot line that had complete visibility to the control parameters being monitored on the plane, prevented the saving of these lives. Thus, unlike our astronauts, this pilot wasn't given any expert advice that included the benefits vehicle simulation. He was on his own, experiencing a situation that he had never encountered and 229 people died in a horrific crash. RAFT would have prevented this, and future situations in this class, from occurring. Too often we look to fix specific problems, via our traditional crash investigations. New problems will always emerge that can lead to fatal accidents. Fortunately in most cases there is sufficient time to bring a plane down to a safe landing. What's needed to substantially drop the fatal accident rate is a proactive real-time system that tackles whole classes of unanticipated problems before they become fatal accidents. Aircraft problems need not turn into fatal accidents. The lack of a real-time monitoring and a proactive system is the real cause of most fatal accidents. RAFT, on a global basis, prevents these aircraft problems from turning into fatal accidents.

2.2 DETAILED DESCRIPTION

RAFT is a worldwide real-time aircraft remote monitoring recording system that is used for enhancing airspace capacity, operational efficiency, passenger safety and security. It brings the digital flight data recorder information out of an archival database and plugs it into a real-time usable accident prevention system. It ends the information vacuum created between the aircraft and air traffic controller. Presently each is acting separately lacks the sensors to directly measure the necessary parameters required for preventing aircraft mishaps. Combining these data sensors enhances the effective sensor suite so that many events can be anticipated. This event anticipation capability provides the visibility and time mandatory for the prevention of accidents. A best estimate of the location of a downed aircraft for timely search, rescue and retrieval operations may be provided by linking the global telemetry of the DFDR parameters to a ground processing and distribution station.

RAFT updates the federated system and unifies the communications approach so that the relevant data parameters are globally visible and readily available for timely and cost-effective problem resolution. It is a system engineering approach that potentially can eliminate or minimize the need for the costly and time intensive recovery of the aircraft's recorder. An alternate is to keep the existing FDR and to use RAFT as a redundant system that essentially eliminates the need to recover, in all but a very small percentage of the crashes, the recorder. By so doing, it also eliminates the need to routinely post flight down load the recorder for FOQA data. The FOQA data will automatically and securely be disseminated, at essentially no cost, to the proper people. Thus RAFT alleviates a broad spectrum of problems. As time progresses, and RAFT proves its reliability over many years of service, the existing on-board FDR will atrophy (similar to Omega, Loran and sextant star fixing navigation equipment).

Twenty-four hours worth of DFDR data, for all of the US air carrier, taxi and cargo aircraft is not an insurmountable data quantity to be managed and can be contained on 32 gigabytes of disk space. This amount of data presently fits on only two personal computer (PC) disks. Because of the advances in information processing and communications technology, a modern airspace information system can be built that will effectively simplify the aircraft avionics and provide redundancy as well as add capability. One major advantage of this system is that it can provide routing, weather, map and topographical data while also providing redundancy.

RAFT remotes the DFDR and its communications system will integrate the ATC, air carrier dispatch and the aircraft into an integrated system that will reduce the number of aircraft LRUs while providing redundancy. The two-way data super highway can handle the information of the DFDR data transmitted from the aircraft to the ground. By balancing the uplink and downlink transmissions, it can also provide the communications pipeline for safety advisories, weather, terrain/map and differential GPS corrections transmitted from the ground to the aircraft. It is a total global system approach to the problem that is aimed at reducing maintenance, enhancing operational efficiency, and increasing air space capacity and safety. The following paragraphs, figures, and descriptions illustrate the advantages of RAFT system.

Figure 1 depicts the RAFT Avionics System. It shows an aircraft consisting of a sensor multiplexer transceiver, also called the sensor multiplexer receiver and transmitter (SMART), that receives the inputs from the aircraft's performance and control sensors. The GPS and/or GLONASS navigation satellite data, if available, are also other inputs into the SMART. The RAFT transceiver antennae radiates to a communications satellite the sensor data compiled from SMART along with cargo bay, passenger compartment, and cockpit video information, and acoustic data. SMART also receives advisory data from the communications satellite, which is then shown on the Advisory Display System (ADS) panel located in the cockpit. Although Figure 1 depicts two antennae, it is possible to utilize only one antenna depending on the uplink and downlink frequency selected for the communications satellite. Although the figure shows separate LRUs for the display and data multiplexer functions, it is possible to utilize the existing LRUs aboard the aircraft, in multi-functional mode, for the RAFT displays.

Figure 2 depicts the worldwide communications link. It illustrates an aircraft communications with the nearest satellite and then the communications satellite link. The aircraft's data reception satellite then relays this data to other satellites in a line-of-sight communications data link until it reaches the closest satellite with an unobstructed data transmission path to the Central Ground Based Processing Station (CGBS). Communications is duplex, and thus the CGBS receives aircraft data and communicates with each aircraft or with all of the aircraft in the net simultaneously. Major safety data advisories in the form of cautions, warnings, and alerts are transmitted to the operating aircraft based on the ground processing of the information from the aircraft and ATC system. The ATC system consists of air traffic control radar and GPS surveillance data along with in-route weather information and map & topographical databases. These advisories are transmitted to the cockpit ADS as depicted in Figure 1.

Figure 3 depicts the CGBS. It shows the processed and stored data, aircraft simulators, aircraft advisory generators, display and control of the CGBS, and data transmission modules to the ATC, aircraft manufacturer, and air carriers. Because some of the data are air-carrier privileged, a number of the data parameters are ciphered at the aircraft's SMART so that only the air carrier has the encrypt keys. This is similar to the telecomputing banking and Internet charge card systems. The ground transmission of the data will utilize existing high band width fiber optic backbone communications links with capabilities of 45 to 155 million bits per second. These links are presently being used on the Internet.

Figure 4 depicts the Ground Based Distribution system. It shows the ground processor communicating with the map, topographic and weather data base systems. It also depicts the aircraft manufacture and air carrier communications links and the ATC/M communication system. RAFT encompasses both the Terminal Radar Approach Control (TRACON) and the En-route ATC/M functions.

Some other examples of accident occurrences relating to data deficiencies in the present ATC/M system are airport runway/ground incursions. The salient example of this type of accident occurred on 3/27/77 at Tenerife in the Canary Islands. Two Boeing 747s (KLH and Pan American) crashed head on along a runway killing 583 people. Although this accident occurred some 20 years ago its root cause still exists. Two recent examples of runway/ground incursions include (1) the 2/1/91 LAX, Los Angeles, CA ground collision where a US Air Boeing 737 landed or a Skywest Fairchild Metroliner that killed 34; and (2) the 12/3/90, Romulus, MI Northwest Boeing 727 and Northwest DC-9 runway incursion that killed 8. These runway/ground incursion killers can and will continue to occur unless RAFT is implemented to plug the hole in the information system. RAFT will alter the future ATC/M and CAS global displays. The current blip/point/dot plan position indicator (PPI) type radar displays, which are 1950 vintage carry over presentation technology, are incapable of showing the aircraft rotation. RAFT displays depict actual aircraft and shows the status of their brakes, landing gear, thrust, track, Euler angles; and a safe path or collision alert in a timely simple presentation. These new displays will decrease the flight deck and controller workload while increasing their situation awareness. The present blip/dot/point displays are ambiguous and as such require excessive interpretation and concentration to be utilized in future systems. They are incapable of meeting low fatal-accident rate criterion. Most of the current ATC and CAS physical displays can be programmed to RAFT compatible presentations. These will depict actual aircraft, terrain and map data on simple human friendly displays that will increase the situation awareness of both the flight crew and traffic controllers while decreasing their workload. This physical representation of aircraft and terrain while minimizing the formerly ambiguous blip/point/dot displays is an excellent example of where the fusion of DFDR and ATC data simplifies human interface during routine and stressful operations.

Figure 3 and 4 combine to provide not only the ATC/M function but also a global weather and air turbulence reporting and advisory system for operational efficiency and safety. The most current weather maps, made available from government and flight operation center meteorology departments, are transmitted to the flight crew via the telemetry system. RAFT provides a global communication system so that the flight crew and the flight operational centers jointly makes routing decisions based on the best available weather and airport status data. The ATC/M are automatically informed and can participate in these critical decisions. Planes that are experiencing weather data anomalies, such as clear air turbulence and lightning, report their findings to the central ground based weather system in order to update the database. Decisions such as fuel remaining, distance to destination and aircraft location are automatically factored into the efficiency and control equation to assure safety. The ground processor performs the real time booking keeping effort to assure that an aircraft isn't following too closely into the clear air turbulence, disturbance, wake created by a preceding aircraft that was flying close to the same local trajectory. The computer keeps track of wake extinction coefficients by aircraft, derived analytically and experimentally, to assure that the proper time delay and safe separation distance are met. The weather data created in the flight deck is automatically time and position tagged. Since the system has all of the best data available, and a global wide bandwidth communication system, it can disseminate the information to all of the people who need to solve the weather and routing problems in a timely manner. Thus optimal decisions for the routing of an aircraft can be made.

Figure 5, Tenerife et al, Raft Provides Automated Collision Avoidance Alerts, ATC/M and CAS Enhanced Capability Display, generically shows the situation of the 583-fatality head on Tenerife collision. It illustrates two aircraft on a runway orthogonal to each other. Both aircraft have their thrust on, brakes off, and are heading for a collision. Due to the inability of the ATC to see that brakes are off, thrust on, or the possibility of a collision, a fatal accident could occur. The ATC under these conditions depends on voice communications with the pilots, which may be misinterpreted. RAFT because of its access to all of the parameters going to the flight recorder, can show the ATC the brakes, thrust, velocity, and heading of both of the planes in a simple graphic display as well as process the data to anticipate a collision. The map inputs to the system can provide the ATC with pictorial displays similar to those shown in Figure 5. The processor solves the estimated collision point long before it occurs and sends automated advisories/alerts that will enable the aircraft to take anti-collision maneuvers. Using RAFT the crash-avoidance advisories can be sent to the aircraft via manual as well as automated voice and ADS alerts. Working with air traffic controllers and pilots will optimize the exact colors of the displays utilized as well as the blinkers and human engineering crash prevention alerts. The pictorial data will be made to work with existing monochromatic displays; however, color monitors provide more human performance enhancements, are more user friendly, more effective, and are the current display technology.

Figure 6, Tenerife, et al., No More, Raft Provides A Safe Trajectory Display ATC/M & CAS Enhanced Capability, depicts a safe takeoff condition for the previous example. Here the display will show a green safe path for takeoff for the plane that has thrust on and is moving. The red aircraft at the cross-runway condition is stopped with brakes on and engine thrust low. The digital processor computes a safe trajectory, which is depicted by a safe trajectory arrow. This simple ATC display pictorial is an example of the type of display RAFT is capable of providing. With the existing radar, or even future GPS non-cooperative system, these accidents will continue to occur since the ATC doesn't have access to the brake and thrust vectors that are recorded away in the DFDR. Using radar and/or GPS and differentiating the position vectors to get velocity and then differentiating again to get acceleration is both too noisy and time consuming to use for collision avoidance in the close encounter ground/runway incursions areas.

The conditions requiring a safe takeoff trajectory arrow are more complex than just the collision case. Clear air turbulence, weather, topographical and runway status, length, and icing conditions will be part of a safe-to-take-off simulation that takes into account the aircraft type, weight, etc. to arrive at a pilot advisory. The caution/warning safe-to-take-off advisories can be automatically sent to pilots on the ADS displays. Accidents such as the 3/22/92, Fokker F-28-MK4000, that crashed at the end of the runway at La Guardia Airport, Flushing, NY are too often attributed to pilot or controller error, but are in fact system breakdowns. The complex relationships required for take off under adverse conditions should be aided by a pre-takeoff computer simulation that advises the pilot of the probability of a successful take off on the ADS display. It is possible that the takeoff and landing safe algorithms will be time dependent since it may be important to alter the time between takeoffs to account for the air turbulence wakes generated by the preceding aircraft. Turbulence wake extinction coefficients could be used, or past history based on tests, may have to be used in the absence of active laser/microwave turbulence sensor data. The RAFT system aids the controller and prevents work over-loads by providing the bookkeeping of the time dependent operations and simple aircraft animated real-time visual displays.

The Avianca, 1/25/90, Boeing 707 accident that killed 73 in Cove Neck, NY as a result of an aircraft running out of fuel after being put into a holding pattern, is an example of where data being sent to the DFDR should be used in real-time. The ATC would have knowledge of the remaining fuel with its estimated flight time capability and not solely depend on voice communications. A fuel-remaining icon can flash on the ATC's display; for example, to indicate when an aircraft has only 15 minutes of fuel remaining. The fuel caution icon could be only illuminated during the low remaining fuel conditions and thus would not clutter the display during routine operations. The low fuel icon displayed on the ATC terminal would be similar to the low fuel warning light in an automobile. This Avianca accident was also attributed to pilot/first officer error when in reality the pre-RAFT existing federated, non-cooperative safety system was the cause of these fatalities.

In a similar fashion the fire monitors can have their alarms displayed simultaneously in the cockpit and as a fire icon on the ATC's display. This remote alarm capability is similar to many of the fire alarm systems installed in private residences, businesses and government buildings. This dual alarm system would have provided an early warning, followed by mitigating actions which would have prevented the Value Jet, Miami, 5/11/96, 100-fatality accident.

The entire class of Controlled Flight into Terrain (CFIT) is still another example of where RAFT will substantially reduce accidents. This is accomplished by terrain map databases uplinked to the cockpit for synthetic vision as well as the terrain map information superimposed on the ATC in air and runway displays. The displays will also show the aircraft animation and not just ambiguous dots to show their rotations. These displays can be simpler than the present blip/point/dot rotation displays. RAFT permits these high fidelity displays by way of its cooperative safety data sharing capability.

In addition the present airborne X-Band, 3 cm wave length weather radar sensor, which is capable of seeing objects in all weather, day and night, must get restored to it's original multi-function mode. Even though CFIT has been responsible for a high percentage aviation fatalities (see TABLE 1), over the last thirty years the airborne radar has been allowed to atrophy from an anti-collision and weather capability to just a weather radar. This radar must be returned to its original multi-function mode of weather and surveillance. In the maritime industry it is the X-band radar that provides the anti-collision capability for both boats and ships. The low cost X-band airborne radar, implemented via a modified control and display system, can eliminate almost all of the CFIT. This day and night, all weather, radar will provide the visibility of terrain to essentially eliminate CFIT fatal accidents such as the 8/6/97 Korean Airlines, B-747 Agana, Guam, the 4/3/96 US Air Force, B-737, Dubroynik, Croatia, the 12/20/95 American Airlines, B-757 (Cali) Buga, Columbia and the 9/27/97 Garuda Indonesia Airlines, A-300 Buah Nabar, Indonesia.

The X-band radar supplemented with runway corner reflectors will also provide a much higher signal strength robust landing system than the GPS stand alone versions. The stand alone GPS landing systems are too easily prone to navigation data outages. This is due to the GPS navigation receivers being susceptible to only nano-volt electro-magnetic interference from intentional jamming and unintentional man made or natural electro-magnetic L-band radiation noise sources. The aircraft's radar can also provide the robustness needed for Cat. I, II and III landing systems and combined with GPS and INS in a complementary filter system it will provide the required redundancy and high operational availability. There are even compelling arguments for keeping the present microwave Instrument Landing System (ILS) and integrating it with the other sensors to add more redundancy into this critical function. This complementary filter system will minimize the GPS deficiencies (e.g.: A one watt jammer - the size of pack of cigarettes- will render the GPS navigation signals useless for 25 miles. Four-watt GPS jammers that fit into the palm of your hand are now internationally available to render GPS useless for a 100-mile area.). Thus the X-band radar will add an all weather direct viewing rf visibility to the flight deck that enhances the crews visual perception to essentially eliminate CFIT. The information system would be supplemented with synthetic vision objects provided by map and terrain databases. The X-band radar, which can see both fixed and mobile targets, can be used to automatically register the synthetic visual system as well as to eliminate synthetic vision problems that result from faulty data bases or mobile objects. Thus the radar and data base map systems complement each other to enhance the optical visual system.

Figure 7, the RAFT CAS Display presents another example of the benefits of RAFT. The system can provide the aircraft with a Collision Avoidance System (CAS) aircraft display or an enhanced Traffic Alert CAS (T-CAS) display that works in the close encounter environment. The present aircraft CAS only works when the planes are widely separated, moving at constant velocity, and statistically have few or no collisions. This enhanced T-CAS display (that can be put aboard the aircraft) has the necessary data parameters to anticipate and prevent crashes. This figure shows two planes on a collision course. With the sharing of cooperative data, such as the velocity and Euler angle vector data that come from the INS and go to the DFDR and the aircraft's present T-CAS transponder data, all of the necessary data parameters to anticipate and prevent a collision exist. In the close encounter environment, differentiating the existing aircraft CAS radar or GPS position vectors to derive velocity is too noisy and time consuming for a reliable collision avoidance capability. Thus RAFT, by its cooperative sharing of data, provides a means toward the global prevention of many of the in-air collisions (e.g. Lockheed C141 Starlifter and German/Russian aircraft that collided over the southern coast of Africa on 9/13/97 killing 33; Boeing 747 and Ilyushin II-76TD collided over New Delhi, India killing 349). These fatalities can be avoided with RAFT CAS or a RAFT enhanced ATC or preferably both. Another advantage of the RAFT implementation is that it permits the CAS display in the flight deck and ATC to work both in the air and on the ground to prevent air, runway, and ground to air boundary incursions. It also will permit the ATC and aircraft to select and view, on demand, identical displays to prevent misunderstandings of intent.

Figure 7 also depicts a plane flying on a non-collision course that is experiencing two problems. One problem is that it only has one of its landing gears down and the other is that it only has fifteen minutes of flight time fuel remaining. These are depicted with a flashing landing gear and low fuel remaining icons that pulsate so as to increase the flight crew and controllers situation awareness of the problems. The problem icons only come on when a problem exists so as not to increase operator work loads or unnecessarily clutter the displays during routine operations. In fact, like the warning icons in a car, these icons decrease work load by permitting the operator to concentrate on the main task and not so much on the inferences of the metered displays or misinterpretations of verbal communication.

Figure 8 depicts how RAFT provides an aircraft data super highway, similar to the Internet that respects an air carrier's privileged data. It shows air carriers having both privileged and safety related data. This data is transmitted to a global satellite communications link that provides two- way communications to the ground CGBS. Once the data is on the ground the data packets are sorted and distributed to the air carriers and ATC. Each air carrier receives its own data, including safety and privileged encrypted data. At their facility they can decipher their privileged data. The safety data on the other hand is cooperatively shared with the air traffic controller management systems and the air carriers. This will fill the present safety data vacuum by providing the sensor data necessary to prevent most information deficient accidents. It provides on a timely basis, via the Internet at essentially no cost, the FOQA data to the air carriers. RAFT substantially increases safety and increases air carrier operational efficiency. Once the data is at the air carriers the standard FOQA post-flight software tools can be utilized. In addition RAFT permits a paper-less inspection, maintenance log and Aircraft Safety Reporting System (ASRS). Thus, it corrects the deficiencies in the present flight recorders and provides a significant enhancement to air safety and operational efficiency by providing an aircraft data super highway. It unifies the communications approach so that relevant data parameters are globally visible and readily available to users.

Figure 9, Aircraft On-Board Layout, depicts the sharing of DFDR data with the ground system. It shows some of the most salient parameters being shared to greatly enhance air safety, security and efficiency. It also illustrates how RAFT will bring a much needed level of globally enhanced capability, redundancy and optimality to the existing system that is presently overly dependent on voice communication and inferences. The 1998 losses of ATC radar visibility of the President's plane over CONUS from the ATC/M system is still another reason for RAFT. It provides a satellite based ATC/M surveillance system that would be a redundant back up to the existing ground based radar ATC systems. In the low air traffic density areas that extend beyond the radar horizon or don't have radar coverage it would provide a non-redundant ATC/M global safety net function. RAFT, by it's global coverage, can prevent many of the collisions that take place beyond ATC/M surveillance radar horizons. Thus RAFT provides significant enhancements to the present system that is prone to failures of omission, commission and misinterpretation as well as equipment outages.

Figure 10, shows a chronology of the communication costs per plane per average flight. The curve shows that the communication costs for a global system is being drastically reduced. This is a direct result of the technology advancements increasing the channels and bandwidth while reducing the cost of Low Earth Orbit (LEO) digital data communication satellites. By the year 2003 several low cost high band width LEO satellite communication systems will be operational and other low cost LEO satellite constellations will be in the process of getting to be globally fully operational. These LEO systems, projected to the year 2008 will bring down the average cost of the RAFT system to only nine dollars per flight. It is estimated that the safety benefit alone for RAFT at that time will represent a savings to the total of all air carriers of over $400 million per year. When the other operational efficiency benefits of RAFT are factored in, the savings will reach over a billion dollars per year.

Table 1 is a tabulation of the worldwide air carrier fatalities and fatal accidents between 1987 and 1996. This table is a compilation of accidents sorted by causal type for all of the world's air carrier operators and by only the US operators. It tabulates the percent of fatalities and the percent of fatal accidents by accident type for the present system and compares these actual statistics with an estimate of what they would be if an operational RAFT system were in place. It shows that the RAFT system is more effective for the US operators than for the worldwide operators. This is because world wide air carriers presently experience more sabotage and highjacking than the US air carriers. Even though RAFT is not very effective in preventing sabotage and high-jacking accidents, it can help through its video system by ensuring that the person checking in at the ticket counter is the same person that boards the plane. Other applications of the passenger compartment video is to monitor, record and hopefully discourage passengers from trying to enter the flight deck, seriously interfering with the function of the flight attendants, and endangering the aircraft. This is similar to the security video monitoring done in many businesses and government offices. A cargo area video sensor also serves as a backup fire and smoke detector as well as a detector of potentially dangerous cargo shifts. RAFT can reduce US fatal accidents by 78 percent.

3. CONCLUSIONS

RAFT is a world wide real-time remote aircraft flight recording telemetry system for enhanced air space capacity, passenger safety, security and operational efficiency. It utilizes existing state-of-the art communications, Internet, computer and software technology to unify the total avionics system. The DFDR sensor information, supplemented with video and radar data, is brought out of an archival database and into a real-time usable accident prevention system. In addition, it ends the information vacuum created by the aircraft and air traffic controller, where presently each acting independently, don't have the necessary measurement sensors that are required to prevent a crash. This information vacuum has compromised the safety net and is the major cause of the stagnant air carrier fatal accident rate. It has led to a situation where **currently air travel is over nine times more lethal than bus travel[1], and over three times more lethal than car travel. In addition it is now fifteen times more lethal to be a passenger on a commercial airliner than it is to be a passenger on the space shuttle.** The space shuttle utilizes a real time ground based global monitoring, recording, simulation and expert advisor system to make space flights safe. In this day and age, this proven safety technology can be harnessed and utilized for commercial air travel. This will drastically reduce the fatal accident rate as well as make air travel more economical.

By the cooperative combining of the aircraft and ground data sensors, and thus sharing the safety parameters in real time, the effective sensor suite is enhanced and the system can now anticipate many types of crashes. This crash anticipation capability provides the visibility and time necessary for the prevention of fatal accidents. Furthermore, by the global transmission of telemetry of the DFDR parameters to a ground processing and distribution station, it provides a best estimate of a downed aircraft position for timely search and rescue operations. It also minimizes and eventually can eliminate the need for the costly and time-intensive recovery of the flight recorder. RAFT unifies the air space communications information system. It provides an aircraft data super highway, similar to the Internet, to assure that the relevant data parameters are globally visible and readily available to the people who need them in order to timely and optimally solve problems in a cost-effective manner prior to them becoming accidents. Furthermore, it optimizes the safety net and adds a level of redundancy to the present and planned sub-optimal capacity and safety systems, which are prone to single thread failures. The system, which can be operational in five years, alleviates a broad spectrum of operational efficiency, air space capacity and air safety problems. RAFT provides the safety net that should be in place prior to any transition to free flight.

NOTES:

1. **Recent DOT Statistics show that air travel is over nine times more lethal than bus travel:**

★ US Air Carriers have 4.8 fatalities per 100 million miles traveled based on 5.9 billion vehicle miles.

★ US Buses have 0.5 fatalities per 100 million miles traveled based on 6.4 billion vehicle miles.

(Buses were taken for the comparison statistics with carrier aircraft since both are classified as multi-passenger transportation carrier vehicles and their annual vehicle miles are equivalent.)

The recent statistics also show that air travel is over three times more lethal than bus travel and fifteen times more lethal than travel on the space shuttle.

The air carrier fatal accident rate has remained essentially constant over the last twenty years. This constant fatal accident rate is in spite of the advances in:

Pilot training do to the use of high fidelity flight simulators.

Aircraft materials due to enhanced fabrication methodology and superior metallurgy that has made them stronger and less subject to fatigue.

Avionics enhancements due to large scale integrated (LSI) semi-conductors that made the electronics smaller and more reliable, and improvements in engines and fuel that have made them more reliable.

Engine reliability due to advancements in engine fabrication and materials, computer aided design (CAD) and simulations.

In the years between 1965 and 1970 there was a significant reduction in the fatal accident rate and fatalities. This was due largely to improvements in jet engines that made them more reliable, microwaves that provided enhanced surveillance radar ATC/M and Instrument Landing Systems (ILS), and inertial navigation systems (INS) that reduced the aircraft's dead reckoning position errors. The radar based ATC also significantly enhanced the automated sharing of safety data between the plane and the ground monitoring system. Since the 1970's, there has not been a significant increase in the number of safety parameters that are automatically shared between the flight deck and the ATC. It has been this stagnation in avionics information that has directly caused the two decades of stagnation in the air carrier fatal accident rate. RAFT, which can be operational in five years, ends this information vacuum and thus reduces the fatal accident rate while making air travel more economical.

BIOGRAPHY: SY LEVINE

For the past several years Sy has been working on a world wide, real time, remote monitoring system called RAFT that will enhance air transportation safety, security, operational efficiency and air space capacity. Prior to this endeavor he was the Chief Engineer at the Northrop Grumman Corporation Electronic Systems Division in Hawthorne, California. One of his early patents, that dramatically changed commercial aircraft navigation, was for the first commercial inertial navigation system, INS, put aboard Pan American aircraft. He is an internationally recognized expert in program management, systems, navigation and servomechanisms.

FIGURE 1 AVIONICS SYSTEM

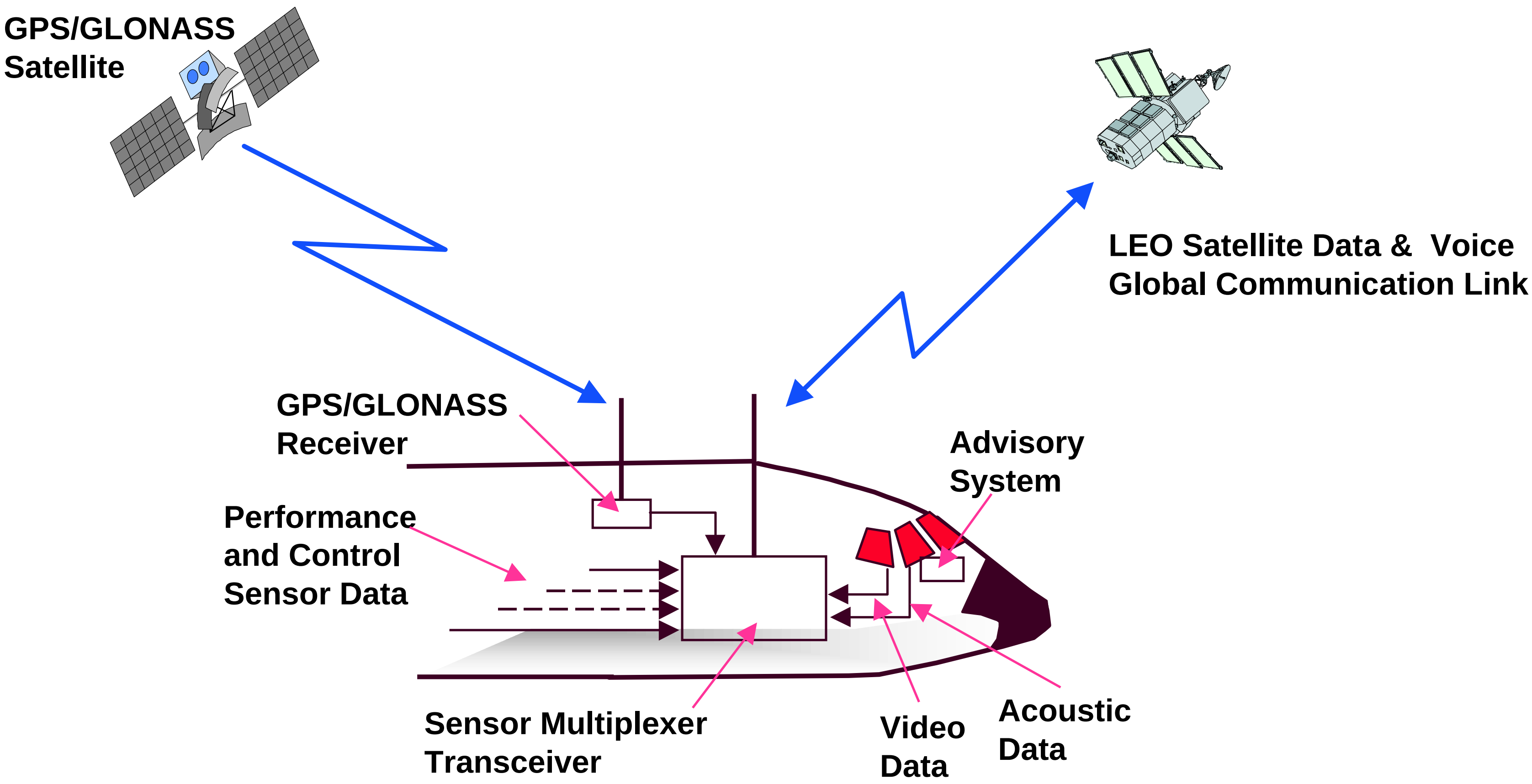


FIGURE 2

LEO SATELLITE DATA & VOICE GLOBAL COMMUNICATION LINK

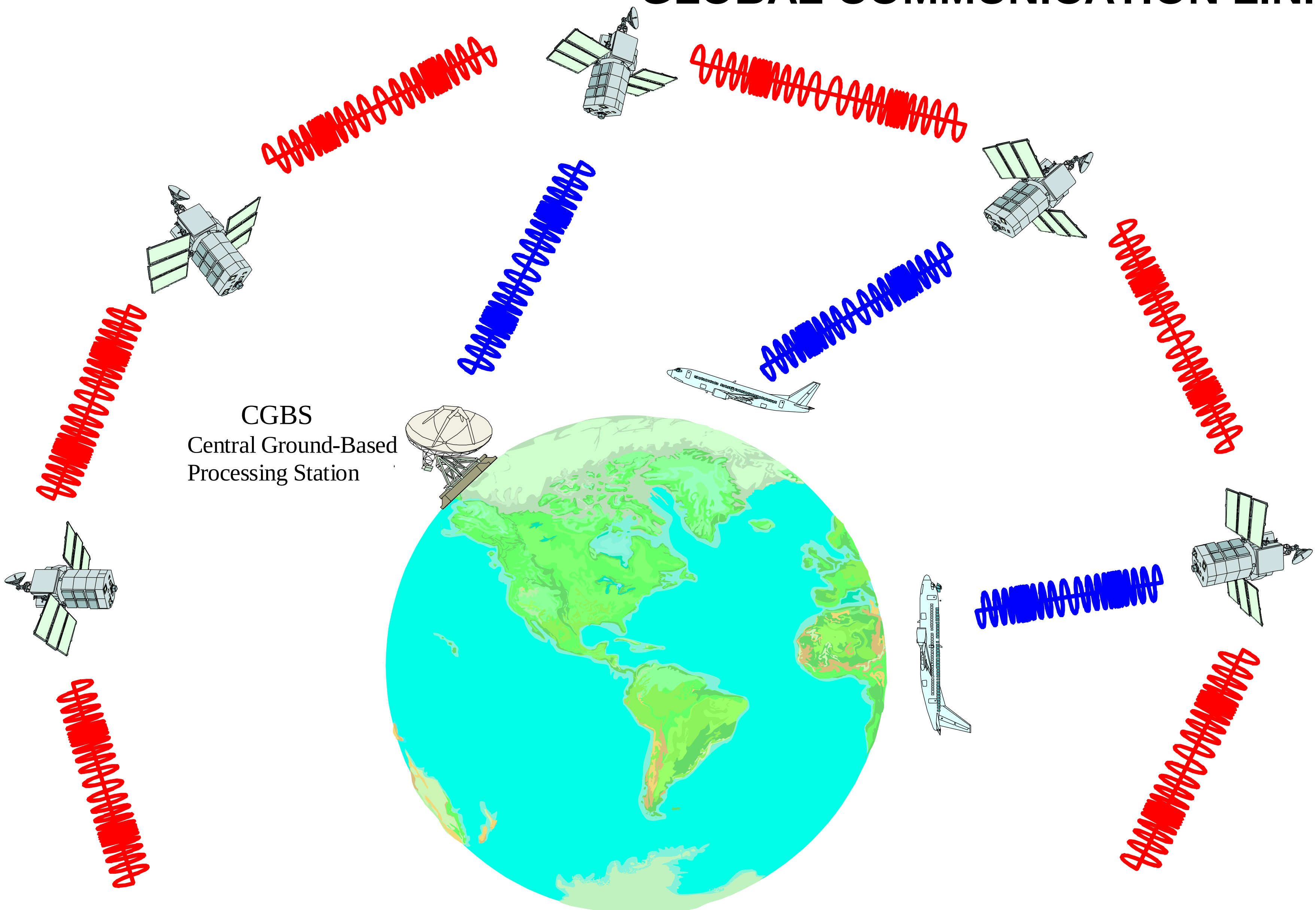


FIGURE 3

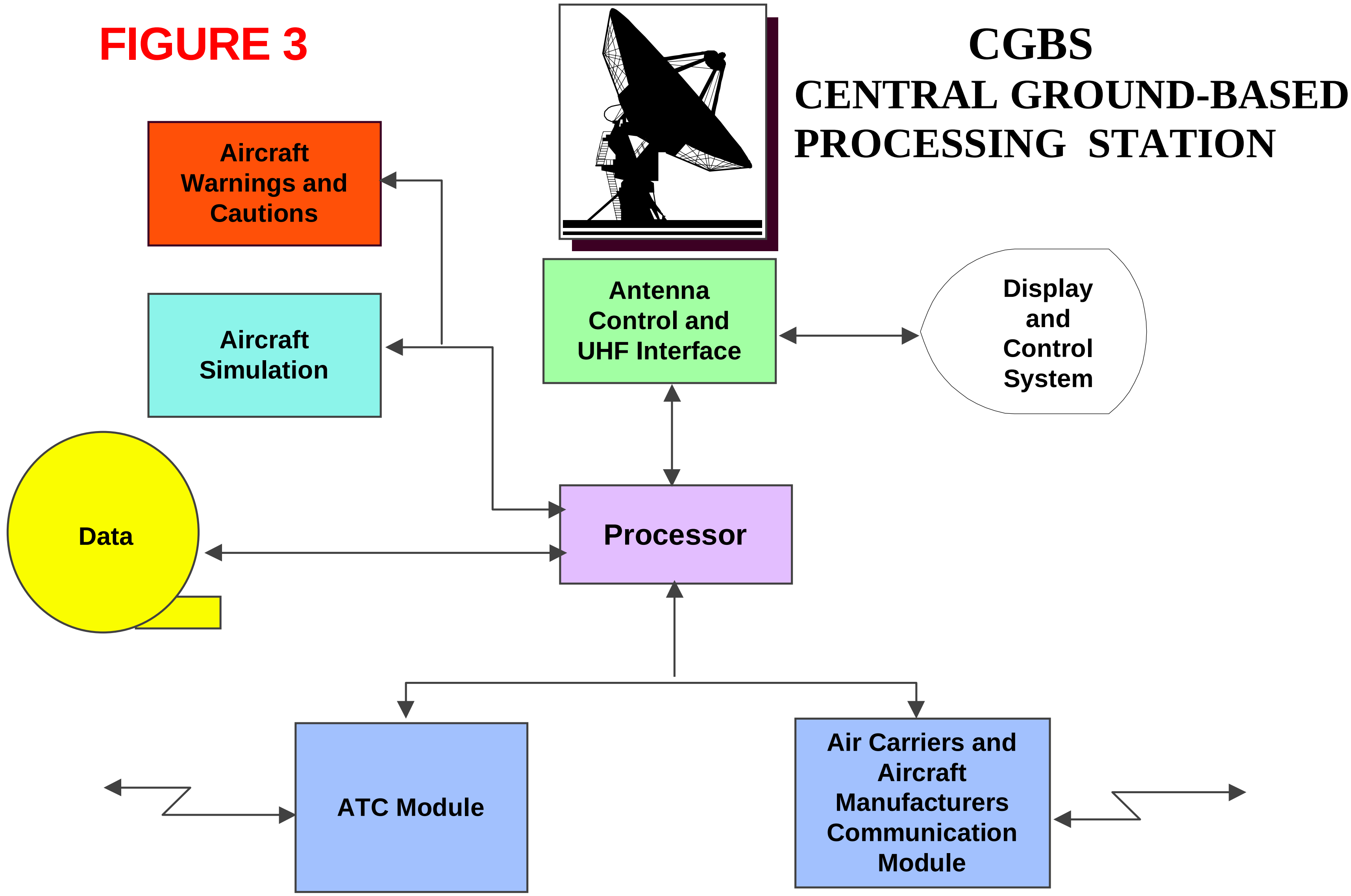

CGBS
CENTRAL GROUND-BASED PROCESSING STATION
Aircraft Warnings and Cautions
Aircraft Simulation
Antenna Control and UHF Interface
Display and Control System
Data
Processor
ATC Module
Air Carriers and Aircraft Manufacturers Communication Module

FIGURE 4

GROUND-BASED DISTRIBUTION SYSTEM

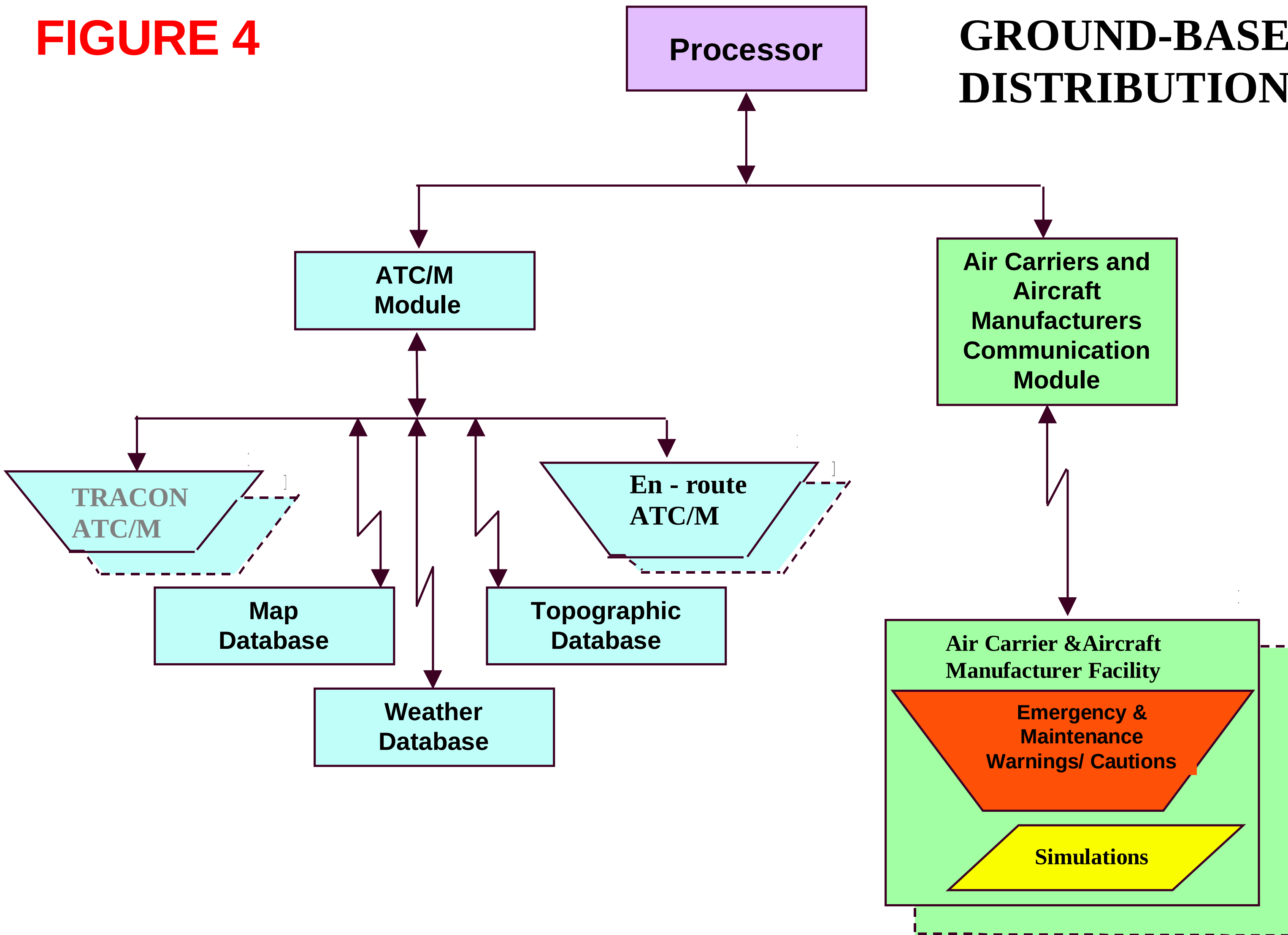


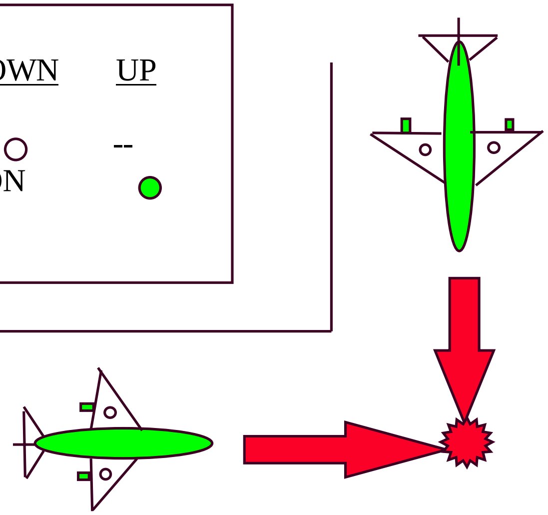
FIGURE 5 TENERIFE ET AL.

RAFT PROVIDES AUTOMATED COLLISION AVOIDANCE ALERTS

ATC/M & CAS ENHANCED CAPABILITY DISPLAY

TRANSLATOR

	DOWN	UP
LANDING GEAR	○	--
LANDING GEAR DOWN- BRAKE ON		●



Note: The 583 fatality Tenerife crash was head on. This pictorial is a generic representation and shows aircraft orthogonal on a runway crossing.

COLOR CODE TRANSLATOR

AIRCRAFT	GREEN	RED	YELLOW
FUSELAGE	PLANE MOVING	STOPPED	--------
ENGINE	HIGH THRUST	OFF	LOW
BRAKE	ON	-------	------

PROJECTION

COLLISION TRAJECTORY

ESTIMATED COLLISION POINT

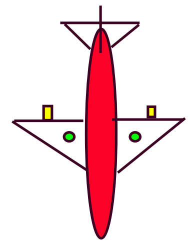
FIGURE 6 — TENERIFE, ET AL., NO MORE

RAFT PROVIDES A SAFE TRAJECTORY DISPLAY

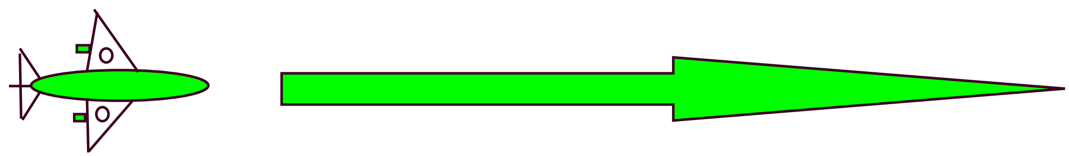
ATC/M & CAS ENHANCED CAPABILITY

TRANSLATOR

		DOWN	UP
LANDING GEAR	○		--
LANDING GEAR BRAKE ON	●		--



Note: The 583 fatality Tenerife crash was head on. This pictorial is a generic representation and shows aircraft orthogonal on a runway crossing.



COLOR CODE TRANSLATOR

AIRCRAFT	GREEN	RED	YELLOW
FUSELAGE	PLANE MOVING	STOPPED	-------
ENGINE THRUST	HIGH	OFF	LOW
BRAKE	ON	-------	-------

PROJECTION

SAFE TRAJECTORY

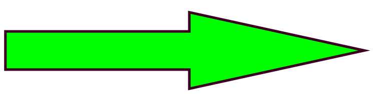


FIGURE 7 RAFT CAS DISPLAY

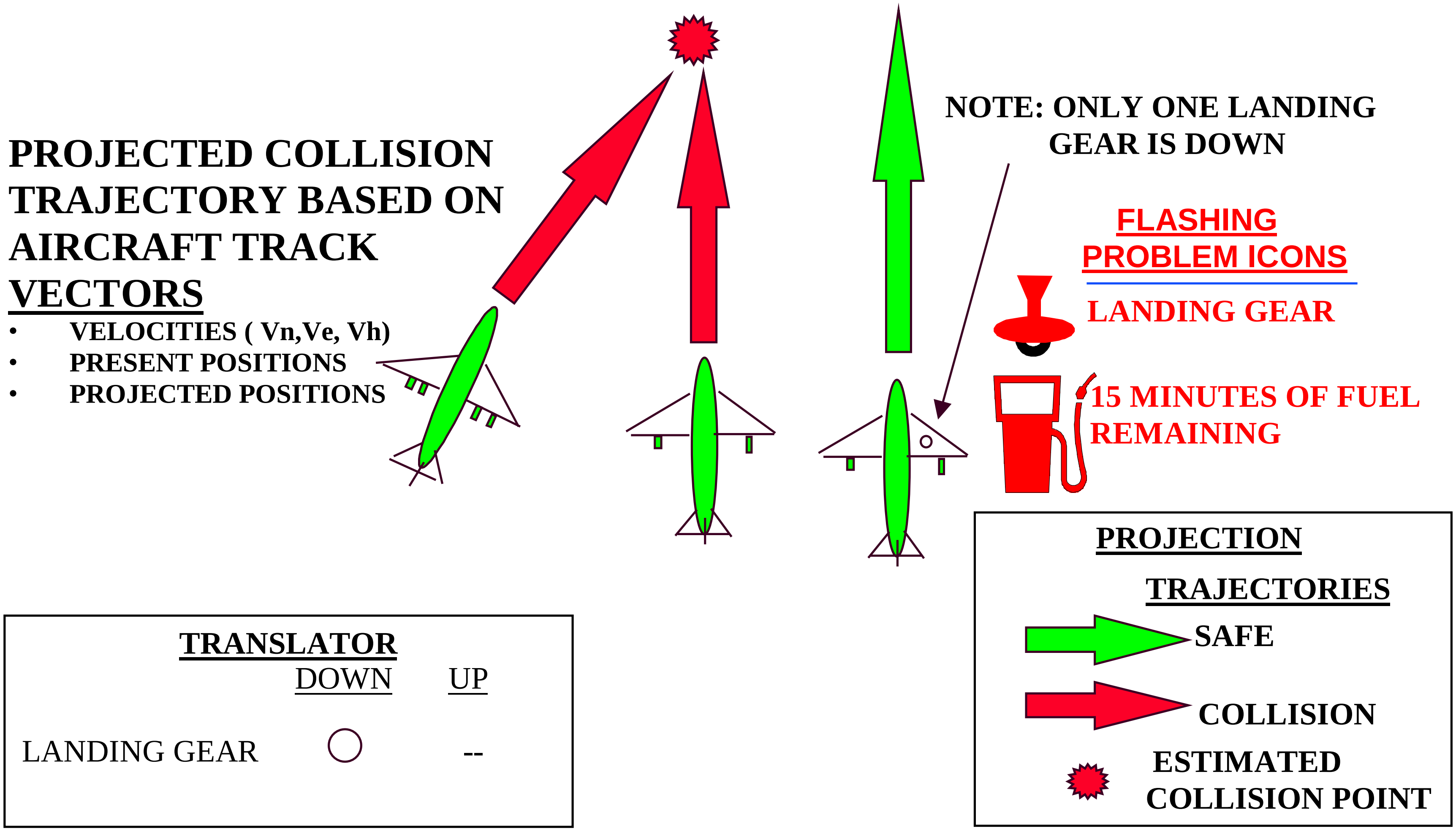


FIGURE 8 RAFT PROVIDES AN AIRCRAFT DATA SUPERHIGHWAY (SIMILAR TO THE INTERNET) THAT RESPECTS AN AIR CARRIER'S PRIVILEGED DATA

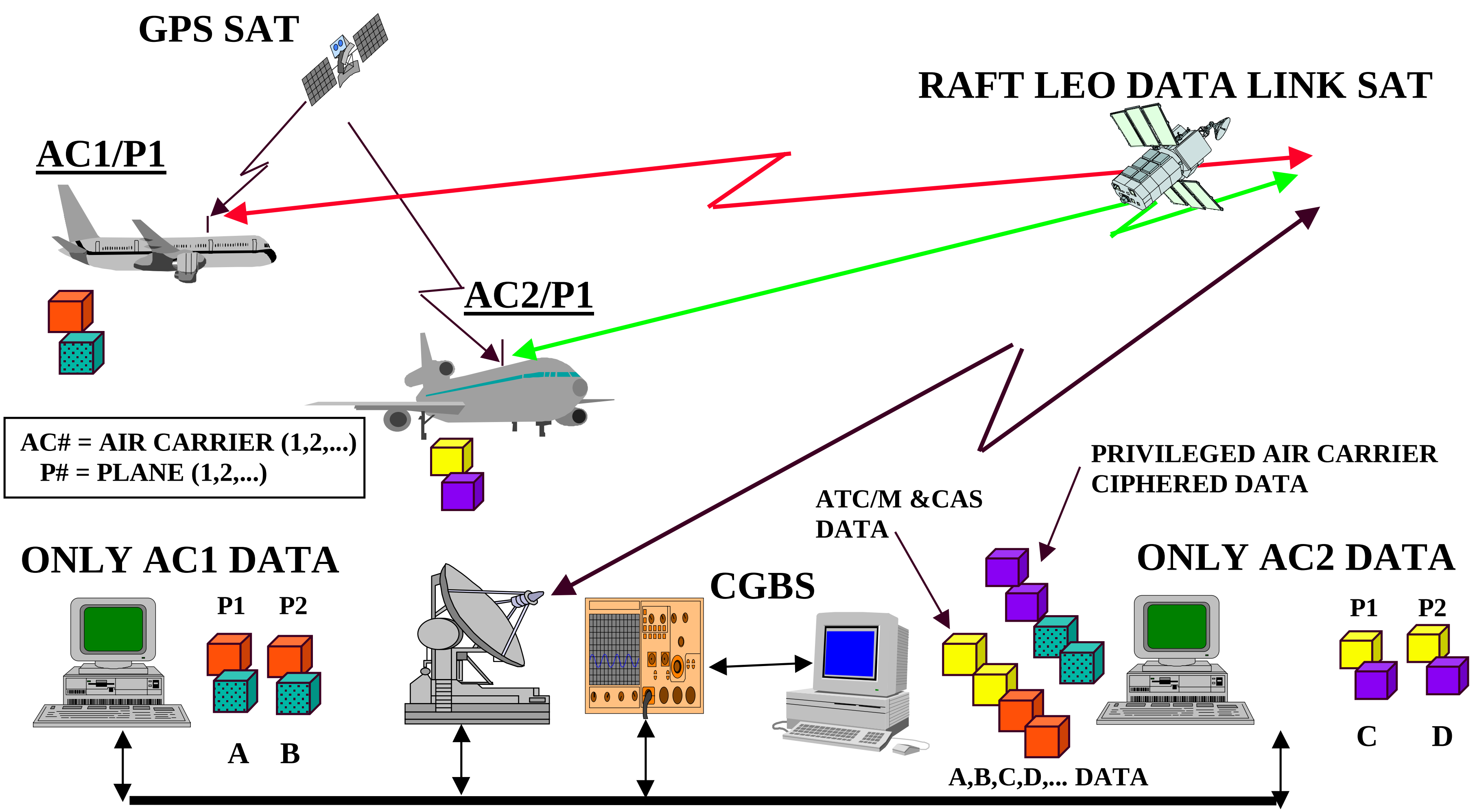


FIGURE 9

RAFT Aircraft On- Board Lay-out

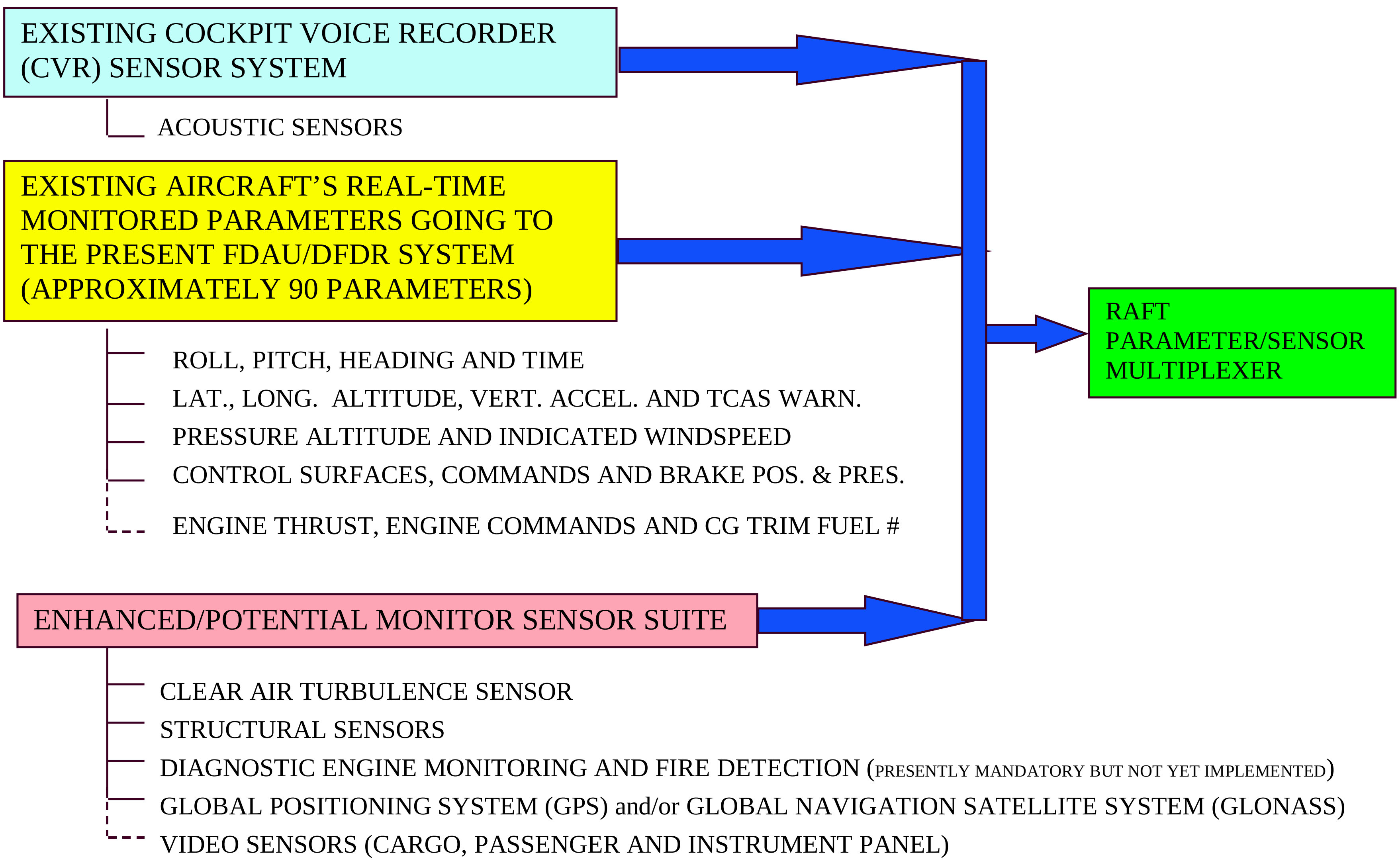


FIGURE 9 (CONTINUED) RAFT Aircraft On- Board Layout (CONT.)

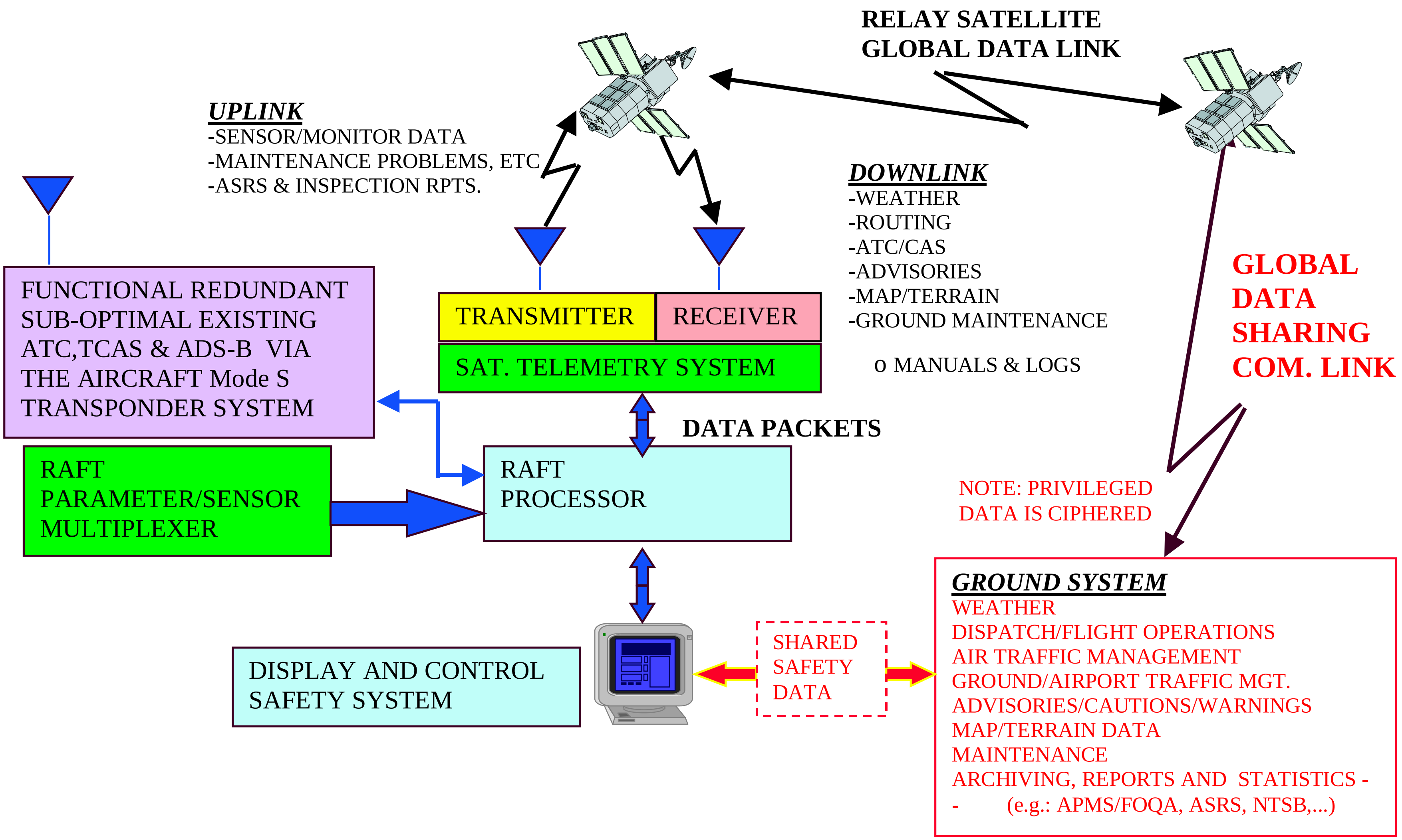


FIGURE 10

CHRONOLOGY OF SATELLITE PER FLIGHT COMMUNICATION COSTS

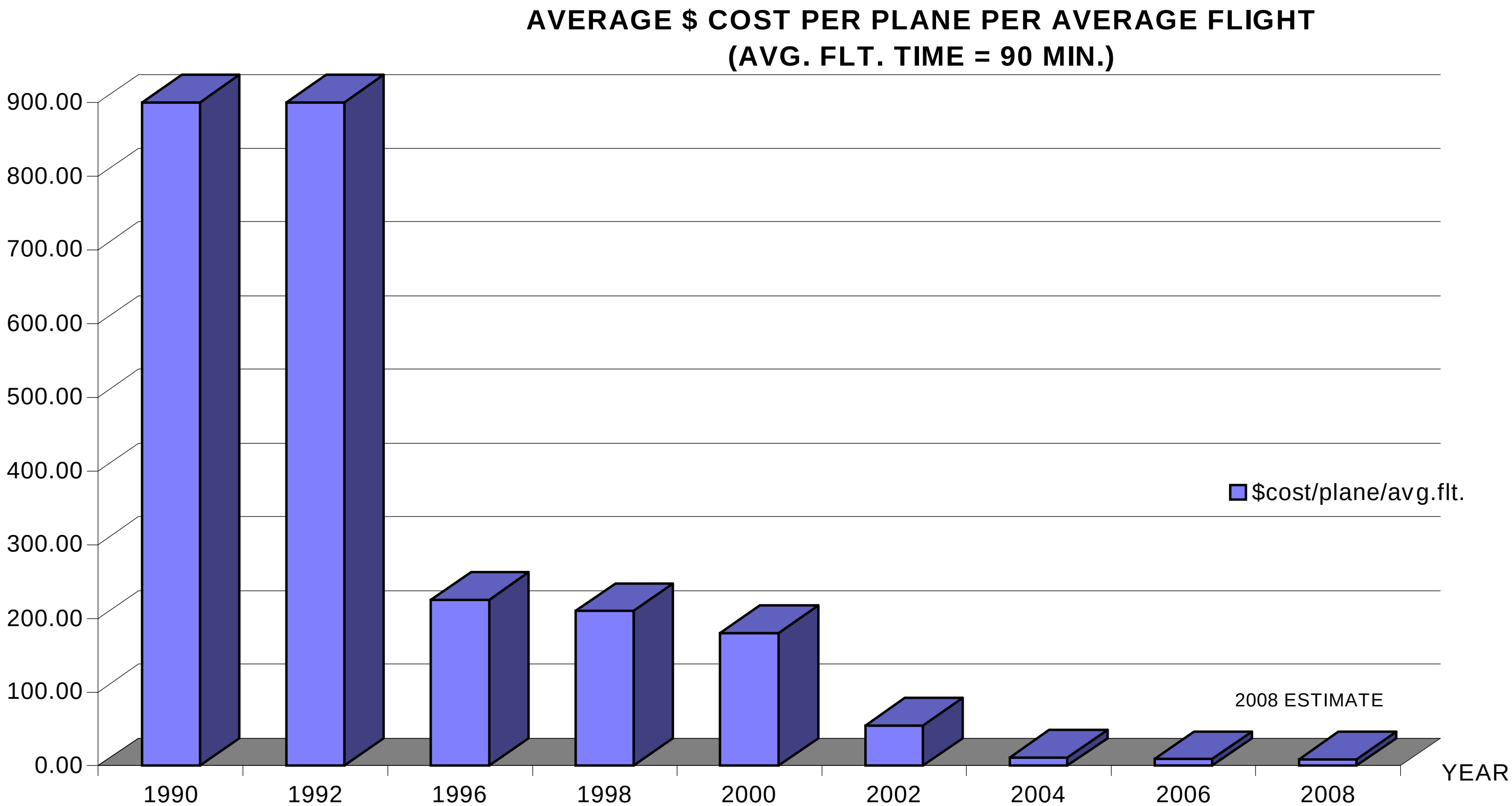


TABLE 1

WORLDWIDE AIR CARRIER FATALITIES AND FATAL ACCIDENTS FOR THE YEARS 1987 THROUGH 1996

					RAFT	RAFT	RAFT
	Total	Total	US Operators	US Operators	Total	Total	US Operators
FATAL ACCIDENT TYPE/QTY	Fatalities	%Fatalities	Fatalities	%Fatalities	Fatalities	%Fatalities	Fatalities
Controlled Flight Into Terrain (CFIT)	2396	32.01%	312	19.68%	479	17.04%	62
- CFIT Only On Approach	957	12.79%		0.00%	191	6.81%	0
Loss of Control In Flight	2228	29.77%	482	30.41%	1114	39.62%	96
In Flight Fire	760	10.15%	340	21.45%	152	5.41%	68
Sabatage	607	8.11%	254	16.03%	546	19.43%	229
Mid-air Collision	506	6.76%	0	0.00%	101	3.60%	0
Hijack	306	4.09%	38	2.40%	275	9.79%	34
Ice and/or Snow	162	2.16%	57	3.60%	32	1.15%	11
Landing	128	1.71%	3	0.19%	26	0.91%	1
Windshear	119	1.59%	37	2.33%	36	1.27%	11
Fuel Exhaustion	113	1.51%	0	0.00%	23	0.80%	0
Other Unknown	111	1.48%	17	1.07%	22	0.79%	3
Runway Incursion	45	0.60%	45	2.84%	5	0.16%	5
Rejected Take Off (RTO)	3	0.04%	0	0.00%	1	0.02%	0
TOTAL FATALITIES	7484	100%	1585	100%	2812	100%	521
% REDUCTION IN FATALITIES					62%		67%
					RAFT	RAFT	RAFT
	Fatal	% Fatal	US Fatal	US % Fatal	Fatal	% Fatal	US Fatal
FATAL ACCIDENT TYPE/QTY	Accidents	Accidents	Accidents	Accidents	Accidents	Accidents	Accidents
Controlled Flight Into Terrain (CFIT)	36	26.47%	4	11.76%	7	15.32%	1
Loss of Control In Flight	38	27.94%	11	32.35%	19	40.43%	2
In Flight Fire	4	2.94%	2	5.88%	1	1.70%	0
Sabatage	5	3.68%	1	2.94%	5	9.57%	1
Mid-air Collision	2	1.47%	0	0.00%	0	0.00%	0
Hijack	8	5.88%	1	2.94%	7	15.32%	1
Ice and/or Snow	5	3.68%	3	8.82%	1	2.13%	1
Landing	9	6.62%	1	2.94%	2	3.83%	0
Windshear	3	2.21%	1	2.94%	1	1.91%	1
Fuel Exhaustion	7	5.15%	0	0.00%	1	2.98%	0
Other Unknown	14	10.29%	6	17.65%	3	5.96%	1
Runway Incursion	4	2.94%	4	11.76%	0	0.00%	0
Rejected Take Off (RTO)	1	0.74%	0	0.00%	0	0.00%	0
TOTAL FATALITIES	136	100%	34	100%	47	100%	8
% REDUCTION FATAL ACCIDENTS					65%		78%

Digital Eye-Witness Systems

John J. Mackey, Christopher J. Brogan, Edward Bates, Stephen Ingalls, Jack Howlett
Loss Management Services, Inc., 36 Surf Road, Lindenhurst, NY 11757

HIGHWAY MOBILE ACCIDENT CAMERA

According to the National Center for Health Statistics, "National Health Survey", in 1996 there were 35 million motor vehicle accidents with an associated total economic loss of $120.8b. Approximately 60% of the $120.8b was spent on claims payment and an additional 12% in legal fees. What is not known is how much of this amount was spent settling or defending fraudulent and frivolous claims. However, Loss Management Services, Inc. (LMS) does have a way to control these costs. LMS has developed systems to control claims pay out and litigation costs while deterring fraudulent and frivolous claims, along with providing for a real crash data bank for regulatory agencies.

LMS has developed the MAC (Mobile Accident Camera) Box system which will record the events leading up to an accident, capture accident data and record the aftermath. The MACbox will provide a "driver's eye view" of the entire incident from beginning to end. The only difference is that the MACbox will disclose without bias, the event as it occurred. The system is an application of existing commercial technology answering the most common and most vexing mystery: Whose fault was it? And, what happened?
By working closely with our client companies, the insurance industry and our technology partners we will also establish a rich repository of information that will be used to help mediate claims, assign responsibility, advance vehicle safety and reduce the total economic loss that results from motor vehicle accidents.

The MAC Box system will be capable of providing benefit to the entire 200 million plus vehicles on the U.S. roads today. Unfortunately, like seat belts and anti-lock brakes, this system will take time to gain acceptance. Part of the problem is that the world does not change quickly and the insurance industry needs to accumulate actuarial data before they can offer financial incentives to change. Based on our research, the initial market will be the "Self- Insured Retention" (SIR) type risks. Between state and local governments, along with private fleets, this represents a market of over 9 million vehicles. With two years of data and some direct involvement with selected insurance industry partners, we believe that we can establish the statistical and business basis for these insurance companies to offer incentives to their clients that purchase our product.

We have been in contact with the National Highway Traffic Safety Administration and they have formed a committee with representatives from the major automotive manufacturers, the insurance industry, universities and medicine to develop a standard for a less aggressive product that will only capture motion information and contact the emergency services. The NHTSA has expressed a strong desire to have us present our solution to this august body. Most recently, we had the opportunity to do so at NHTSA's EDR Working Group. LMS is now apart of that group and is currently involved with identifying issues to make clear what is needed within the EDR environment.

Future versions of our product will have added functionality and reduced unit costs expanding coverage to the total motor vehicle market. We envision a MACbox fitting in the rear view mirror of every automobile and providing the ability to not only see and record accidents, but to contact police and pass important medical information to emergency medical technicians that are responding to the call. Additionally, the real world accident data gathered will be of great value to both the Federal Government, local law enforcement and car manufacturers in improving vehicle safety systems, along with an accurate assessment of highway infrastructure conditions. The foundation has been laid for making this vision a reality. A prototype is complete. LMS has entered into marketing, manufacturing, and technology partnerships with industry leaders to ensure that there will a ‘best of breed’ in developing the system for commercialization.

The Market

LMS will direct market the MACbox to insurance companies, long and short haul trucking companies, charter bus companies, car and truck rental companies, corporate fleet and limousine companies, along with municipal transit authorities and taxi and limousine exposures. According to the 1996 FARS/GES published Report, the number of vehicles in operation at that time was:

124.6 million Passenger cars
65.4 million light trucks (includes vans and utility vehicles)
7.4 million large trucks

The vehicle base is growing at a rate of 2% plus annually.

The initial target market will be commercial and rental vehicles. The estimate of this market alone is in excess of 25 million vehicles. With the second phase of the product, we will have a cost-effective solution for the private passenger vehicles. This will expand the market to the total population of vehicles in operation.

Insurance Companies

LMS will develop strategic alliances with the top five insurance carriers in the United States. The purpose of the alliances will be to develop a database of information regarding claim cost reduction and its relation to premium discounts. To date, discussions have begun with Allstate, Geico, State Farm, Liberty Mutual and Prudential Property and Casualty.

Long and Short Haul Trucking

Long and short haul trucking companies often provide a portion of their liability protection through Self-Insured Retention (SIR). Within the SIR marketplace, the insured typically assumes liability up to a predetermined limit. In the case of long haul truckers this may be the first $500,000 per occurrence. It is in their best interest to limit their exposure to long and costly claims management and potential litigation. With the MACbox, those companies would have an expert witness with each of their vehicles. In the event of an accident, the information provided could be used to help limit the overall expense involved with the claim, along with providing for future safer routes.

Charter Bus Companies

Charter bus companies such as Laidlaw/Greyhound represent a significant potential market for LMS. These companies provide much of their own liability protection with SIR, and have tremendous potential exposure for personal injury claims. These operators are looking for proactive technology solutions to limit their roadway exposure. LMS plans to modify the MACbox to record accident information within the bus to help determine personal injury exposure.

Car and Truck Rental Companies

These companies represent a tremendous opportunity for LMS. The likelihood of having a driver involved in an accident return to testify during litigation is very low considering that most drivers are from out of state. This presents a very difficult situation for the legal departments of the rental companies. They are often presented with indefensible claims and settle more claims than they would have to if they were to incorporate a MAC box in each vehicle.

Corporate fleet and Limousine Companies, Municipal Transportation Authorities and Taxi and Limousine Commissions

These potential customers represent a tremendous potential for LMS since they all involve operators for hire. The representative management involved with these risk exposures has a vested interest in maintaining the safety of the vehicles and their passengers. The ability to have an expert 'Digital Eye-Witness' available at the scene of every accident is an invaluable tool to these management teams. Both management and legal council will benefit from the information provided. They will be provided with information necessary to determine whether to litigate or settle as well as determine whether to terminate the employment of operators. LMS is presently in discussions with the New York City taxi & Limousine Commission.

Private Passenger - Transportation - Vehicles (PPV)

The MACbox provides a unique method of reducing accident claim expenses incurred by insurers as well as those companies providing liability protection via Self Insured Retention (SIR). A 1996 report by the Insurance Information Institute stated that the entire vehicular insurance market incurred $120.8 billion in losses during 1996. According to their data bank 6,115,000 private passenger motor vehicle (PPV) accidents were reported nationwide in 1996. This equates to $77.7 billion dollars in losses for the PPV's alone. These costs represent the total claim expense and settlement costs absorbed by PPV insurance companies. These costs could be drastically reduced if the extent of litigation were reduced. The MACbox acts as a 'Digital Eye-Witness' to the occurrence of a crash and removes any doubt as to which driver is at fault. This information will allow the insurers to immediately evaluate their exposure and decide whether settlement of the claim is in order. The impact of clearly establishing fault via video recording of the accident will drive the insurance companies to participate in this program.

Self Insured Retention (SIR)

Within the SIR market we have identified the following vehicular populations:
Long/Short Haul Trucking 800,000
Light Trucks 1,200,000
Buses (private charter/school) 500,000
Municipal (State & Local) 7,500,000
PPV (rental cars/fleet vehicles) 1,500,000

TAXIES_3,500,000

Total 16,000,000

Future Vision

Data Bank:
LMS will create and manage a database of image and crash data for use in determining roadway safety by Government agencies and the private sector.
Civil Court Database:
LMS will provide for data transmission to the courts for automatic denial or a lack of causation of the Plaintiff regarding the liability portion of the action. That is, to determine, without jury selection, the validity of Plaintiff's case.
Trucker's Log:
The next generation of the MACbox will incorporate a "trucker's log" necessary in long haul trucking. The system will use accelerometer data to determine the movement and stationary positions of the truck. Trucker's logs are currently mandated by the Department of Transportation (DOT) and are used to determine a driver's activity.

Elevator MACbox:
Piloting commercial buildings with the MACbox within an elevator to capture sudden acceleration. The sudden drop or acceleration will cause the system to capture images within the elevator cab to determine the potential injury to any occupants. The Elevator MACbox can be used to indicate required maintenance.

Partners:
LMS has two partners that are currently committed to working on the development of the beta version of the first MACbox system. The parties and their component of the solution is as follows:

Phoenix Group Inc.	Specialized PC with Ruggidized enclosure and System Integration
Instrumented Sensor Technology	Shock and Motion Sensors and Trigger
Kodak	Image/Data Repository

Major Contacts

Targets for the Pilot Program
During our conversations with numerous organizations, some have expressed interest in being part of the initial 600 unit pilot program. They are:
Allstate Insurance
Avis Rental
New York City, NY MTA & Long Island, NY MTA

John Deere Insurance Services

Insurance Industry Interest
A key to the success of the MAC Box system will be the acceptance by the insurance industry. Our measure of their acceptance will be their premium discounts for the installation of our product. While we are a couple years away from that level of acceptance, a number of insurance companies, transportation companies and agencies have expressed strong interest in working with us on this project. They are:
Allstate Insurance
Prudential P&C of New Jersey
John Deere Insurance Services
State Farm Insurance
Liberty Mutual Insurance Company
Office of Safety Performance Standards – NHTSA Research
NY MTA Buses - Fleet of 3,900 units
NYC Taxi & Limousine Commission - 12,000 units
UPS - Fleet size - 164,000 units
AVIS Rental – 500,000
Enterprise Rental - 400,000
Greyhound/Laidlaw – 43,000
Northeast Trucking – 4,300

Current Service Offerings

LMS will offer a number of services that make use of the information developed by the MACbox or support the system. After we have developed the business with these foundation services we will expand the service offerings to include video recreations, expert witness testimony and arbitration services. As we move forward with the MACbox, the company is confident that we will find additional products and services that we can offer from the information that we collect.
Installation Services
LMS will offer our clients installation services with the new systems. Our organization will develop an installation process document that can be used by a local vendor to install the MACbox system into the vehicle and test the unit after installation. We intent to contract with electronic equipment installers that are local to our clients to make the process as convenient as possible for them. The initial installations will be performed under our supervision. The knowledge gained from these efforts will be incorporated into our process documentation. As part of the installation process, we will develop a remote certification procedure that will allow us to test the system prior to placing it into service.
Membership Fee
All users of the MACbox system will be charged an annual user fee. This fee will cover the maintenance of vehicle records containing, VIN number, owner, address and other user defined fields such as primary driver on our roster, quarterly remote testing of the MACbox to ensure that it is functioning properly and support from our help desk on the unit. The membership fees will be assessed per vehicle.
Accident Reports
LMS will provide accident reports for our clients. The information taken from the MAC box system will remain the property of LMS and users of that information will be required to

purchase the information from us in the form of an "Accident Report". These reports will be available in both a hard copy format and an electronic format that will be accessible over a secure link to the Internet. The reports will be generated by LMS and moved from our internal repository to a customer repository that is managed using a sophisticated image and data management system. A security system will be used that ensures compliance with local, state and federal law related to defendant and plaintiff access to information. Billing for the reports accessed via the Internet will be automatic and clients will receive a monthly statement for usage. While the electronic access vehicle will be the most efficient way for our clients to receive accident information, certain clients may require hard copy. For those clients, a printed version of the report, including video images will be available. The accident report will contain all information from our data repository including vehicle information, time and date detail on the accident, the entire image file containing approximately 300 images and the motion data. The images will be taken at 10 frames per second for 15 seconds before and after the accident and the motion data will be saved for the same period of time. The motion information will track changes in velocity on two axes for the vehicle.

Future Services:
Video Accident Recreations:
Using a combination of the video images, motion information and computer based animation tools, LMS will be able to produce a video recreation of the accident from multiple angles. These recreations will incorporate the live video images where appropriate and augment the live video with animation to recreate the entire incident.

Expert Witness Services:
LMS will develop a network of "Expert Witnesses" from the ranks of educational institutions and industry that will be available for testimony in accident related cases. This network will span the country using individuals with the appropriate professional credentials to assist in explaining the physical characteristics of the accident and their professional opinion on the dynamics of the incident. LMS will contract with our clients for these services and retain the network of expert witnesses on our staff, as consultants that are compensated on an as needed basis.

Accident Arbitration Services:
LMS will offer arbitration services that will allow the parties involved in an accident a means outside of the court system to resolve accident related claims. Drawing on the information collected at the time the accident occurred, we will employ professional arbitrators to mediate cases using information taken from our repository.

The Products

'Product' Overview
With our partners, LMS is developing the Mobile Accident Camera (MAC) Box. LMS will provide these systems, which *Capture and Secure* 'driver's eye view' images and telemetry data prior to, during and immediately after an actual accident; *Manage* this data, including chain of

custody; and *Distribute* the data, through the use of emerging digital and communications technologies.

By taking a component approach toward the development of the MACbox, LMS leverages the individual expertise of industry leaders to build a 'best of breed' solution. Partnered with Instrumented Sensor Technologies Inc. and Phoenix Group Inc. LMS will develop and manufacture the lowest cost, most reliable system for recording storing and transmitting accident data.

Within the MACbox resides a digital video camera as well as circuitry and software to:

- 'Sense' when an accident has occurred
- Capture video and telemetry data prior to, during and immediately after an accident
- Store and lock accident image and telemetry data after an accident
- Upload accident image and telemetry data to wireless networks
- Download accident image and telemetry data to a portable computer

The MACbox is made up of five functional components:
1) Digital Video Camera utilizing a real-time software video compression engine - licensed through Phoenix Group, Inc. (www.ivpgi.com)
2) IST biaxial accelerometer and 'trigger' system - developed by Instrumented Sensor Technology, Inc. (www.isthq.com)
3) Transceiver (vendors under evaluation)
4) CPU including system and flash memory as well as related interface circuitry for the other system components. The x86 CPU operating system is Windows CE. - System developed by Phoenix Group, Inc.
5) Power Supply and Battery Backup - developed by Phoenix Group, Inc.

Phoenix Group will provide the integration of all of the components with the digital video camera subsystem, CPU and power supply. PGI will be responsible for final assembly and testing.

Functional Overview

The MACbox continuously records: a) Video data in a software 'video loop' from the driver's point of view and b) Acceleration in two axis at a sampling rate of 2000 times per second. When an accident occurs, the IST subsystem 'senses' that accident signature parameters have been matched or exceeded. This event 'triggers' the CPU to permanently store a video sequence which encompasses a definable period of time before and after the accident. The MACbox then transmits the video and accelerometer data that was acquired during and after the accident through the Motorola cellular transceiver. The MACbox then encrypts and 'locks' this data to prevent tampering. The result is a group of images and associated data transmitted by the MACbox, immediately after the accident has occurred, to a secure server.

The system allows a crash investigator, or other authorized party to see the crash develop before and after the impact from the driver's perspective. Accelerometer and video data are time-stamped to allow a complete re-creation of the crash. This data set will facilitate an accurate reconstruction of the crash.

The use of a personal computer based system will allow us to enhance the systems to include multiple cameras, driver monitoring and the other related features.

<u>System Programmability</u>
The system software embedded within the MACbox is programmable and can be tailored to the particular vehicle or application. System parameters including system thresholds and the number of images taken prior to, and immediately after, an accident can be altered to meet the requirements of a particular application.

For instance, if the default setting allows for the capture of images for 30 seconds prior to an accident and for an additional 30 seconds after the accident but then it is determined that it is advantageous to have more images before the accident than after, the system can be re-programmed to store 48 seconds worth of images prior to the accident and only 12 seconds after.

Engineering Requirements

The following companies are supplying and integrating the components of the MAC box system.

The Phoenix Group, Inc.

PGI, formed in 1994, is comprised of a cadre of highly skilled engineering and management personnel who have worked together for more than twenty years. Lead by Dick Pandolfi, this team built Miltope Corp. from a 1975 start-up into a 100 million dollar a year company. Under the auspices of Mr. Pandolfi, PGI is dedicated to the design and development of rugged, truly portable miniature computer systems.

The comprehensive PGI product line has been designed for demanding industrial and military field applications, where performance under harsh environmental conditions is essential. PGI products are ideally suited for vehicle, aircraft, shipboard and outdoor field applications.

PGI will design and manufacture a custom variation of one of their standard products to meet LMS's specifically defined criteria. PGI has years of experience integrating systems for end user application for their traditional customer base including OEMs (Original Equipment Manufacturers), VARs (Value Added Resellers) and Systems Integrators.

PGI's customers include Fortune 500 Companies, the U.S. Department of Defense as well as Foreign Ministries of Defense. PGI's Design capability coupled with its in-house automation offers LMS a source of quick prototyping and unique customizing skills. PGI's in-house integrated facility includes
AutoCad supported by CAM, allowing quick and efficient conversion from design to final product. A modern, automated NC sheet metal and machining capability is combined with in-house mold making and injection molding capability. This will allow us to use the most cost effective and superior space age high strength carbon filled materials, pliable rubber and plastics in all LMS designs.

Instrumented Sensor Technology, Inc.

IST, celebrating its 10th year in the business, is an industry leading high-technology instrumentation company focused on developing innovative products for field measurement and data recording. The company specializes in development of physically compact, high performance digital data acquisition and recording systems for high-speed mechanical measurements.

IST's mission is to provide high quality, high reliability data recording products and software at reasonable cost, and supported with high-level customer and applications support and service. The company's products are used widely in such applications as transportation measurement, packaging and handling shipment monitoring and recording, automotive shock and vibration testing, crash recording, airborne vibration measurement, accident re-construction, and many others.

IST offers a unique source of expertise and industry experience. They will design and manufacture a custom variation of one of their standard products to meet LMS's specifically defined criteria.

Media Motion, Inc

Media Motion is a private company developing video systems for the commercial market. They have developed what we consider the most appropriate real-time video compression systems and related applications for Loss Management Services products.

By leveraging the individual strengths of each partner, LMS will be able to offer its customers best-of-breed solutions at a competitive price. And the fact that each of these partners is a technology leader in their respective areas makes their support of the start-up company that much more significant.

Engineering

All existing system components were originally developed for the mobile computing/data recording market. For this reason, the completion of a prototype and ensuing production is less of a development process than a re-engineering and integration of components used in the Proof of Concept. The component suppliers are leading development, engineering and manufacturing firms in their particular markets. The greatest challenge is the re-engineering - for cost reduction and ease of integration - of LMS partner components and the development of the proper triggering thresholds.

Proof of Concept (began July 15, 1998; ended January 1, 1999)

- Sept. 15, 1998 - Media Motion installs XX on PGI Nightingale
  PGI interfaces IST box
- Oct. 1, 1998 - PGI interfaces Media Motion software and IST EDR-3 box
- Dec. 7, 1998 - IST tunes integrated system
- March 5, 1999 - Product Demo

Prototype Stage (began December 30, 1998; end April 30, 1999)

- 1) Requirement Analysis (began September 30, 1998; end October 30, 1998)
  - b) Determine System Specifications
    - i) Enclosure: ruggedized/environment/construction/X and Y-axis orientation/mounting
    - ii) Camera (shock dampening, windshield mount, operational light level, resolution)
    - iii) Cabling (connection specifications)
    - iv) Upgradeability
    - v) Extensibility
    - vi) Real-time Operating System Requirements
      - Startup requirements
      - Shutdown requirements
      - Diagnostics - remote monitoring, fault detection/prediction

vii) XY Sensitivity
trigger threshold waveform development
viii) Video Memory:
Resolution and 'frame-rate'
X Seconds before
Y Seconds after
ix) Power supply requirements
Main Power
Battery Backup

2) Prototype development and testing (begin development March 15, 1999 - April 30, 1999)
a) Re-engineering of system components
b) Re-engineered system component integration

Beta Test Stage May 15, 1999 – August 30, 1999

600 Units placed in various vehicle types for data collection and testing. Preferably Buses, Trucks and Private Passenger Commercial Fleet Vehicles.
a) Re-engineering of system components
b) Re-engineered system component integration

First Revenue Ship November 1, 1999

By working closely with the transportation industry, insurance companies and our technology partners, we will establish a rich repository of information that will be used to help mediate insurance claims, insurance fraud, assign responsibility, advance vehicle safety and reduce the total economic loss that results from motor vehicle crashes. The System will finally answer the most vexing mystery: What happened? And, whose fault was it?

References
1. Phoenix Group, Inc./www.ivpgi.com
2. Instrumented Sensor Technology, Inc./www.istq.com

Management Team

John J. Mackey
Chief Executive Officer and Founder of the MACbox - Mobile Accident Camera

John Mackey, 41 years old and residing in Lindenhurst, New York. John graduated from Slippery Rock University, PA, with a Bachelor of Science in Education. John has been in the insurance industry since 1980 starting out his insurance carrier with The Hartford Insurance Group. Thereafter, John became a police officer and developed an appreciation for both crash aided victims and response time to emergency calls. John then returned to the insurance industry, and has been involved in property and casualty claims since and worked for such companies as Liberty Mutual Insurance, American International Group, two independent claim companies, and President of Loss Management Services, Inc. (LMS). John currently holds a New York State Independent Adjuster’s license under LMS.

Stephen Ingalls CPA
President

Mr. Ingalls 44 years old, and residing in Centerport New York. Stephen is currently the president of Wilsearch Information Network, Inc. a public records research company that provides their clients with information from across the country. As part of his role in Wilsearch he designed, developed and implemented all of the computer systems that are currently in use at the company for report production, order entry, billing and financial management. In addition to working with Wilsearch, he has 16 years with Digital Equipment Corporation in the capacity of a consultant, finance manager and programmer. Stephen is a member of the American Institute of Certified Public Accountants. He holds a Masters in the Science of Finance from Bentley College and a Bachelor of Business Administration from the University of Massachusetts.

Edward J. Bates
Vice President of Marketing

Mr. Bates, 38, and residing in New York City, New York is president of First National Services, Inc. where he is responsible for the company's development, marketing and sales of various insurance products. In addition, Mr. Bates has provided consulting services in the areas of Business Development, Marketing and Sales, and Financial Advisory to many high technology start-up ventures, which have been involved in various areas of computer hardware and software development. Prior to holding his position with First National Services, Inc., Mr. Bates was a Senior Computer Design Engineer with the Grumman Corporation for eight years. His responsibilities included the management of subcontractor hardware/software integration and test, system/software design and compliance, the development of system and software performance specifications, and the development and scheduling of hardware, software and system tests. Mr. Bates holds a Master of Business Administration from Columbia Business School and a Bachelor of Science in Electrical Engineering from Polytechnic University.

Christopher J. Brogan
Vice President of Technology

Mr. Brogan, 38, and residing in Fulton, California has a broad background with high technology ventures in startup and growth phases. He has provided business development; engineering requirements analysis and definition; and sales and marketing consulting. Mr. Brogan's engineering background and experience in developing sales channels and strategic alliances with industry leaders such as Sun Microsystems, Oracle, Informix and IBM will provide LMS with additional expertise in selling and marketing LMS's strategic systems into our target markets. Prior thereto, Mr. Brogan served as a United States Naval Aviator for over eight years. His various responsibilities included: Strike Syllabus Instructor Pilot, Electronic Warfare Officer, Squadron Systems Training Officer, and Program Development Officer. After graduating Manhattan College with a Bachelor of Science in Electrical Engineering and now enrolled in Columbia University's Executive MBA Program., he held positions as a software engineer at Nippon Electric Corporation and hardware/software design engineer at Lucas Aerospace Corporation.

Jack Howlett

Vice President of Sales

Mr. Howlett, 42, residing in Farmingdale, New York and brings 20 years of property and casualty claims experience to LMS. As a licensed General Adjuster, Mr. Howlett has spent his entire career providing nationwide independent claims adjustment and third party administrative services to self insured corporations in both the municipal and private sectors as well as insurance carriers. In 1989, Mr. Howlett founded and was named CEO of Network Adjusters, Inc. Currently, Mr. Howlett is President of Precise Claims Administrators, Inc., which services third party claim administration for municipal accounts. He was elected President of the New York Association of Independent Adjusters, and is a member of the New York Claims Association and the National Association of Insurance Adjusters.

EUROCAE WG-50 ACTIVITY

AIRCRAFT ON BOARD VIDEO RECORDING

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EUROCAE WG-50 ACTIVITY

AIRCRAFT ON BOARD VIDEO RECORDING

KEYWORDS

Aviation,
EUROCAE
On-board video recording
Data-link

INTRODUCTION

The subject of the presentation is to introduce the work done by the Working Group 50 of EUROCAE regarding flight recorders performance specifications and mainly the on-board video recording..

EUROCAE

EUROCAE is a non-profit making European association established in 1963. The primary objective of EUROCAE is the development of performance specifications for civil aviation equipment to be adopted as regulatory documents by European authorities. EUROCAE membership comes mainly from industry, civil aviation administrations and users. The association works in close cooperation with its American counterparts, RTCA and SAE, with the permanent objectives of publishing compatible documents and supporting the interests of manufacturers and users worldwide.

EUROCAE:
70 member organizations
14 nations worldwide
7 international organizations
17 working groups
600 engineers
80 documents published

WG-50 TERMS OF REFERENCE

Aeroplanes and helicopters are respectively required by JAR-OPS 1 and 3 subpart K to be equipped with a Flight Data Recorder and/or a Cockpit Voice Recorder. Today, the interpretative/explanatory material of JAR-OPS 1 and 3 refers to EUROCAE MOPS ED-55 (FDR) and ED-56A (CVR).

The ICAO FLIREC Panel (FLIRECP) has recommended that: « All aeroplanes equipped to utilize digital Air Traffic Services (ATS) communications and required to carry a CVR shall record the digital communications messages on the CVR. »

The airborne flight recorder regulatory framework does not take account of the introduction of Communications, Navigation, Surveillance (CNS)/ Air Traffic Management (ATM) concepts. Air Traffic Services are to become more dependent upon digital communications. Consequently, EUROCAE WG-50 is tasked with the development of specifications to facilitate incident and accident investigation. These documents will be made available as a basis for Civil Aviation regulation.

WG-50 completed a MASPS (Minimum Aviation System Performance Specification) for CNS/ATM message recording systems in November 1998. This document is published by EUROCAE as ED-93. To assist the approval of data-link recording systems, WG-50 is now developing a MOPS (Minimum Operational Performance Specification) documents for airborne equipment.

WG-50 has also determined that ground recording systems within Air Traffic Control Centres often use widely differing standards. Replay of these recordings may therefore prove inefficient and inadequate. To improve this situation and provide "end to end recording" as recommended by the air accident investigators, WG-50 will prepare a standard for ground recording systems.

Working Group 50 will:
a) Review existing MOPS's ED-55 (FDR) and ED-56A (CVR) and produce a MOPS for airborne recording systems. This new document will define minimum performance specifications for Audio, Parametric, Video and Data-link messages recording:
- to be completed in December 1999 for a first publication including audio and parametric portions
- to be completed with all 4 portions in December 2000.
b) Produce a standard for ground recording systems for CNS/ATM application to be completed in October 2000, taking into account new CNS/ATM development and in particular WG-53/SC-189 activity.

To achieve these new tasks, WG-50 will co-operate with appropriate international bodies and in particular with ISASI, ICAO, and AEEC.

The MOPS for Flight Recorders Systems uses the basis of CVR and FDR MOPS and will integrate data-link messages and video recording. The MOPS will include the latest improvements regarding flight recorders: high intensity fire survivability (1 hour), audio duration (2 hours), extended list of parameters, combined recorders, recorders location, deployable recorders, CVR independent power supply...

ON-BOARD VIDEO RECORDING

Following some recent accident investigations the Bureau Enquêtes-Accidents (BEA) along with other accident investigation authorities (NTSB, TSB, AAIB, BASI, BFU, ...) have been considering the need for flight deck video recording. It is seen as a potential major enhancement to the accident investigation tools available. On-board video recording is also encouraged by ICAO. The last FLIRECP meeting considered the work done by EUROCAE and ARINC/AEEC. FLIRECP has agreed that it's strongly committed to the introduction of video recordings in an appropriate and agreed format and that this should form part of the future work of the panel.

The Terms of Reference agreed by EUROCAE for WG-50 include the production of a MOPS for on-board video recording. The working group is constituted notably of investigators from Investigation authorities worldwide. Recorder and aircraft manufacturers plus certification authorities are also represented. The group commenced discussion of the fundamental needs of the on-board video recording during the Toulouse meeting in February 1999.

Video recording can be use for the investigation in several different ways.

The flight deck video recording can be split in two areas, the first being a view of the instrument panels, and a second view showing the pilot's activity area on the flight deck.

External views may show the outside parts of the aircraft. This information may also be useful for the crew members and so for the investigation if the information is recorded.

The third aspect is the cargo bay with special cameras to detect smoke or fire.

During the Toulouse meeting, WG-50 agreed that the accident investigators must define the fundamental needs since the video recordings are intended only for incident/accident investigations purpose.

The fundamental needs will be defined regarding both camera and recording technologies available now or in the near future.

⇒ Why is video required?
It is felt that video recording should not be provided at the expense of the flight data recorder and that there is a need for video data recording to enable accident investigators to fully understand incident/accident of what pilots are seeing.

⇒ What should be recorded?
Having decided that the video data recording discussions should be limited to incident/accident investigation it was proposed that the only useful source of video was coverage of the flight deck instruments. This suggestion was based on the premise that fitting external cameras would be expensive and of limited use. It was further agreed that if operators choose to record other video data (e.g. external), for entertainment system installed on board for commercial expects, it should also be recorded in the accident recorder.

The group discussed the possible use of cockpit area video and agreed that while this could have some accident investigation uses, the potential for misuse of this data posed a sufficiently large problem for the pilot community that any benefits could be outweighed.

CONCLUSIONS

As soon as the MOPS for Flight Recorders System is available, it will be proposed to JAA as amendments for JAR-OPS 1 and 3. WG-50 hope to see these official requirements in place by 2005.

The next step for airborne recording systems may see combined recorders using Solid State Memory to record audio, video, parameters, data-link messages in a single, crash protected, box.

ACKNOWLEDGEMENTS

To all WG-50 sub-group chairmen, secretaries and members for their work to enhance safety.

Improving ship safety and efficiency with proactive use of Voyage Data Recorders

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KEYWORDS
Marine, safety, efficiency, cost-saving

INTRODUCTION

The use of Shipborne Voyage Data Recorder (VDR) in the commercial maritime industry can raise both safety and operation efficiency levels. Although it is late coming compared with aviation industries, the International Maritime Organization (IMO) has recently passed the resolution A.861(20) Performance Standards for Shipborne Voyage Data Recorders. The International Electrotechnical Commission (IEC) is currently finalizing the technical specification of the VDR for type approval. Carriage requirements are now under discussion at IMO and will become a reality in the near future.

While mandatory carriage requirement is still years away, some progressive shipping companies have already started to install VDR as part of an advanced Integrated Bridge System (IBS). Actual field experience shows that cost-effective VDRs can be built and maintained to meet reasonable performance requirements with today's technology. Although the primary purpose of the VDR is for accident investigation after the fact, innovative uses of the VDR by the operators both in real-time and post voyage modes have demonstrated VDRs can improve safety as well as efficiency of operations. The concept is similar to the use of flight recorder to store engine data for maintenance in the aircraft industry. This paper describes several areas of proactive use of VDRs for central alarm management, performance efficiency monitoring, heavy weather damage avoidance and seamanship skill training.

SAFETY

The safe operation of commercial ships is most important to ship operators, regulators and the private sector. Just as in other industries, the prudent operator strives for a high degree of safety in its transportation operations. Operating safely and efficiently is a basic business requirement, which must be met just to stay in business. Today’s legal liabilities make it non-profitable to operate unsafely, and can soon put sub-standard operators out of business. The risk of fighting law suits and paying judgements and fine for loss of life, injuries, damage to property, and damage to the environment make it impractical and foolish to operate un-safely.

Tools that encourage and ensure that shipping operations are conducted safely must be a priority. The VDR and its potential for improving marine transportation safety are far reaching. The extensive recording of ship navigation equipment, propulsion system and bridge command as well as alarm status provides a comprehensive analysis database. The data could be used to aid investigators in identifying causes of the accident. More important, it can also be used to study trends and precursor events, which lead to an incident, thereby assist in formulating proper procedures to avoid future similar scenarios. Incident data could be used as a training tool to make operators aware of potential hazards and assist in the avoidance of incidents. Data could also be used in the evaluation of certain critical equipment, to ensure proper maintenance and operation or to install added redundancy to further improve safety.

Furthermore, in the real-time mode and without affecting the recording function of the VDR, data can be made available for viewing by the operator to prevent accidents. The following are a few examples of the real-time use of VDR data:

Heavy Weather Damage Avoidance
Containers are lost and ships are damaged in severe sea states. Monitoring of vessel motion and hull stress can alert the operator when the safe operating threshold is about to be exceeded. The real-time display and analysis coupled with analytical prediction of motion and sea load with observed or forecast sea and swell condition can reduce the risk of heavy weather damage. Using these tools, the operator will be able to answer many "what if" questions on changing ship speed and heading to reduce motion and stress before it is carried out. The sensors will further confirm the operator's actions.

Central Alarm Management
With the proliferation of alarm signals on each piece of equipment and sensors on a modern ship, the sound and light signals quickly become confusing and unmanageable. The crew may take days to become familiar with the alarms and how to turn them off. Since the VDR is already monitoring all the major alarms, a Central Alarm Management System can automatically monitor, record and display ship's alarm at a central location so that the crew can easily identify the alarm and manage the condition in a timely manner. The entire system is designed to assist the mariner in overcoming the uncontrolled proliferation of alarms and warning sounds on modern ships by displaying the alarm status so that:

- Alarms are easily distinguishable
- Alerts or informs which important actions are to be taken
- Non-important action can be postponed or transferred
- Responsibilities, procedures, and routines are easily understood through the use of check lists and graphic display including video
- Records are kept for later investigation and training

Directional Stability
A large vessel with blunt hull form can sometimes exhibit directional instability in slow forward speeds. When ship's turning is not responding to the rudder action, it can lead to collision in congested waters and grounding in narrow waterways. Real time display of turn rate, rudder angle and other factors influencing the ship's maneuver can alert the operator of potential dangers.

Incident Investigation
As in other transportation incident investigations, the marine incident requires accurate data records in order to gauge system and personnel performance as well as operating status prior to an incident. In maritime industry, most of these incidents are not fatal, the

actions taken by the crew after the incident is also important. The VDR can record and save the data so that analysis can be made when the ship arrives next port. The determination of factors, which caused, or contributed, to an incident is most important in the prevention of similar future incidents.

Perhaps the most notable are maritime investigation involve passenger vessels and the loss of human life. It is critical to determine which regulations, equipment, and operational procedures require modification to prevent these incidents. Also incidents which damage the environment have a "high profile" with a lot of public demand to find ways to prevent future incidents. For the operator, all ship incidents are important if lessons can be learned to avert damage in a potentially dangerous situation. The second by second replay of important ship data recorded by the VDR could be a critical tool for the marine accident investigator in the determination of specific precursor events, sources causing incidents, and subsequent actions taken to avert the incident.

Bridge Team Training

Shipping companies spend a great deal of effort in bridge team resource management training to ensure safe operation. Playback of VDR recording of actual operation data can provide realistic scenario to improve bridge team effectiveness and evaluate procedures for accident prevention. Corrective measures can then be reinforced via training.

EFFICIENCY

Operating efficiency is another important element in the competitive commercial shipping industry. In the long run, only the safe and efficient operator will survive in business. Efficiency can be improved only when the management can compare performance to an established base line standard. Ship operators currently rely on the crew to make observations of time, ship position, speed, engine output and other pertinent voyage data, then record them on a sheet of paper or input them into a computer data base. Uncertainties in weather conditions, effect of current, averaging process used to determine SHP, speed etc on once or twice a day basis degrade the overall data integrity. Since there is no way to check the validity of each input, the data is often of little use in performance monitoring except for record keeping purpose.

The continuous monitoring of navigation and engine data by the VDR creates an ideal database for performance evaluation in an automated fashion. Passage reports can be generated from past time history records on any selected data fields. Inferences can be made regarding the hull, engine, and propeller efficiencies as well as fuel consumption. The results can assist the management in making optimum dry-docking schedules, choosing fuel types, as well as validating claims of energy saving devices. In the real-time mode the VDR can supply critical engine data to alert operator of abnormal operating conditions before they result in engine damage. The following are a few examples of the use of VDR data in enhancing operation efficiencies:

Engine overload

Ships with low sea margin design of fixed pitch propeller and low speed diesel engine combination can often lead to engine overload when encountering head sea conditions.

Monitoring of Shaft horsepower and RPM and displaying them on an engine overload diagram can alert the operator when approaching such conditions. The engineers can then take appropriate actions to minimize the engine wear when operating in restricted zones.

Hull and propeller roughness monitoring
An increase in Hull and propeller roughness can result in a large increase in fuel consumption over time. In the worst scenario, the added resistance will also cause frequent engine overload even in favorable weather conditions resulting in reduction of operating speed. The detailed recording of engine SHP, propeller RPM, and ship speed just after dry-docking can be used as a baseline for comparison with current conditions. Savings in fuel cost can be traded-off between early dry-docking, using long lasting anti-fouling paint and underwater propeller polishing.

Performance evaluation
Ship performance evaluation has been an elusive target due to lack of detailed navigation and engine data. Uncertainties on the effect of weather and ship's loading on fuel consumption plus changes in schedule requirement makes the performance evaluation difficult if not impossible.

With the VDR recording actual ship position, speed, engine RPM, SHP and wind speed, it is possible to compare the performance to a known based line standard. Charter party speed claims can now be based on actual recorded ship speed and wind measurements. For owner operated ships, management can compare performance of sister ships running on the same trade route and identify deficient operating practice to improve efficiency. Historical data can also help the company naval architect in specifying proper sea margin when building new ships.

BEYOND VDR BASICS: ADDED ECONOMIC BENEFITS

Although the primary purpose of VDR is to record data for accident investigation, many real-time applications of the VDR can lead to improved safety by identifying and warning of impending danger or organize the alarms. VDR data could prove valuable for the training and education of mariners. Real life data of unfolding events could be used to simulate actual problematic situations and the decision of the student could safely be evaluated and guidance provided. Data could be used and reviewed by crews who operate in a problematic area to improve their decisions. VDR data can play a key roll in the education and training of our mariners to enhance the safety of operations.

Companies trying to become more efficient could also use VDR’s information. Data collected and analysis performed by companies could be used to increase their competitive advantage. Historical vessel operating efficiency data could be collected and monitored to determine the need for vessel maintenance or modification to reduce operating cost. Performance evaluation could be carried out to identify operating deficiency. By using the VDR data, companies can improve their operating efficiencies. Safer and more efficient operations can be directly translated into cost-saving and increased profitability of those shipping companies utilizing the VDR technology.

CONCLUSION

Carriage requirements for commercial vessels will happen. It is not a question of if there will be a VDR requirement, just when. IMO has passed resolution on Performance Standards of VDR and encourages member states to vote for mandatory carriage of VDR. Discussions are focusing on passenger vessels, which have potentially the greatest impact on human life; followed by vessels which have the potential for environment impacts, such as tankers and chemical carriers, then cargo vessels. Progressive IMO implementation of carriage requirements is expected in the near future.

Currently the IEC is completing the final draft of the technical standard for the VDR. The specifications will have to be consensus standards developed collaboratively by all parties with an interest. They must allow for the cost-effective production VDRs, which can be used by the majority of the commercial shipping industry. In addition, innovative use of VDR data in both real-time and archived mode should be encouraged to bring about added benefits for the owner and operators.

In conclusion, VDRs can positively impact the commercial maritime industry. Safety will be increased just by the awareness of their existence. The utilization of VDR’s in the commercial shipping industry will be a plus for the maritime industry. Just through the awareness of their existence, they will heighten operator’s diligence in operating their vessels safely and efficiently. With the carriage requirements for the maritime industry coming out in the near term, the industry must be prepared for their implementation. As ships are required to carry such recording equipment, operators should take advantage of the VDR hardware and derive added benefits in enhanced safety as well as efficiency.

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References

Chen, H. Cardone, V. and Lacey, P. "Use of Operation Support Information Technology to Increase Ship Safety and Efficiency", Society of Naval Architect and Marine Engineers, Annual Meeting 1998.

Biographies

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The Benefits of Vehicle-Mounted Video Recording Systems

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KEYWORDS

Inter-modal, Secure, Video, Recorders

INTRODUCTION

This document will explore the topic of **Vehicle-Mounted Video Recording Systems** and the potential benefits they will provide to the Transportation, Law Enforcement and Insurance Industries. Currently, there is technology available that will permit the development and deployment of Vehicle-Mounted Video Recording Systems, however this technology is not being effectively utilized. It is the belief of the author, that the introduction of such recording systems would offer numerous benefits to all entities concerned with transportation safety and efficiency.

The current methods of accident investigation and re-construction being used by the Transportation Industry are inefficient and outdated, based on today's technology. This paper will examine current methods of transportation recording and accident investigation, while pointing out the potential benefits of Vehicle-Mounted Video Recording Systems.

MAIN SECTION

CURRENT METHODS OF ACCIDENT INVESTIGATION

Accident investigations are typically conducted by three types of entities including Government Agencies, Law Enforcement/Police Officers, and Insurance Companies. Each of these entities may tend to investigate an accident from a different perspective or for different purposes, however they all have one common goal. That goal is to determine the exact cause of an accident, based on the best information available to them.

The data gathered after an accident occurs consists of background information, physical evidence at the scene, eyewitness accounts, and data stored in transportation recording devices. Each accident that occurs is unique in the information it provides for investigators. All accident investigations will have some degree of background information and physical evidence available for review. Others will provide eyewitness accounts of what occurred, however this information is subject to individual perceptions and opinions and therefore, cannot be completely relied upon. (In many cases, eyewitnesses will give conflicting reports of the same accident.) Another source of information available to investigators is data retrieved from Transportation Recorders. This type of data is present in Flight Data Recorders, Marine Trip Recorders, Railroad Trip Recorders and recently, in Trip Recorders found in larger commercial trucks. Although these recorders do in fact provide a wealth of information to investigators, they tend to concentrate only on data collection such as speed, direction, mechanical conditions and geographic locations of vehicles. This data is then used to assist in re-constructing the events leading up to an accident, so the exact cause can ultimately be determined.

The problem with current accident investigation methods is that investigators are forced to rely on accident **re-**construction methods, with only limited information available. This is especially true with highway vehicle accidents, which often occur without witnesses and where no transportation recording devices are present. Future Transportation Recorders for all modes of transportation, should focus on gathering as much information as possible before an accident occurs, and concentrate on accident event **construction**, rather than **re-**construction.

VEHICLE-MOUNTED VIDEO RECORDING SYSTEMS

Development of new technologies including the **Secure, Vehicle-Mounted, Incident Recording System**, will have a drastic impact on the future of transportation recorders. New technology will allow recording of live video from multiple cameras into a transportation recording device. This information, coupled with extensive mechanical data taken from a vehicle's instruments, would provide investigators with a highly accurate record of the events surrounding an accident. Investigators would be able to actually see, frame by frame, the events leading up to and including the actual collision or mishap, and in most cases even the moments following the actual impact. The main purpose of the system would be to capture an unimpeachable record of the events surrounding an accident and format it to be accessible only by proper authorities. This inter-modal recording system could be installed in almost any type of vehicle including trucks, cars, aircraft, marine vehicles and railroad vehicles.

These types of recording systems would have to be of a secure nature, in order to prevent the tampering of critical evidence. The recording device would also have to be housed in a crashproof, fireproof and waterproof enclosure, similar to those used in commercial aircraft, but smaller in scale. The system would capture actual video footage of a vehicle's travels and securely store an accident recording until it could be accessed by authorities. Several different camera angles could be captured simultaneously, including front, rear and side views from a vehicle. By utilizing secure data codes, authorities could feasibly access the recording device and watch a video replay of an accident, minutes after its occurrence. This type of system would also provide authorities with a permanent visual record of the incident, as it actually developed and occurred.

BENEFITS OF VEHICLE-MOUNTED, VIDEO RECORDING SYSTEMS

The potential benefits of utilizing Vehicle-Mounted, Video Recording Systems are numerous. They could assist all entities involved in accident investigations, including Police Officers, Government Agencies, Insurance Companies and adjusters, and Self-Insured Fleets. Use of such systems would streamline the entire accident investigation process for all parties concerned. By having access to actual video footage of an incident, Investigators would not have to rely solely on information gathered after the accident occurred, or on accounts from witnesses. The Video Recording System would not be a substitute for current methods of investigation, but would serve to enhance and compound the effectiveness of all data gathered from an accident. This type of collective data would promote a much more accurate and scientific analysis of the events surrounding an accident. Higher quality data and analysis would assist in the future mitigation of all types of transportation accidents and their associated human and economic losses.

Government Agencies

Vehicle-Mounted, Video Recording Systems would assist Governmental Agencies in streamlining their current methods of accident investigation and re-construction. Currently, governments spend large sums of money attempting to determine where, how and why a commercial aircraft crashed. Much time, money and effort is focused on re-constructing the aircraft and/or the event in order to determine the exact cause of the crash. With the use of a video transportation recording system, Investigators may have the opportunity to actually **see** what occurred, and this could potentially shorten the investigation thereby saving time, effort and money in the process. As in any investigation, the lapse of time from the initial occurrence is detrimental to the investigation. This is especially true with large-scale disasters such as Commercial Aircraft crashes, where critical pieces of evidence are lost to fire or explosion, or sink to the bottom of the ocean. Any successful attempt to expedite the completion of a large-scale accident investigation would result in substantial savings of money and manpower associated with it. In addition, a Vehicle-mounted Video Recording Device would provide the Agency with more reliable data than could have been gathered in its absence.

Law Enforcement

Police Officers are involved in millions of automobile accident investigations annually, in the U.S. alone. They have a multi-task duty of responding to the scene quickly, securing the accident scene, assisting the injured, investigating the accident cause, and in some cases determining culpability. Many times there are no witnesses present at an accident scene. Other times there will be conflicting versions by both witnesses and drivers, as to what actually occurred. Due to the traumatic nature of many automobile accidents, police are unable to interview the parties involved, or to gather reliable information from those that are interviewed. This is due to the different perceptions that each individual has as to the circumstances he or she witnessed. Other factors such as weather, traffic, and safety concerns can seriously hamper the effectiveness of an accident investigation.

If a police officer had access to a Vehicle-Mounted Video Recording System following a crash, the officer could potentially access the system within minutes of the crash. The officer could then watch a video replay of the incident as it actually occurred. This in turn would allow the officer to see what most of the circumstances were surrounding the incident including, traffic controls, location of other vehicles, lighting conditions, road conditions, weather conditions, visual obstacles or many other contributing factors. Instead of relying solely on second-hand information, conflicting drivers' accounts and witness accounts, the officer could see first-hand, what actually occurred.

By having a video file of the accident to review , the officer could then complete his investigation in a much shorter time period than is now required. The officer could also issue citations with confidence in determining which party was at fault. Further benefits of this feature would be increased safety of the officer and accident parties through expedited accident clean-up and less disruption to traffic. A faster investigation would also free the officer to return to other duties more quickly.

Insurance Companies

It is estimated by the Insurance Industry that there were over 35 million automobile accidents in 1997 in the U.S. costing $123.7 billion. A majority of these accidents are investigated by the Insurance Industry regardless of prior Law Enforcement investigations. Insurance Companies incur a myriad of costs involved with the investigation and settlement of accident claims. Some of these costs include property damage payments, damage appraisals, scene investigations, police reports, vehicle storage fees, rental car expense, fraud investigation, forensics studies, arbitration, litigation costs and general operations and payroll costs.

Another major factor that affects the Insurance Industry is casualty insurance fraud. It is estimated that 10% of all casualty claims filed are fraudulent and account for nearly $13 billion in losses annually for U.S. Insurance Companies. Since these losses tend to get passed on to the consumer, it is also estimated that insurance fraud costs the average household $200 to $300 a year in premiums.

Insurance Companies and their policyholders could benefit substantially through the use of Vehicle-Mounted Video Recording Systems. Some of the potential benefits are:

- First hand physical evidence of accident circumstances
- Concrete evidence to fight fraudulent claims
- Lower insurance premiums due to increased efficiency
- A deterrent to accident fraud, due to increased risk of prosecution
- A reduction in the cost of insurance company operations
- Protection of innocent drivers' deductibles and driving records
- Fewer and shorter recorded statements needed by insurance companies
- Higher quality customer service for policyholders and claimants
- Video evidence of hit and run incidents
- Decreased expenses for damaged vehicle storage fees
- Lower car rental expenses due to shorter liability determinations
- More accurate loss reserves for insurance companies and their agents
- Fewer scene investigations required by insurers
- Lower expenses for Special Investigation Units
- Additional evidence for use by Special Investigation Units
- More reliable evidence for arbitration hearings
- A reduction in the number of forensics studies required in low- velocity impacts
- A reduction in Road Rage due to accountability
- Fewer court cases resulting from car accidents
- Fewer "Bad Faith" claims against insurance companies

Overall, the use of Vehicle-Mounted Video Recording Systems will benefit the Insurance Industry as a whole, through increased operational efficiency and a reduction in fraudulent claim losses.

A Case in Point

As of this writing, investigators from the National Transportation Safety Board are reviewing a tragic accident between an Amtrak train and a tractor-trailer outside of Chicago, IL. (USA), in which at least 11 people have died and numerous more are seriously injured. A tractor-trailer hauling a load of steel was attempting to cross the train tracks when the Amtrak train carrying 217 passengers, collided with the trailer. The engineer and truck driver both survived the accident and both have given very different accounts of what occurred just prior to the crash.

The truck driver stated that he entered the crossing and that the gates and signals were not down but became operational after he had already entered the tracks. Contrarily, the train engineer maintains that he saw the signals operating correctly and that the truck was stopped, but then that it began to proceed over the tracks illegally. Preliminary investigation is focusing on tire tracks that would indicate the possibility that the truck proceeded around the crossing gates and onto the tracks. Investigators have reviewed the information provided by the train's "black box", and have determined that the train was traveling at a legal speed and attempted to brake before the impact. Although this information is useful, there are still many unanswered questions as the investigation continues.

Assuming that either vehicle or both vehicles involved in this accident had a **Secure, Vehicle-Mounted, Incident Recording System** on board, investigators would already know exactly what occurred. A video system on board the train would have shown the view that the engineer had just prior to the crash and would prove his story either correct or incorrect. A video system on board the truck also would have shown the view that the truck driver had prior to entering the tracks. If both vehicles had on board video recording systems, the NTSB would have a near perfect record of the incident from both drivers' perspectives, and would be able to complete the investigation more accurately and efficiently. If only one of the vehicles involved had such a system, investigators would still have been provided with enough additional information to determine the cause of the crash, based on the video evidence available.

CONCLUSIONS

Future Transportation Recording Technologies should focus on gathering video evidence of accidents as they occur. The current methods of accident investigation in place rely on accident re-construction with limited information available. With the use of Vehicle-Mounted Video Recording Systems, investigators would have a secure, video recording of accidents to review. The additional information provided by this type of system, would streamline the investigation process and allow investigators to complete their job more accurately and efficiently. This developing technology is inter-modal and can be installed in all types of vehicles including automobiles, trucks, trains, ships and aircraft. Government Agencies, Law Enforcement Officers and Insurance Companies would all benefit from the use of such systems. The main benefits provided by such systems would be a drastically increased efficiency in the accident investigation process, economic savings, and more accurate data which could be used in the future mitigation of the human and economic loss associated with transportation accidents of all types.

REFERENCES

1. Insurance Information Institute 1999 Factbook
2. National Transportation Safety Board
3. National Highway Transportation Safety Administration

AUTHOR'S BIOGRAPHY

R. Jeffrey Scaman is CEO of Evicam International, Inc. and inventor of the **Secure, Vehicle-Mounted, Incident Recording System**, also known as the "**EVICAM**", an acronym for *evidence camera*. Mr. Scaman has prior experience is project management, data analysis and claims adjudication. He has personally investigated hundreds of automobile accidents, with emphasis on auto-theft and fraud investigations. His past experiences inspired him to begin focusing his efforts on developing Vehicle-Mounted Video Recording Technologies.

Feasibility of Battery Backup for Flight Recorders

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KEYWORDS

Aviation
Cockpit Voice Recorder
Flight Data Recorder
Battery backup

INTRODUCTION

On March 9, 1999, the National Transportation Safety issued Recommendations A-99-16 and A-99-17 calling for revisions to the FAA Regulations dealing with Cockpit Voice Recorders and their installation in commercial aircraft. These recommendations read as follows.

> Require retrofit after January 1, 2005, of all cockpit voice recorders (CVRs) on all airplanes required to carry both a CVR and a flight data recorder (FDR) with a CVR that (a) meets Technical Standard Order (TSO) C123a, (b) is capable of recording the last 2 hours of audio, and (c) is fitted with an independent power source that is located with the digital CVR and that automatically engages and provides 10 minutes of operation whenever aircraft power to the recorder ceases, either by normal shutdown or by a loss of power to the bus. (A-99-16)
>
> Require all aircraft manufactured after January 1, 2003, that must carry both a cockpit voice recorder (CVR) and a digital flight data recorder (DFDR) to be equipped with two combination (CVR/DFDR) recording systems. One system should be located as close to the cockpit as practicable and the other as far aft as practicable. Both recording systems should be capable of recording all mandatory data parameters covering the previous 25 hours of operation and all cockpit audio including controller–pilot data link messages for the previous 2 hours of operation. The system located near the cockpit should be provided with an independent power source that is located with the combination recorder, and that automatically engages and provides 10 minutes of operation whenever normal aircraft power ceases, either by normal shutdown or by a loss of power to the bus. The aft system should be powered by the bus that provides the maximum reliability for operation without jeopardizing service to essential or emergency loads, whereas the system near the cockpit should be powered by the bus that provides the second highest reliability for operation without jeopardizing service to essential or emergency loads. (A-99-17)

A key element of these recommendations is the requirement to provide an independent power source which provides 10 minutes of continued operation following the removal of the main aircraft power. This paper will discuss the feasibility of an independent power source for the Flight Data Recorder and the Cockpit Voice Recorder. And in addition, offer two options for complying with the recommended requirement and offer some comparative analysis of the two options.

MAIN SECTION

The purpose of the independent power supply is to enable continued operation of a flight recorder following an event which otherwise would prevent operation of the system. In the March 9, 1999, letter to the FAA (Reference 1), the NTSB cited several accidents in which continued operation of either recorder would possibly have provided investigators with valuable additional information. Events which pose threats to the power supply for the recorder also threaten the aircraft wiring which connects the recorder to the signal sources providing the requisite information to be recorded. Therefore, any attempt to provide for continued operation of a flight recorder in a situation which jeopardizes the aircraft must consider both the power and the signal source interconnections.

FEASIBILITY CONSIDERATIONS FOR THE FDR

The flight data recorder is a single component of a data acquisition and recording system that is widely distributed in an overall aircraft system. The recording system includes individual sensors that provide voltage signals representing a wide variety of activities and digital links to other aircraft systems such as the Digital Air Data Computer. The information is gathered and formatted into a predetermined digital representation by a Digital Flight Data Acquisition Unit (DFDAU) which is usually a separate LRU centrally located for ease of interconnection. In the most modern digital aircraft systems, the function of the DFDAU may be performed by an individual element of a larger system instead of a dedicated LRU. The formatted digital representation of the aircraft information is then sent to the Digital Flight Data Recorder, which serves as the crash protected memory element of the entire data recording system. Figure 1 provides an illustration of the complexity of an aircraft flight data recording system.

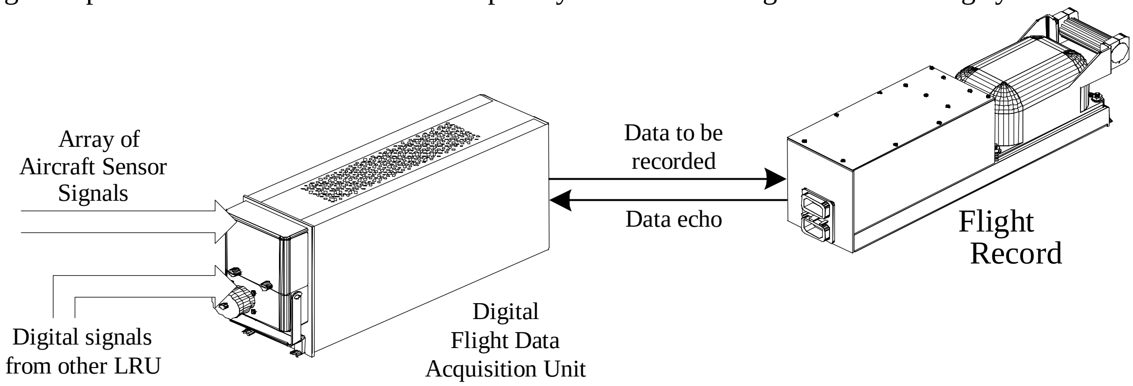


Figure 1: Flight Data Recorder System

For an uninterruptable power scheme to be effective for the data recording system, it would be necessary to supply a very large array of sensors and other aircraft avionics. In addition, the elements of the flight recording system are interconnected with an extensive, complex network of aircraft wiring. For the system to continue useful operation during a hazardous situation the integrity of the interconnection network would have to be maintained. It is unlikely that the system wiring integrity can be maintained during a serious threat to the aircraft. Therefore, it is not practical to attempt to design a flight data recorder system that is capable of continued operation during an extensive aircraft failure.

FEASIBILITY CONSIDERATIONS FOR THE CVR

Compared to the flight data system, the Cockpit Voice Recorder (CVR) system is contained and concentrated. The system is comprised of a Cockpit Voice Recorder, a subsystem for the Cockpit Area Microphone (CAM), and the interconnections to the aircraft audio system for pilot, co-pilot, and public address/flight engineer audio signals. The system is illustrated in Figure 2. The CAM subsystem receives power directly from the CVR. Therefore, for the CVR and the CAM an independent power source would provide a high probability of achieving the goal of continued operation during an extensive aircraft failure of the kind cited in the reference. In addition if the CVR were to be located in the forward section of the aircraft, particularly close to the cockpit, the length of wire necessary to connect the CAM subsystem to the CVR could be minimized, thereby providing additional assurance that the system would continue uninterrupted operation during hazardous situations. For the other components of the system, namely the aircraft audio controller, a design complication similar to that discussed in relation to the flight data recorder exists. Namely, the involvement of other aircraft systems whose function is not specifically related to the flight recorder adds sufficient complexity to prevent the likelihood of successful continued operation. Consequently, it is not practical to attempt to continue to record audio signals other than those from the CAM.

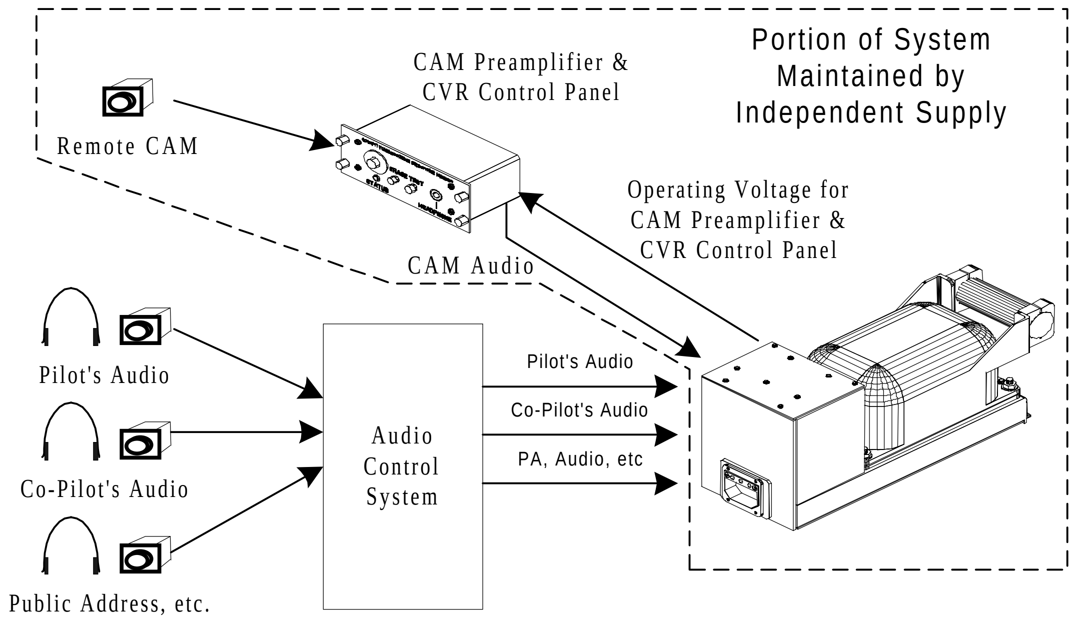


Figure 2: Cockpit Voice Recorder

INDEPENDENT POWER SOURCES

To date, there have been two design approaches suggested for the provision of an independent power source capable of supplying sufficient electrical energy to enable the CVR to continue operation for 10 minutes following the loss of main aircraft power. The first of these is a large capacitor to store charge during normal operation, and then discharge through the CVR when main power is removed. The second is a separate battery to supply the CVR following removal of the main power, and to be recharged during normal operation. The remainder of this section will deal with proposed system requirements, design considerations for each type of system, and a comparative analysis.

Requirements

Proposed requirements of an independent power source for the CVR are shown in the following table. Since emphasis on the subject of independent power source is relatively recent, this list is preliminary and will likely experience extensive revision. For some entries, suggested tolerance ranges are indicated.

Requirement	Specification
Duration of continued operation	10 minutes ($10 \leq t \leq 12$ minutes)
Voltage	Greater than the minimum operating voltage for the CVR for the duration.
Charging time	< 30 minutes {The system must be capable of providing the required function from the actual departure from the originating terminal gate until the safe arrival at the destination terminal gate.}
Isolation from aircraft systems	During charging, must not interfere with the continued proper operation of other LRU supplied from the same buss; during discharge, must supply only the CVR.
Maintenance	Minimal
Interconnection	The installation must minimize the risk of interconnection failure during hazards to the aircraft.
Prevention of accidental erasure	The system should be installed to prevent continued recording should the CVR become separated from the aircraft.

Capacitive System
A capacitive system is illustrated in Figure 3. Simple computations show that to maintain sufficient voltage for uninterrupted operation of a CVR consuming 10 Watts would require 26 to 30 Farads of capacitance. These computations are illustrated in Figure 3, which also illustrates the nominal voltage range.

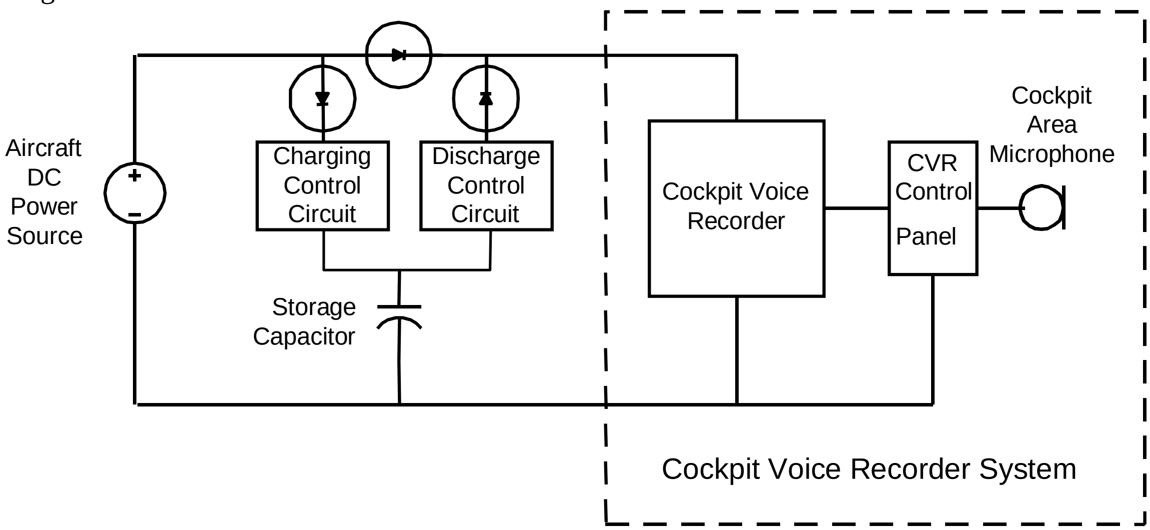
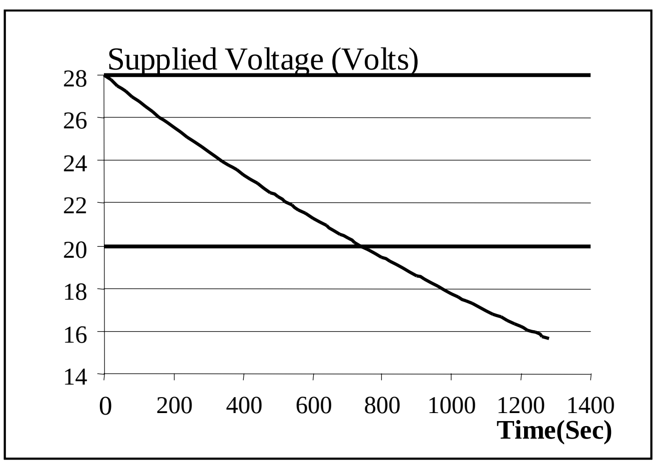


Figure 3: Independent Power Source Using a Storage Capacitor



5 Derivation of Capacitor Size

$W = 10$ Watts

$\Delta t = 600$ secs

$V_0 = 28$ VDC

R = Load of the CVR

Following the removal of main aircraft power

$$V(t) = V_0 e^{(-t/RC)}$$

Using the values for W, V_0, and Δt:

$$C = \frac{\Delta t}{R \bullet Ln\left(\frac{28}{20}\right)} = 28 \text{ Farad}$$

Figure 4: Capacitor Size Selection

Battery System
A battery system is illustrated in Figure 5. Since available batteries typically supply considerably more energy, of the order of 10 Amp-Hours, than is required for this application, a mechanism to disconnect the battery after the specified operational duration is necessary. For the battery system, the design must include a timer element in the Discharge Control Circuit.

The charging control circuit will require functionality to sense the state of the battery charge and provide for controlled recharging.

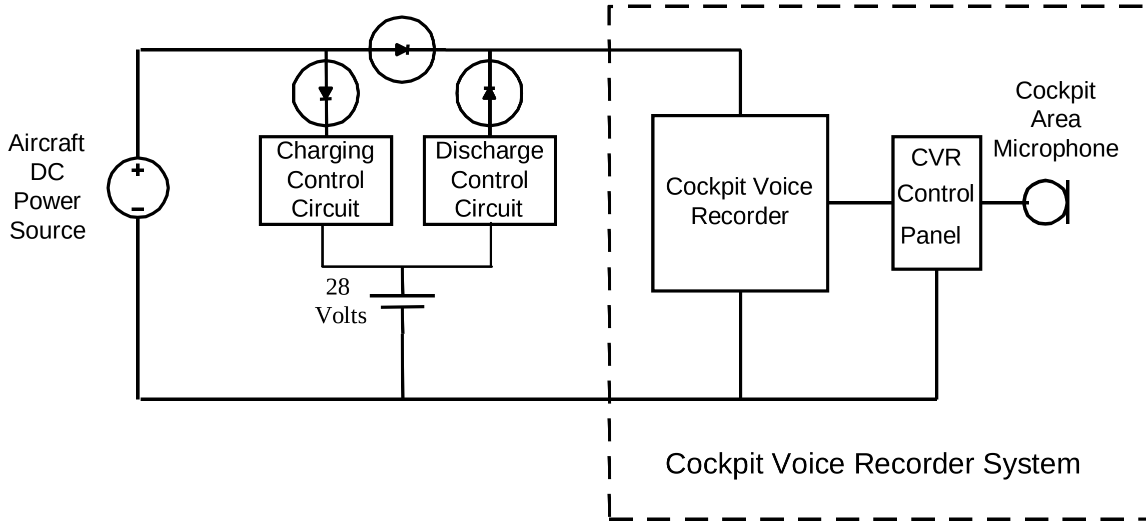


Figure 5: Independent Power Source Using a Battery

Comparative Analysis
The following table lists a number of design considerations and provides a relative indication of the complexity of the two independent power options discussed above. The information provided is intended only as a qualitative indication of the relative standing of the two options. As quantitative information becomes available, many of the assessments may indeed prove trivial and unimportant.

Item of Comparison	Capacitor	Battery
Cost	-	+
Charging circuit complexity	-	+
Discharging circuit complexity	+	-
Weight	-	+
Volume	-	+
Maintainability	+	-
Reliability	-	-
Maintenance hazard	-	+

+ indicates a relatively favorable characteristic.

AIRCRAFT INSTALLATION CONSIDERATIONS
Supplying the flight recorder with an independent power source capable of maintaining proper operation following the removal of the main aircraft power requires that the flight recorder by supplied from a DC power bus. Historically for large transport aircraft, Flight Data Recorders and Cockpit Voice Recorders have been supplied with 115 VAC @ 400 Hz AC power. In order to comply with this requirement flight recorders capable of operating from DC power must be available, and in the retrofit case, aircraft wiring must be altered. To achieve the maximum probability of continued operation of the CVR during a hazardous condition, the equipment should be located as close to the cockpit as possible. For retrofit the addition of a small, lightweight, DC powered CVR, while leaving the existing system untouched, may very well prove to have the least design, installation, and cost impact on the aircraft.

CONCLUSIONS

Installation of an independent power source to provide continued operation following removal of main aircraft power is practical for the Cockpit Voice Recorder and the Cockpit Area Microphone subsystem. Indeed, the technology for at least two design approaches exists and is available to system designers. Consideration of the continued integrity of the aircraft wiring dictates that the CVR provided with the independent power supply is located in close proximity to the CAM subsystem. Because of the distributed nature of the flight data recorder system and the associated, extensive wiring network, an independent power source for the FDR is not practical.

REFERENCES

1. National Transportation Safety Board, Safety Recommendation A-99-16 & A-99-17, March 9, 1999.

BIOGRAPHIES

Mr. Schofield has been employed by AlliedSignal, Inc. Air Transport & Regional Avionics in Redmond, Washington. He has been involved in customer support engineering, project engineering and engineering management for the company's flight recorder product line since 1986. His current assignment is Manager, Flight Recorder Products. Mr. Schofield holds a Bachelor of Science in Electrical Engineering from Pennsylvania State University.

Standardized Flight Recorder Documentation

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KEYWORDS

Aviation
Flight Data Recorder (FDR)
Flight Recorder Configuration Standard (FRCS)
Accident Investigation

INTRODUCTION

The need for an international standard to document the format and arrangement of flight data recorded by Flight Data Recorder Systems (FDRS) has long been recognized by air safety investigators responsible for the retrieval and analysis of FDR data following an occurrence. Significant time delays can be eliminated where complete and accurate information about the Flight Data Recorder System is readily available to investigative authorities.

THE NEED FOR A STANDARD

With the introduction of modern aircraft and recording devices, the quantity of recorded flight parameters available on the FDR and other recording devices continues to increase. With this increase in available information comes a corresponding increase in the demands for documentation to describe the data recorded by FDRS. Currently, FDRS documentation available to air safety investigators may vary in both format and content and is typically supplied as a paper document.

Investigators are faced with the time consuming task of finding and then extracting the necessary information from the supplied documentation (i.e., all of the information required to convert raw recorded data into time-stamped engineering units). This information then needs to be transcribed into an electronic format suitable for the particular FDR replay and analysis system used by the investigative agency. When a large number of flight parameters are recorded, the manual transcription process may be both time consuming and error prone.

This process of extracting and transcribing FDRS configuration information can affect both the timeliness and accuracy of the recovery of data after an occurrence. This in turn affects the timeliness and effectiveness of recommended safety improvements. Standardized format and content for documenting the data recorded by FDRS, as well as, a standardized electronic format for the exchange of such information is necessary.

Figure 1 illustrates the process involved in recovering recorded flight data.

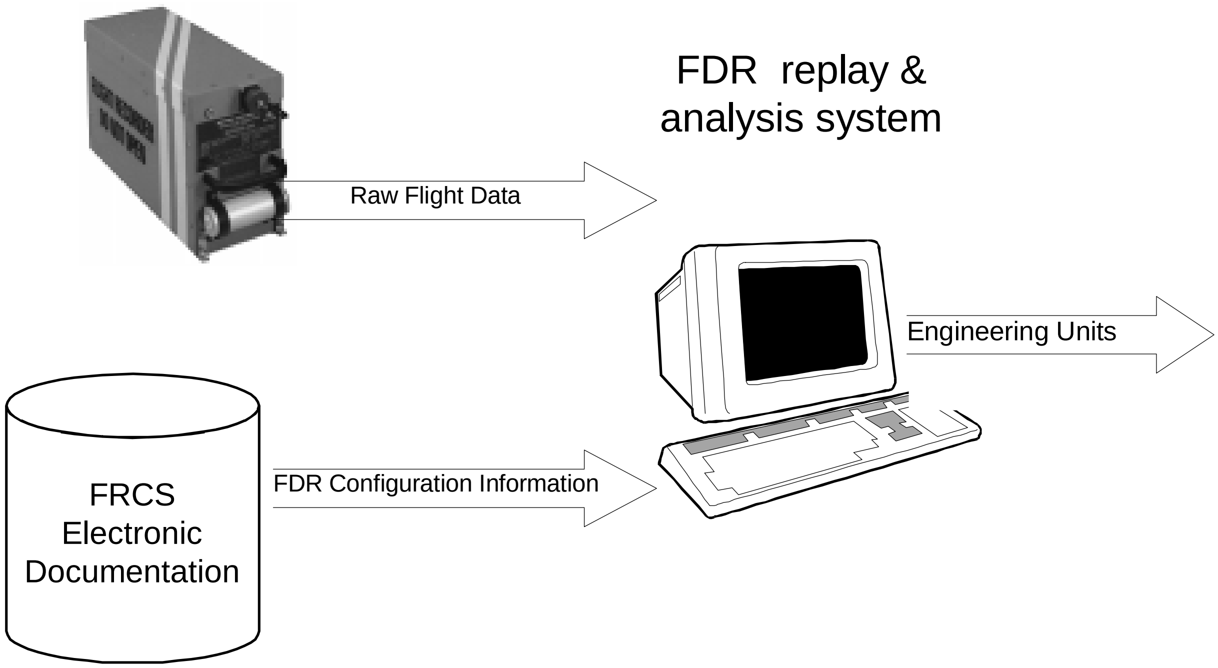

Figure 1: Recovery of flight data

EFFORT TO DEFINE A STANDARD

Over the past two years, Transport Canada's Transportation Development Centre has sponsored a project to define a Flight Recorder Configuration Standard (FRCS). This work has been performed with the participation and input of an international Project Review Committee with both government and industry representation.

The effort has focused on documenting and defining those FDRS documentation items that are required specifically by investigators for the recovery and analysis of FDR data. Items in the standard are defined as either mandatory or optional. While the investigators desire as much information as possible, it was recognized that some information may not be readily available to those responsible for maintaining the documentation. The mandatory items represent the minimum set of information required by the investigators.

The second aspect of the effort was to define a portable electronic format that is suitable for the exchange of the flight recorder configuration information. Existing electronic formats tend to be tied to particular manufacturers ground replay stations. These formats are subject to frequent change with the evolution of the products. The FRCS does not seek to replace these existing formats, rather the desire is to have a common format, which can be "exported" from and "imported" into the wide variety of products in use today. Eventually, it is hoped that all manufacturers will adopt the FRCS.

During the project, a preliminary version of the standard was developed along with a sample software application that makes use of the standard for demonstration purposes. The sample application is illustrated in Figure 2. This material was distributed for international review and has been tested in a Field Trial. The standard was revised based on the comments received and acceptance is being sought from various industry, government, and international organizations such as ICAO, ISASI and EuroCAE.

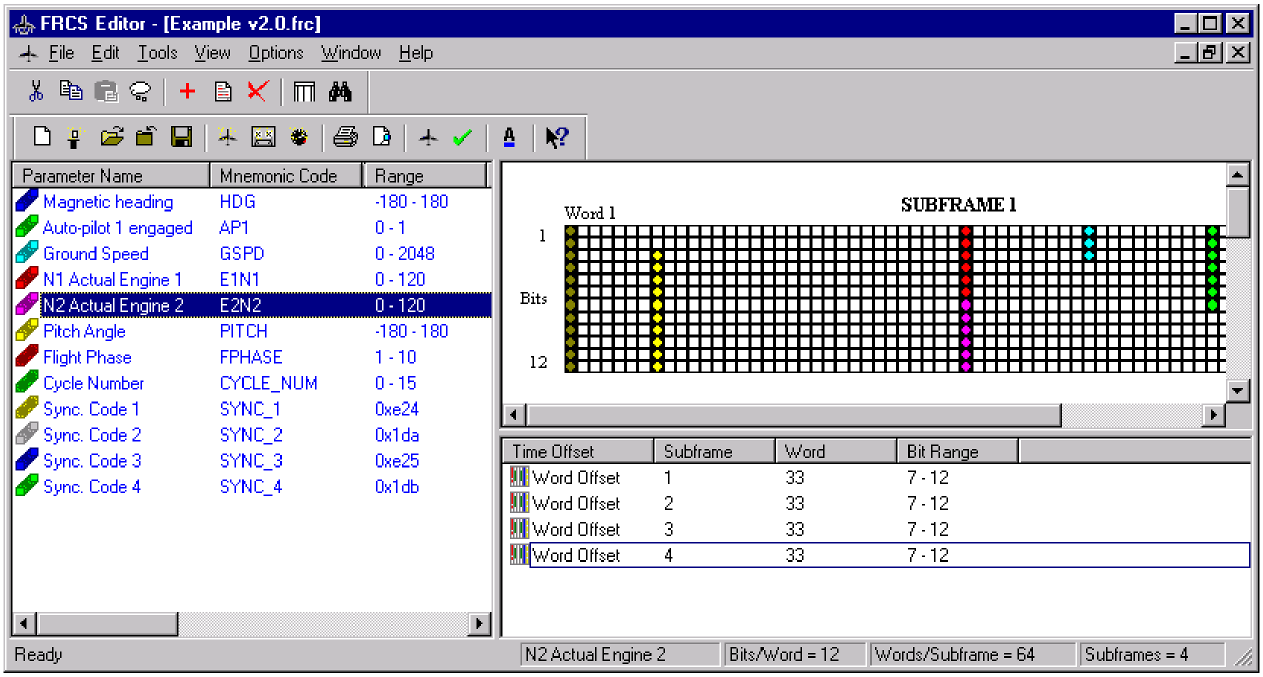

Figure 2: Sample Application Using FRCS

FLIGHT RECORDER CONFIGURATION STANDARD

The FRCS content is grouped into header, record (subframe) and parameter information. Furthermore, the standard has been defined to accommodate differences in formats for the different manufacturers and aircraft configurations [1] [2].

CONTENT

The header contains information specific to the aircraft, on-board data acquisition and recording equipment and record (subframe) definition. The record (subframe) information consists of word length, record (subframe) size and duration.

The information associated with each parameter includes:

- Identification items

  These include name, mnemonic, identifiers, user-definable fields, date, time and comments.

- Location items

  These contain details referring to the sample and component locations in the frame.

- Conversion items

  Equations and tables for converting the raw data to engineering units and the accuracy of the mathematical conversion are documented.

- Accuracy items

  Some examples are valid operational range, accuracy, resolution and transport delays.

- Sensor and signal items

  These include the sensor type, signal type and signal source.

- Digital Information Transfer System (DITS) items

  These items refer to the label, bits numbers and coding.

DESIGN CONSIDERATIONS
The standard is defined to be as flexible as possible to accommodate non-standard and future recording formats. For example, the number of bits per FDR word is not assumed to be 12 even though this is the most common size. A second example is the ability to accommodate the documentation of recording formats using variable length records (subframes) as currently used in some military flight recording applications.

To ensure maximum portability of the electronic files, the standard specifies an ASCII format rather than a less portable binary format. The layout of the electronic file is defined by a "grammar" which can be parsed using common software tools. The approach of using a grammar to define the layout was chosen to reduce the likelihood of ambiguity in the interpretation of the format. The information for an aircraft configuration is contained in a single electronic file. The use of a single file simplifies the electronic transfer of the information.

In response to international comments and to enhance the usefulness of the standard for non-investigative agencies such as operators and manufacturers, the standard allows individual users to add their own specific fields and data values. For example, a manufacturer may wish to define a field "DFDAU Input Port" for their own use. While the FRCS does not require this field, the standard is flexible enough to allow additional information to be saved with the file. This flexibility can provide benefits to Flight Data Monitoring (FDM) and Flight Operational Quality Assurance (FOQA) programs.

CONCLUSIONS

The maintenance of flight recorder configuration information in a common, standard electronic format should facilitate and expedite deciphering recorded flight data.

Adoption of the FRCS by industry is a key step to achieving international acceptance. A mechanism must exist to promote the use of the standard and to ensure FDRS documentation is adequately maintained throughout the life cycle of an aircraft and a means must be in place to make the information available to investigation authorities when required. Endorsement of the FRCS by industry, government authorities, and international bodies would be instrumental in achieving international acceptance.

The FRCS is currently endorsed by the FAA and Transport Canada as an acceptable means of documenting data recorded by FDRS [3] [4].

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REFERENCES

1. Transport Canada, *TP 13140E Flight Recorder Configuration Standard Version 1.0*, January 1999.
2. Software Kinetics Ltd., FRCS web site, http://frcs.sofkin.ca
3. Federal Aviation Administration, *DRAFT Advisory Circular 20-DFDRS-1*, December 3, 1998.
4. Transport Canada Aviation, *Airworthiness Manual Advisory (AMA) 551.100*, December 1, 1998.

BIOGRAPHIES

Mr. Ian Smith manages the Advanced Systems group at Software Kinetics. He is currently the project manager for the Flight Recorder Configuration Standard project. Over the last 11 years, he has been involved in a number of flight data recorder, avionics, and air traffic control related projects. Mr. Smith holds a B.Sc. from the University of Guelph as well as an M.Sc. in Computer Science from Queen's University.

Mr. Howard Posluns is the Acting Chief, Advanced Technology, of Transport Canada's Transportation Development Centre (TDC). TDC, established in Montreal in 1970, is Transport Canada's multi-modal R&D arm. For the past 15 years Mr. Posluns has been involved in the management of various R&D projects related to aviation safety efficiency, and security. Mr. Posluns holds an electrical engineering degree from Concordia University, and is a member of the Institute of Electrical and Electronic Engineers (IEEE).

Design of a Crash Survivable Locomotive Event Recorder

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KEYWORDS

Rail Event Recorder, Crash Survivable Memory, FRA Crashworthy Event Recorder,
FRA Rule 49 CFR 229.135

INTRODUCTION

The FRA is presently preparing a regulation covering the crash survivability of the Locomotive Event Recorder. This regulation will also specify the minimum number of parameters to be recorded and how this requirement will be phased-in on existing and new locomotives. The parameter selection reflects the more advanced control systems now in use or planned for use in the modern passenger or freight locomotive. In lieu of periodic inspection and test, the regulation will require the Event Recorder to incorporate internal self-monitoring. Self-monitoring will extend the inspection interval to one year and, based on good one-year results, extend the interval to three years.

The crash survivability test levels and test methods are based on the European Organization for Civil Aviation Equipment (EUROCAE) documents, ED-55, "Minimum Operation Specification for Flight Data Recorder System," and ED-56A, "Minimum Operation Requirement for Cockpit Voice Recorder System." The tests, test levels and methods have been modified to reflect the lower speeds and heavier structure of the locomotives. The product of the crash survivability is the recorded data. Specifics covering the recovery of the data are not intended to be incorporated into the regulation. However, the rail system, like the airborne flight data recorders, must have provisions to recover the data down to the memory board and memory chip level.

PROPOSED FRA REGULATIONS

The present FRA regulation 49 CFR 229.135 requires all lead locomotives and remote distributive power locomotives that travel over 30 miles per hour to have an Event Recorder capable of recording a minimum number of parameters (nine). The new ruling will modify 49 CFR 229.135 and catagorize locomotives by manufacture date, to be-equipped-with or to phase-in crashworthy event recorders over a period of time or at an overhaul. The minimum number of parameters (nine) must be recorded on locomotives built prior to a TBD date. For locomotives having a tape recording medium, their recorders must be removed from service during a five-year period and replaced with crashworthy recorders capable of recording the same number of data channels as the recorders they replace. All locomotives built after a TBD date, and those built prior to a TBD date and undergoing a rebuild overhaul, must have a crashworthy recorder capable of recording 27 parameters. MU locomotives built after a TBD date will be required to have a crashworthy recorder capable of recording 20 parameters.

The criteria for the crashworthy Event Recorder Memory Module (ERMM) have been adopted from the EUROCAE ED-55 and ED-56A documents with different test limits and time durations. The crash survivability tests include impact shock, static crush, fluid immersion, fire and hydrostatic pressure. The testing procedures must be as specified in EUROCAE ED-56A.

The fire test requires the ERMM to be subjected to both high and low temperature fire tests. The high temperature test requires that the entire external surface of the ERMM be exposed to a flame temperature of 1000^{o} C for a period of 60 minutes. The low temperature test requires a constant air temperature of

260^o C for a period of 10 hours. These tests simulate fire-pool and hot wreckage bake exposures respectively.

The impact shock test requires the ERMM to survive a shock pulse of 23 g's for 250 milliseconds duration applied to the most damage-vulnerable direction. This simulates impact of an 80-mph locomotive into an unyielding object.

The static crush requires a static force of 25,000 lbs. applied continuously to each face of the unit for a period of five minutes. In addition, a static force of 10,000 lbs. must be withstood for a period of five minutes using a loading surface that is 25% of the total surface of each face. This simulates a locomotive derailment and blunt object impact.

Fluid immersion tests require the ERMM to be immersed in regular and salt water, number 1 and 2 diesel fuel, and lubricating oils individually for 48 hours. In addition, immersion in currently used fire extinguishing agents for 48 hours is required.

The hydrostatic requirement is immersion in salt water to an equivalent depth of 100 feet at a nominal temperature of 25^o C for a period of 48 hours. This duplicates the deepest anticipated water submersion for a derailed locomotive.

The testing sequence allows split-branch testing, permitting separate recorders to be tested for fire and hydrostatic performance since it is unlikely that an ERMM would be involved in fire and sunk in water as a result of the same incident.

	Requirement	Air	Rail
6	*Shock*	3,400 g's/6.5ms	23 g's/250 ms or energy equivalent
7	*Penetration*	10 ft. Drop 500 lbs., $0.05in^2$	8 *Not required*
9	*Static Crush*	5,000 lbf, 5 min., faces and diagonals	25,000 lbf/5 minutes, each face
10	*Face Crush*	11 *Not required*	10,000 lbf/5 min. Applied to 25% of a face
12	*Fire, High Temperature*	13 *1100^o C, 60 minutes*	1000^o C, 60 minutes
14	*Fire, Low Temperature*	15 *260^o C, 10 hours*	260^o C, 10 hours
16	*Immersion, Fuel/Fluids*	17 *48 hours*	48 hours
18	*Immersion, Sea Water*	19 *9 feet, 30 days*	48 hours
20	*Immersion, Fire Exting.*	21 *8 hours*	48 hours
22	*Hydrostatic, Sea Water*	23 *20,000 feet, 30 days*	100 ft, 48 hours

Table 1: Comparison of crash survivability requirements.

RAIL VERSUS AIR REQUIREMENTS

The EUROCAE specifications for airborne recorders were used as a reference point to define the required rail crash survivability levels. The requirements differ as a result of the lower speeds and higher weights of the rail equipment. A comparison of the rail and air survivability requirements is shown in Table 1. The aviation recorder requirements are detailed in FAA regulations in 14 CFR that refer to TSO-C124a, which in turn refers to the EUROCAE documents.

PRESENT RAIL RECORDERS
Locomotive event recorders currently in use range from older tape units with a minimum of channels to more recent solid-state units with a variety of input capabilities. Data storage is provided by magnetic tape, battery-backed RAM, nonvolatile EEPROM or "flash" memory. Solid state memory is available from 256K bytes to 2M bytes and can be downloaded via a communications unit or a removable memory card.

Inputs for non-integrated stand-alone recorders are typically analog or discrete (digital) channels with limited capability. In these systems, the recorder interfaces directly with the sensors in the locomotive. The recorder must process each signal individually. Since signal types can vary, specialized hardware and software are required within the event recorder. The stand-alone approach also increases the complexity of the recording system by requiring the routing of additional wiring from the sensors to the recorder. The flexibility of the stand-alone recorder is limited in that changes to sensors and numbers and types of channels will require changes to the recorder hardware and software as well as wiring changes within the locomotive.

More recent recorders are integrated digital systems that interface with the Locomotive Process Controller (LPC) computer via a serial data bus. In these systems, the LPC interfaces directly with the sensors in the locomotive. The recorders acquire the sensor readings as digital data from the controller. This approach permits access to all the parameters available to the LPC with only a recorder software configuration. Wiring is minimized, and parameter changes require only software reconfiguration. In addition, the integrity of data transmission is preserved by a check-byte field and error-correcting protocol.

The FRA presently requires an event recorder, but it need not be crash survivable. In anticipation of the regulation, Electrodynamics, Inc. has developed, tested and installed a crash survivable event recorder, to a General Electric Transportation Systems (GETS) specification, that meets or exceeds the GETS specification and the proposed FRA regulation requirements.

CRASHWORTHY RECORDER DESIGN

Locomotive recorders must survive shock, crush, fluid immersion, fire, bake, and/or hydrostatic pressure in the order they would naturally occur. It is advantageous to include design features that address two or more of these requirements simultaneously. This is easier to do in rail recorders than in aviation recorders.

SHOCK
Shock damage is avoided by not using brittle items such as ceramic or glass circuit cards or electrical components in the crash-survivable memory unit. In military aviation recorders, some of these items may be needed to meet military-component requirements and to cope with extremes of thermal exposure (thermal coefficient of expansion incompatibilities). Metal-core cards or chip-carrier adapters on plastic cards are used for strength and thermal compatibility. In rail recorders, severe extremes of temperature and qualified-parts lists are not considerations. This allows use of tough, inexpensive commercial plastic-package components and polymer circuit cards that can withstand high levels of acceleration and bend/twist force without damage. Peak acceleration is 150 times higher in air crashes, but is only 33 times longer duration in rail crashes, resulting in 77% less total energy (g-time) in rail crashes than in air crashes. This also assists in lowering costs of circuit packaging in rail recorders.

CRUSH
Static crush forces are five times higher for locomotive accidents than airplanes, but since impact speeds are much lower, penetration forces are less, and are more static than inertial. A strong housing is important for both. A strong housing also provides a solid foundation for mounting of the memory assemblies for shock resistance. Housings are usually rectangular for best crush survival. Minimizing size

and weight of the housing is much more important in aircraft than locomotives. This leads to use of expensive, exotic materials such as titanium housings and intumescent paint coatings that swell into an insulating foam char when exposed to fire. Smaller housings are also inherently stronger in face strength, and have less fire exposure surface. In contrast, crash-protected memory sizes are usually larger and heavier for rail recorders, since size and weight are not concerns. This allows use of inexpensive common steels and paints for housings. The larger face sizes have less inherent crush strength, but rail penetration requirements are not as severe. The larger fire exposure is compensated by use of thicker insulation and heavier thermal mass in the memory unit. Thus, larger allowable size-and-weight yields dramatic cost reductions in rail recorders.

FLUIDS

Fluids that the recorders can be immersed in, such as jet or diesel fuels, oils and lubricants, hydraulic fluids, and fire extinguishers, have some similarities and differences between air and rail cases, but no significant differences. The best defense against fluids is impervious conformal coatings on the memory circuit cards. The strong housings cannot be counted on to provide fluid immersion survivability, since the electrical connector is typically a weak spot.

FIRE

Fire survivability requirements are similar for aircraft and rail recorders, with rail recorders having a slightly lower peak fire temperature due to lower fuel burn temperatures. Fire protection uses a two- or three-part strategy based on delaying and deflecting heat flows. Special high-temperature insulation inside the crash-survivable housing reduces flow of heat to the interior to a small amount per hour. Unlike typical soft fiberglass or Styrofoam insulation, it is a solid fibrous mass, to support the memory cards for shock survival without using heat-conducting metal supports. It is also rated for high temperatures. Large thermal masses that require lots of heat flow to raise their temperature surround the memory circuits. In some aviation recorders, water or other phase-change materials act to absorb or dissipate some of the interior heat as temperatures rise. Solid-state memories that can survive high peak temperatures for a short time without loss of data are used in modern recorders. The goal is to reduce the peak temperature seen by the memory to much less than the fire temperature. Military aviation recorders sometimes use expensive intumescent paints, super-insulations, and beryllium or phase-change thermal masses to reduce size and weight to absolute minimums. Larger and heavier rail recorders can use ordinary paints, thicker but less-expensive solid insulations, and a larger thermal mass of common steel as the thermal heat sink. They do not need special heat-absorbing materials. This allows large reductions in the cost of fire protection for rail recorders.

BAKE

The same thermal features provided to survive short-term fire also provide long-term bake survivability. In rail recorders, there is no reliance on finite “consumable” phase-change heat-dissipating materials.

HYDROSTATIC

There is a considerable difference in hydrostatic pressure requirements. Aviation recorders must survive deep ocean immersion pressures of 8,900 PSI. This is accomplished in commercial recorders by use of solid plastic-encapsulated integrated circuit memories that have a high inherent hydrostatic crush resistance. The deep-water requirement is not often imposed on military aviation recorders that must use fragile, hollow ceramic-encapsulated memories, because it requires expensive pressure-vessel packaging techniques. Rail recorders must only survive relatively shallow river or shore immersions, allowing use of inexpensive plastic memories.

Table 2 compares survival-oriented design features of aviation and rail recorders and the crash environments they help survive.

Recorder	Feature	Shock	Crush	Penetration	Fluids	Fire	Bake	Pressure
Commercial aviation	Plastic parts	x						x
	Plastic cards	x						
	Steel housing	x	x	x				
	Conformal coating				x			
	Solid insulation	x				x	x	
	Phase-change mass					x	x	
	Solid-state memory					x	x	
Military aviation	Metal-core cards	x						
	Adapters/plastic cards	x						
	Titanium housing	x	x	x		x	x	
	Conformal coating				x			
	Solid insulation	x				x	x	
	Intumescent paint					x	x	
	Solid-state memory					x	x	
	Pressure vessel		x	x	x			x
	Beryllium mass		x	x		x	x	
	Phase-change mass					x	x	
Rail	Plastic parts	x						x
	Plastic cards	x						
	Steel housing	x	x	x				
	Conformal coating				x			
	Solid insulation	x				x	x	
	Steel mass					x	x	
	Solid-state memory					x	x	

Table 2: Features of aviation and rail recorders.

DESIGN EXAMPLE

An example of a current event recorder system for locomotives is shown in Figures 1 and 2. This system includes a solid-state recorder unit (Figure 1), a memory-card-based download unit (Figure 2), and PC software. The recorder includes a crash-hardened memory module and a non-hardened recording and playback control module. This division of circuitry reduces the size and cost of the hardened housing while not compromising the crash survivability of the data. The fire survival time of the recorder was extended by over 100% during design optimization by using custom computer heat transfer analysis software. This software was able to predict the peak recorder interior temperature in a fire within a few degrees Celsius.

An RS-232 serial cable allows recorded data to be sent to the download unit's transfer medium, an industry-standard PC Card (formerly called PCMCIA) solid-state "flash EEPROM" memory card. This card can be hand-carried to a data center PC having a PC Card drive for data downloading and analysis. PC Windows software allows examination of the data in tabular or line graph form for maintenance trends as well as incident investigation. The recorder can also be downloaded at the memory module or memory chip levels if necessary. A laptop computer can be used to download files directly without a memory card. A third option is download via a yard radio data system.

Figure 1: Electrodynamics locomotive recorder.

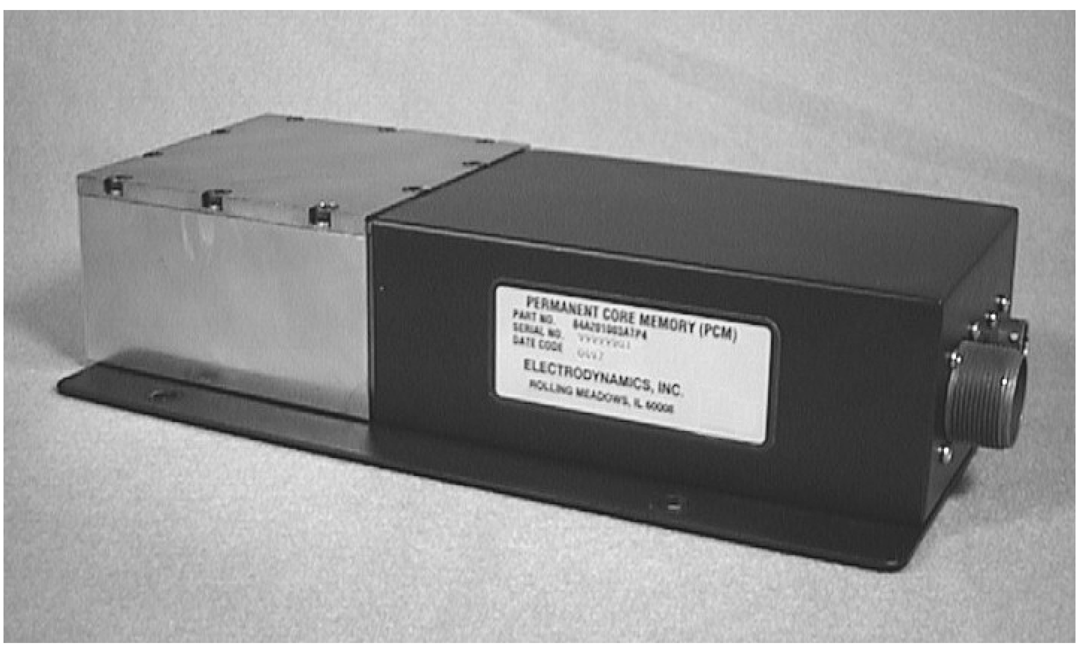

Figure 2: Electrodynamics download unit with memory card.

The recorder system is tamper-proof because alteration or erasure of recorder data is not a provided user function. This system can directly replace existing tape recorders and non-crash-protected solid state recorders. The useful lifetime of the recorder is 20 years. New control software can be uploaded to update the recorder during this time.

QUALIFICATION TESTING

The recorder was tested for compliance to a GETS specification that did not anticipate the draft FRA regulation governing crash survivability of rail recorders. EDI performed some of the testing in the draft regulation as it then existed (1998). Shock testing was performed as 1000-g 6.5-ms shocks using an airgun recorder-launcher and a calibrated-compliance target for controlled deceleration. The new draft FRA regulation waveform has lower and longer shock pulse levels, but allows reshaping of the pulse as long as the total energy remains the same. Static crush tests were performed using a hydraulic press machine. The fire test was performed in a fire bunker building containing four large propane burner jets aimed at the recorder unit, as shown in Figure 3. Continuous regulation of propane pressure and burn mixture is necessary to maintain the proper temperature and flame size as the propane is expended during a one-hour fire test. Hydrostatic pressure was tested in a pneumatically pressurized seawater pressure vessel of the same type as used in testing aviation recorders, but using a much lower pressure level (47 PSIG).

Figure 3: Locomotive event recorder in fire test.

FUNCTIONAL REQUIREMENTS

The Event Recorder interfaces with the locomotive's computer system and provides a crash-hardened record of the locomotive's pertinent data. The recorder, as shown in the block diagram in Figure 4, is a microcontroller-based unit with communication interfaces and a crash-protected nonvolatile solid-state memory (shown in dashed lines).

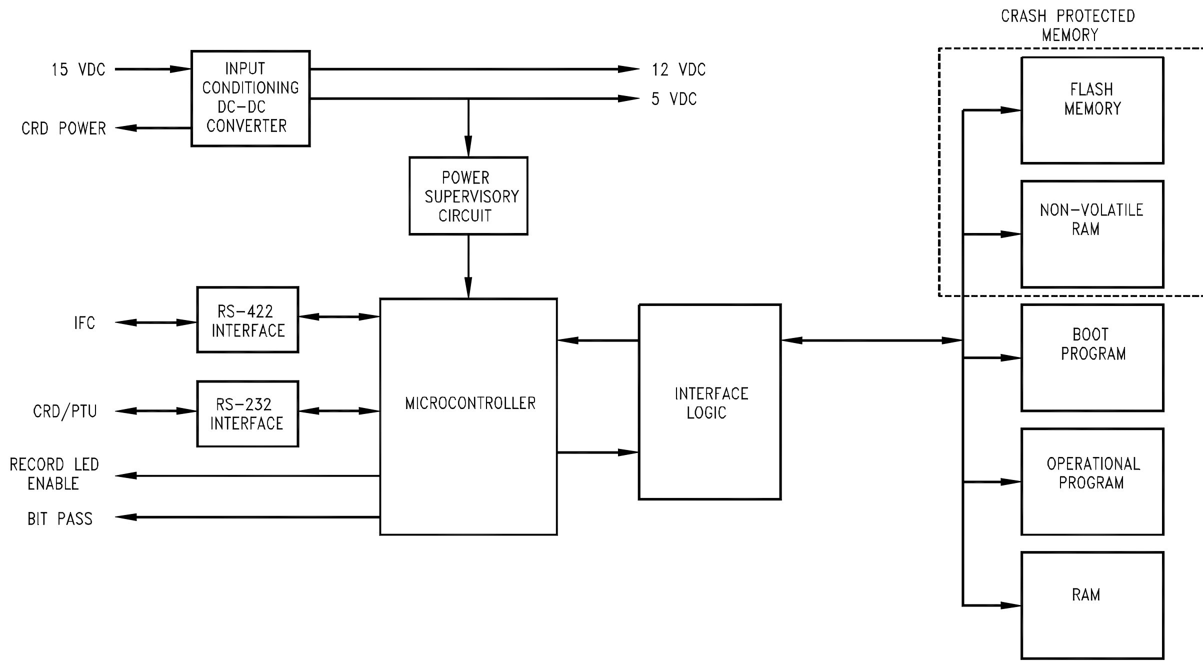

Figure 4: Locomotive event recorder block diagram.

The locomotive's computer system sends parameter data only when value changes exceed preset thresholds (including time). Software filters prevent overuse of memory by faulty channels. The locomotive computer selects the parameters to be monitored, performs the required triggering and filtering, and sends the resulting data to the recorder where it is formatted and written to nonvolatile memory.

OPERATION

In operation, the recorder is powered-up and recording whenever the locomotive's engine is running and its power supply is on. This differs from the military aviation world, in which recording typically begins only when weight-off-wheels is sensed.

The recorder unit connects to the locomotive via a standard RS-422 high-speed serial data link. This link uses a robust error-correcting two-way asynchronous communications protocol that requires only four wires to transmit up to 80 parameters. This saves wiring and reduces maintenance costs. This bus is similar in concept to the MIL-STD-1553B or ARINC 629 buses in the aviation world, but less expensive. The recorder receives parameter messages addressed to it from the locomotive central computer. These messages arrive at a rate of one per second. A few parameters are recorded at 10 samples per second.

The event recorder memory is software-configured as a circular buffer. When a record is written to recorder memory, it replaces the oldest record in memory, thus maintaining a record of the most recent period of time. The number of parameters recorded, the memory size, and data activities determine the recording period retained in memory. The crash regulation requires a minimum of 48 hours of safety and maintenance-related data when the electrical system of the locomotive is operating. Up to 72 hours of data can be provided, depending on parameter activity.

Records are stored once per second. Parameters monitored and storage formats can be customized on a railroad-by-railroad basis. Optional check-bytes at the end of each 1K-byte record verify the integrity of data storage.

At any time, the user can request a data download. The recorder continues to record while downloading. This is another difference from the aviation world, in which most recorders must be stopped in order to examine data.

Recorded data is downloaded via an RS-232 serial data link to a laptop personal computer or to a nonvolatile PC Card memory via a custom recording device interface. The serial link may also be used to download the data to a remote location via a yard data radio. Downloaded data is in a DOS binary file format.

Data analysis software that operates on an IBM PC-compatible computer is available. The software package provides the capability to display selected parameters in either tabular or graphical format as a function of date, time, or another parameter, as shown in Figure 5. Up to 23 additional parameters are derived or calculated from recorded data during data analysis.

A built-in health test checks internal recorder functions periodically on a non-interfering basis. Laptop PC software can reveal the current status of the recorder, allowing a technician to determine the health of the system in detail at any time.

CONCLUSIONS

A cost-effective solid-state event recorder can be provided to the railroad industry by borrowing design and test techniques from aviation recorders while reducing costs in ways unique to the railroad industry.

REFERENCES

ARINC 629, “Multi-Transmitter Data Bus,” Aeronautical Radio, Inc.

EUROCAE ED-55, “Minimum Operation Specification for Flight Data Recorder System,” European Organization for Civil Aviation Equipment.

EUROCAE ED-56A, “Minimum Operation Requirement for Cockpit Voice Recorder System,” European Organization for Civil Aviation Equipment.

Federal Regulation 14 CFR Parts 25, 29, 91, 121, 125 and 135, “Cockpit Voice Recorders (CVR) and Flight Data Recorders,” Federal Aviation Administration.

Federal Regulation 49 CFR 229.135, “Event recorders (Draft),” Federal Railroad Administration.

Federal Regulation 49 CFR 229.25, “Tests (Draft),” Federal Railroad Administration.

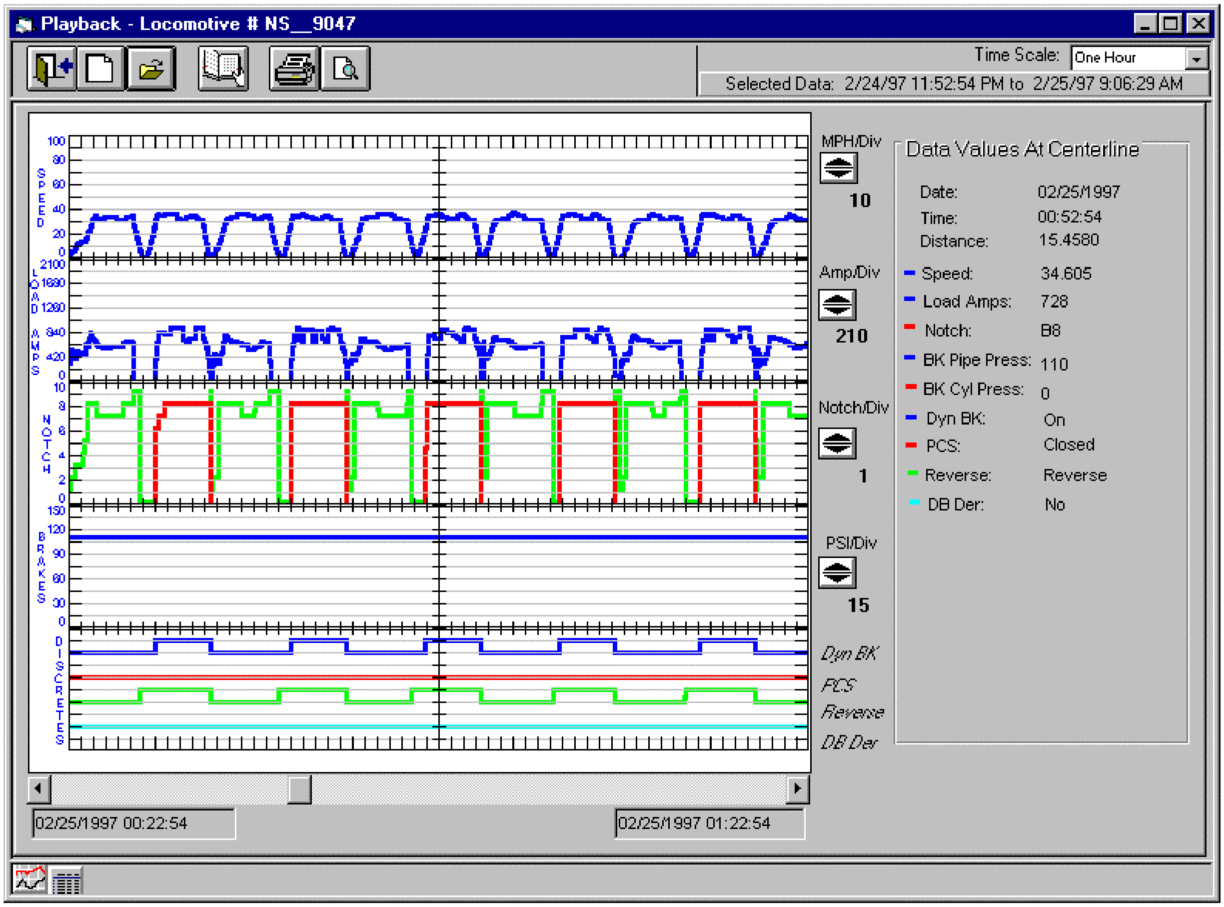

Figure 5: Data analysis software display of recorded data.

Federal Regulation 49 CFR 229.5, “Definitions (Draft),” Federal Railroad Administration.

MIL-STD-1553B, “Digital Time Division Command/Response Multiplex Data Bus,” Naval Publications.

TSO-C124a, “Flight Data Recorder Systems,” Federal Aviation Administration.

BIOGRAPHIES

Thomas Stevens has been involved with design and analysis of solid-state flight data recorders since 1986, and rail recorders since 1996. His area of specialty is systems engineering, including hardware, software, simulation, user interface, safety, publications and trade studies. He has participated in several military crash investigations. He is a member of the Institute of Electrical and Electronics Engineers Computer Society, National Defense Industrial Association and International Society of Air Safety Investigators, and serves on the FRA Rail Safety Advisory Committee Event Recorder Working Group. He has authored or co-authored several papers on missile safety and fuze design.

Robert E. Onley participated in the design of the US Navy’s first experimental solid-state flight data recorder in 1977, and seven airborne recorders since then. He has been active in rail recorders since 1995. His area of specialty is advanced systems engineering, including system design, preliminary circuit design, proposals and trade studies. He has authored or co-authored papers on airborne recorders and air traffic control displays.

Robert S. Morich has designed rail recorder crash-survivable memory units since 1996. His area of specialty is mechanical engineering, including housings, crash-survivable circuit packaging and testing. He has participated in military incident investigations.

ON-BOARD RECORDING FOR COMMERCIAL MOTOR VEHICLES AND DRIVERS: MICROSCOPIC AND MACROSCOPIC APPROACHES

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INTRODUCTION

Approximately 2.3 million drivers operate commercial motor vehicles (CMVs) in interstate commerce. Crashes involving these vehicles are important safety concerns of the Federal Highway Administration (FHWA) for several reasons (FHWA, 1999):

- On average, CMVs travel 5-10 times the annual miles of passenger cars. Although the crash rate of CMVs has held steady for several years, the number of crashes has risen because the number of vehicles and distance traveled both are increasing.
- Heavy trucks make up 3% of the registered vehicle population in the United states, account for 7% of all vehicle miles traveled, but represent 9% of motor vehicles involved in fatal crashes.
- CMV-related fatal crashes and injuries cost the U.S. economy $15 billion annually.
- Non-CMV vehicles and their drivers bear most of costs of CMV-related crashes: 85% of fatalities, 75% of injuries, 67% of economic losses.

Hours-of-service of CMV drivers are covered under the Federal Motor Carrier Safety Regulations (FMCSRs), at Title 49, Part 395, of the Code of Federal Regulations. The regulations prohibit a driver from driving more than 10 hours following a minimum of 8 consecutive hours off-duty, or driving after 15 hours on-duty [including any driving time] following a minimum of 8 consecutive hours off-duty. They require a driver to be given at least 8 consecutive hours off duty between driving and on-duty periods. Drivers are also prohibited from operating a CMV after accumulating 60 hours on-duty in any 7 consecutive day period (if the motor carrier does not operate its vehicles every day of the week), or 70 hours in any 8 consecutive days (if the motor carrier operates CMVs every day of the week).
The requirement for CMV drivers to record their hours-of-service, and for motor carriers to maintain those records is included in regulations written in 1939 and still in effect. The record of duty status (RODS), commonly known as a driver's log, must be completed by all CMV drivers operating in interstate commerce. Details of the requirement are contained in 49 CFR 395.8.

Because compliance with hours-of-service regulations (i.e., not exceeding maximum driving and duty time limits, and being afforded at least the minimum off-duty time for purposes of obtaining rest) has a strong influence on the ability of a driver to perform safely, the recording of duty status and time becomes an essential regulatory issue.

We believe there are merits to both macroscopic (vehicle and operationally-oriented) and microscopic (driver self-monitoring) approaches for planning and monitoring duty and non-duty times to enhance safe and productive CMV transportation. Two FHWA projects -- a research study and an operational test -- are exploring the feasibility of these different, yet complementary, approaches.

RECORDING HOURS OF SERVICE

The FHWA estimates that 1.6 million drivers are required to prepare RODS. The amount of time required to fill out a RODS varies with the number of stops and changes in a driver's status (from on-duty-driving to on-duty-not-driving, for example), but the FHWA estimates approximately two minutes per driver per workday. The agency estimates that these drivers and their motor carriers incur a time burden of 14.3 million hours annually. The annual direct costs of drivers' RODS, not including wage and hour costs, are estimated to be $22.9 million. This is the third-highest paperwork burden of all FHWA regulations, and is among the 10 highest in the DOT.

An option of using a simpler record is available to drivers who operate within a 100 air-mile radius of their normal work reporting location, and who are released from work within 12 consecutive hours of the time they report for work. These drivers may use time cards (required by statute and the regulations administered by the Wage and Hour Division of the U.S. Department of Labor) instead. The FHWA estimates that just under 700,000 drivers fall into this category.

WHY SHOULD MOTOR CARRIERS ADOPT TECHNOLOGY?

Technological tools must justify their worth to their potential users by fulfilling promises of cost savings and improved operational efficiency. Motor carrier transportation has high capital and operational costs and narrow profit margins -- saving fractions of a cent per mile can make the difference between a profitable and a money-losing operation.

Potential savings can be derived through improved communications and operational oversight. This enables motor carriers and drivers to plan trips more efficiently to minimize deadhead miles and fuel consumption, as well as ensuring that drivers have sufficient duty hours available to complete a trip in compliance with the regulations. Automated entry and review of operational information can also generate significant time and personnel savings for both drivers and the back-office part of an operation, as well as providing trend information. Much of the impetus for motor carriers' first petitions to the FHWA to allow automatic on-board recording systems came from a desire to automate the entry and review of RODS data (U.S. Department of Transportation, 1988). The increasing availability and declining costs of real-time satellite communications are driving the trend towards real-time operational monitoring, which we will describe in this paper.

Savings can also be derived from avoidance of adverse occurrences, such as crashes and non-crash incidents. A crash is both a human tragedy and a very costly event. Assuming a 2% profit margin, a motor carrier needs to generate an additional $250,000 of revenue to cover the losses from a $5,000 crash. The losses could include repair costs, lost revenue while vehicles are being repaired, insurance claims, cargo damage, increased insurance premiums and customer relationships (FHWA, 1993).

The human-factors research programs of the FHWA and the National Highway Traffic Safety Administration have placed, and continue to place, a strong emphasis on crash-avoidance warning systems. These have included lane-drift-warning devices, vehicle proximity sensors, and continuous in-vehicle alertness monitoring based on physiological measurement. In this last area, an eyelid closure measure called "PERCLOS" has received considerable attention as a benchmark measure of operator alertness when compared with driving performance related measures. All of these warning systems have considerable potential value to alert a driver of imminent threats. Another class of driver-oriented devices has the potential to be able to predict drivers' performance levels based on the timing, length, and quality of prior sleep and activity periods. One such device is the Actigraph, developed by the Walter Reed Army Institute of Research, to be discussed later in this paper.

Vehicle-Based Operational Approaches

In 1986, the FHWA granted a motor carrier's request to use an automatic interactive on-board recorder to record drivers' hour-of-service. On September 30, 1988, the FHWA revised its hours-of-service regulations to allow motor carriers, at their option, to use certain automatic on-board recording devices to record their drivers' records of duty status in lieu of using the handwritten records of duty status required under 49 CFR 395.8. This provision is codified at 49 CFR 395.15.

The FHWA has noted that many motor carriers that employed that technology found that their compliance with the hours-of-service regulations improved. Emerging technologies are causing the narrowly crafted on-board recorder provision to become outdated (FHWA, 1998). Conventional on-board recorders do not provide real-time information to the motor carrier -- they are downloaded at intervals ranging from daily to weekly. New satellite communications technologies, such as those based on global positioning systems (GPS) technology, can provide this real-time link. These technologies can provide a superior, proactive, "real time" approach to monitoring and controlling drivers' hours. The FHWA posited that the GPS technology and many of the complementary safety management computer systems currently being used by the motor carrier industry provide at least the same degree of monitoring accuracy as the "automatic on-board recorders" allowed by the FMCSRs.

GPS TECHNOLOGIES PILOT DEMONSTRATION PROJECT

On April 6, 1998 the FHWA announced a voluntary program under which a motor carrier using global positioning systems (GPS) technology and related safety management computer systems could enter into an agreement with the FHWA to use the systems in a pilot demonstration project to record and monitor drivers' hours of service in lieu of complying with the handwritten driver log requirements of 49 CFR 395.8 or the conventional on-board recording requirements of 49 CFR 395.15. Consistent with the President's initiatives in reinventing government and regulatory reform, the agency has designed the project to demonstrate whether the motor carrier industry can use the technology to improve compliance with the hours-of-service requirements in a manner which promotes safety and operational efficiency while reducing paperwork requirements (FHWA, 1998).

The FHWA's starting point for defining the parameters of an automatic on-board recording device that would meet the requirements of 49 CFR 395.15 is defined at 49 CFR 395.2: "an electric, electronic, electromechanical, or mechanical device capable of recording driver's duty status information accurately and automatically ... The device must be integrally synchronized with specific operations of the commercial motor vehicle in which it is installed. At a minimum, the device must record engine use, road speed, miles driven, the date, and time of day." Conventional mechanical tachographs are highly subject to tampering and do not comply with the requirement.

There are limited provisions of § 395.15 that are not entirely adaptable to GPS technology and related computer systems. Table 1 sets out those provisions and then describes what the GPS technology and related computer systems have available to satisfy, or go beyond, what is required by § 395.15.

49 CFR 395.15	**GPS TECHNOLOGY**
§ 395.15(a)(1) permits use of "*Automatic on-board recording device" (OBR) as defined at 49 CFR 395.2:* capable of recording driver's duty status accurately and automatically ... must be integrally synchronized with specific CMV functions ... must record engine use, road speed, miles driven (axle revolutions), date and time of day (internal clock).	Records driver's duty status accurately and automatically ... not "*integrally synchronized*" with specific CMV functions ... Computes distance traveled by vehicle position readings (latitude/longitude) provided by satellite ... Road speed **estimated** by time elapsed between vehicle position readings.
§ 395.15(b)(3) Support systems: must provide information about on-board sensor failures and identify edited data.	Support systems provide information about on-board system failures and identify edited data.
§ 395.15(f) ***Reconstruction of records of duty status:*** Drivers must note any failure of automatic OBRs and reconstruct records of duty status (RODS) for current day and past 7 days ... must prepare handwritten RODs until device is operational.	If communications to CMV fail, vehicle position and sensor readings continue to be recorded by satellite and sent to terminal ... retransmitted to CMV after communications are restored ... Drivers can immediately request, by telephone, the previous 7 days RODS be sent via facsimile to roadside location ...unnecessary to reconstruct RODS.
§ 395.15(h)(1) ***Submission of RODS:*** Driver must submit, electronically or by mail, to motor carrier, each RODS within 13 days following completion of each RODS.	Provides motor carrier automatically with access to all driver and vehicle records on a continual, "real-time," basis.
§ 395.15(h)(2): Driver must review and verify all entries are accurate before submission to motor carrier.	Motor carrier furnishes driver with duty status summary ... duty status entries available to driver for review and verification daily.
§ 395.15(h)(3): Submission of RODS certifies all entries are true and correct.	Driver's verification message certifies all entries are true and correct.
§ 395.15(i)(1): Motor carrier must obtain manufacturer's certificate that the design of OBR meets requirements.	The FHWA provides written approval.
§ 395.15(i)(2): Duty status may be updated only when CMV is at rest, except when registering time crossing State boundary.	Company policy prohibits any entry while CMV is in motion ...records violations automatically ...takes remedial action.
§ 395.15(i)(3): OBR and support systems must be, to the maximum extent practicable, tamper proof.	Provides time, location, and sensor signals by satellite service. System provides audit trails of all keyboard interactions.
§ 395.15(i)(4): OBR must warn driver visually and/or audibly the device has ceased to function.	Provides audible and/or visible warnings to CMV driver and motor carrier.
§ 395.15(i)(7): OBR and support systems must identify sensor failures and edited data.	Provides audit trails of all sensor failures and edited data.
§ 395.15(i)(8): OBR must be maintained and recalibrated in accordance with the manufacturer's specifications.	Performs maintenance in accordance with manufacturer's specifications ... Renders calibration unnecessary.

Table 1

In June, 1998, Werner Enterprises, Inc. of Omaha, NE became the first motor carrier to enter into such an agreement with the FHWA. The next month, over 5,000 Werner drivers were operating without the

paperwork burden associated with paper log books. Although Werner is the only motor carrier that has been approved by the FHWA to participate thus far, a number of other motor carriers have expressed interest. The FHWA is currently reviewing their programs and procedures and has extended its deadline for applying to participate until June 30, 1999.

The FHWA plans to evaluate the success of the demonstration project according to four criteria: Level of compliance with the hours-of-service regulations, accident involvement, reduction in paperwork burden, and improvements in operational efficiency (i.e., costs associated with preparing, reviewing, and retaining hours-of-service data). The FHWA believes this project will demonstrate that the motor carrier industry can use GPS technology to improve compliance with the hours-of-service regulations in a manner which promotes safety and operational efficiency while reducing paperwork requirements.

LIMITATIONS OF ON-BOARD RECORDERS

There are significant outstanding issues relating to the practicality of state-of-the-practice on-board recorders (OBR). Currently available devices cannot record the activity of the driver while the driver is not in a "driving" status. They cannot discriminate among any of the myriad activities that constitute "on duty, not driving," and science tells us that the physical and mental exertion associated with these tasks can differ significantly. Current devices also cannot discriminate between on-duty-not-driving and off-duty activities.

There are also substantial concerns regarding the costs and benefits of current on-board recorders. The FHWA engaged the University of Michigan Transportation Research Institute (UMTRI) to study the applicability of on-board recorders to motor carrier operations. Motor carrier fleet response rates for this study were very low, possibly because of early adverse industry commentary on the study. The study, completed in late 1998, found that (1) large fleets were far more likely to use on-board recorders (however 90 percent of motor carriers operate fewer than 9 trucks or buses) and (2) the overwhelming fleet view is that mandatory OBR use would require extremely high expenditures for minimal operational benefits. The study did not address relationships between on-board recorder use and hours-of-service regulations compliance, nor between hours-of-service compliance and overall safety posture.

DRIVER-ORIENTED APPROACHES

Regulations mandating specific equipment have had the effect of limiting and stifling the development of new devices that would go beyond the strict terms of the regulation. Here, the regulatory "floor" becomes the de-facto "standard." We believe that, ultimately, performance-based approaches geared toward driver proficiency -- especially in a predictive mode -- may play a significant role towards ensuring driver alertness and performance.

WORK AND REST SCHEDULES AND DRIVER PERFORMANCE

Several major transportation and industrial disasters -- *Challenger*, Bhopal, Three Mile Island, and Exxon *Valdez* -- had a common set of defining elements: combined time-of-day and sleep-loss effects and severe performance decrements on the part of operators and crews. In their consensus report for the Association of Professional Sleep Societies (Mitler, et. al., 1988) several prominent sleep researchers provide an overview of contemporary research on relationships between the biological clock and human sleepiness and sleep vulnerability, as well as studies of temporal trends of mortality, single-vehicle highway accidents (such as run-off-road), and major engineering and industrial disasters. The authors recommended, among other things, that research be performed to assess the effects of less-than-adequate sleep, even as little as a loss of 1-2 hours, on the tendency for operators to commit errors during the time periods of increased vulnerability to sleepiness.

Most studies of "fatigue" have focused upon the ability to perform tasks requiring motor skills, or upon the effects of total sleep deprivation on physical and mental performance. However, cognitive performance deteriorates faster than motor skills and is seen earlier in partial sleep deprivation. Controlled laboratory studies and assessments of "friendly fire" incidents in the military have demonstrated that an individual may continue to be capable of performing a specific task, but not have sufficient awareness of the general situation, nor the ability, when called for, to move away from a highly conditioned automatic response (Belenky, 1995)

As described earlier, the hours-of-service (HOS) regulations include minimum off-duty times between driving and duty periods, as well as cumulative limits in 7- or 8-day duty cycles. Many motor carriers and drivers have expressed a desire for the duty cycle to be "reset" after a certain amount of off-duty time. This could have the outcome of increasing the 7- or 8-day duty and driving totals significantly. However, a literature review (Tepas, 1992) found no sources of data on rest and recovery cycles, nor on partial sleep deprivation and prediction of subsequent performance. An ongoing study being conducted by the Walter Reed Army Institute of Research helps fill these gaps.

The study is (1) gathering field data on representative wake-sleep cycles of CMV drivers operating in uncontrolled, naturalistic settings; (2) gathering data in a laboratory setting to determine quantitative relationships between sleep amount ("sleep dose") and driving task performance, physiological state, and subjective responses; and (3) using the laboratory and field data to validate and extend a numerical model (Sleep Performance Prediction Model, or SPM) to predict performance based on prior wake-sleep cycles, sleep quality and quantity, and circadian state for a next-generation wrist-worn activity monitor (Actigraph).

In the first phase of this study, data were collected from 25 local and 25 long-distance CMV drivers who wore Actigraphs for 20 consecutive days while engaged in their normal duty and off-duty activities. The Actigraph data indicated that the short-haul drivers averaged 7.7 hours of sleep/24 hours (with 7.5 hours taken while off duty and 0.2 hours taken as naps). The long-haul drivers averaged 7.3 hours of sleep/24 hours (4.3 hours taken off duty and 3.0 hours taken as naps).

In the second phase, 66 drivers participated in a 14-day laboratory study. The drivers were allowed 8 hours in bed each night for the first 3 "baseline" days. On the third day, they were randomly assigned to one of 4 sleep conditions: 9, 7, 5, or 3 hours in bed each night over the next 7 days. The drivers were again allowed 8 hours nightly time in bed during the final 3 "recovery" days of the study. The drivers were tested for cognitive performance (e.g., serial addition/ subtraction task, PC-based driving simulator, and psychomotor vigilance task (PVT)) and alertness (e.g., multiple sleep latency test and Stanford sleepiness scale) periodically throughout each day. Sleep was monitored using standard polysomnographic measures (EEG, EOG, and EMG). The drivers also wore Actigraphs for the entire period.

Initial study results indicate that the 9-hours-in-bed condition resulted in sustained performance and alertness over the experimental period; this may be regarded as the "optimal" time in bed in this study. The 7-hours-in-bed condition resulted in slight but progressive and statistically-significant declines in PVT performance over successive days. However, on other performance measures there was some overlap between the 9- and 7-hour groups, thus indicating no significant decline in performance associated with 7 versus 9 hours in bed for these measures. The 5-hours-in-bed condition was associated with major declines in performance and alertness on all measures. And, not surprisingly, the 3-hours-in-bed condition had the steepest progressive declines on all measures. In short, the results overall have shown systematic, orderly declines in performance/alertness across the 4 sleep conditions.

The SPM model is undergoing testing, validation, and refinement, incorporating results of the laboratory and field tests. Walter Reed is working collaboratively with researchers at Indiana University-Purdue who will address this complex modeling challenge with new computational intelligence techniques.

The new SPM model will be applied to these data to model/predict the effects of these real-world schedules on metrics based on cognitive performance (serial addition/subtraction), driving (performance on simulator), and vigilance and reaction time (PVT). Since another study has validated the eye closure measure PERCLOS in terms of the PVT, the new SPM model should also be able to predict future PERCLOS scores based on sleep/wake history. The new SPM will be integrated into the Actigraph with an improved sleep-scoring algorithm, also under development, for future field-testing and validation.

The study will provide crucial information concerning potential use of personal monitors to prevent fatigue and loss-of-alertness through application of a performance-based assessment. Drivers and motor carriers could gain benefits unavailable under the current prescriptive regulatory system. Drivers could be able to better gauge their present and projected alertness and performance levels, and be able to alter their activity (increase main sleep or take naps) to improve alertness and projected performance. Motor carrier personnel could also be better informed of the drivers' alertness and performance status to optimize both productivity and safety. The driver-oriented and the operationally-oriented approaches could thus converge in a comprehensive safety-proactive paradigm.

CAVEATS AND CONCERNS WITH OPERATIONAL MONITORING

The operational tests of continuous monitoring systems and on-board monitors include several classes of devices for monitoring safe operating performance of the driver and the CMV. Driver-oriented monitoring devices envisioned include devices to measure eye and eyelid movement. These have been shown in laboratory settings to be closely related to driver drowsiness. The Actigraph would allow a driver to self-monitor his or her alertness at a given point in time, and to predict periods of high and low alertness up to several hours in the future. Vehicle-oriented devices might include sensors to measure steering patterns and how well the CMV is tracking in the driving lane.

We expect that technologies for monitoring drivers' alertness and performance would be used primarily by the drivers themselves as tools to help them plan their own wake and sleep schedules, and to adjust their activities (including taking naps and sleep breaks, as necessary) if their alertness level is not sufficient for them to continue driving safely. Motor carriers might elect to use them as part of their proactive safety assurance programs, and require drivers to use them as a condition of employment. We do not foresee active monitoring by the government of drivers or their vehicles via any of these technologies. We believe that the federal government might be more inclined to review detailed data on an individual driver's activity only if there were a compelling reason (such as a crash where we believed driver drowsiness was a contributing factor, and the motor carrier did not document the driver's activities via a record of duty status or by other reliable means). Whether the government would require, at some future time, the use of alertness or performance monitoring devices remains an issue under consideration as we expand our knowledge of the capabilities and costs of various systems.

The FHWA is studying drivers' concerns about the use of information from on-board intelligent transportation systems (ITS) technologies. A recent research study (Penn + Schoen, 1995) asked nearly 1600 drivers for their opinions on six classes of existing and evolving ITS/commercial vehicle operations (CVO) services: fleet management, electronic clearance, administrative processes, roadside safety inspection, hazardous materials incidence response, and on-board safety monitoring. The findings indicated that "... on the whole, commercial vehicle drivers are receptive to and supportive of the use of the CVO service on the road and in their vehicles. Technologies which received the most support were those that 'would make my work easier,' are 'useful for me,' and 'will work [in my vehicle]/I would rely on it." The report went on:

> "However, there was some concern that certain of the technologies would be an invasion of driver privacy by either the government or the driver's company, and also a concern that the systems would rely too much on computers and diminish the role of human judgment. Drivers were wary of services that promised too much and would leave them dependent on unproven, inexperienced technology. They wanted systems that would be reliable, workable, and useful on a consistent basis, and would not pose a threat to themselves, their vehicles, their privacy, or their livelihood."

Furthermore, the report indicated that

> "... drivers tended to evaluate the CVO services from the perspective of their personal experience, rather than focusing on the bigger picture of the industry as a whole. For example, independent owner-operators, who have historically been more skeptical of technology and wary of intrusion by the government or companies, reacted more negatively toward the technologies than did other drivers ..."

In general, drivers were less favorably inclined towards the onboard safety monitoring service than the other CVO services. "While a majority of respondents were able to recognize the potential safety benefits of this service, the idea that technology was too invasive and too reliant on computers made some respondents unwilling to accept this service."

Another study assessed the potential for automated hours-of-service recording via use of smart-card systems. This study responded to Congressional direction to the Federal Highway Administration contained in the agency's 1995 appropriations bill to: "... test the feasibility of a smart [card] system to enhance the security and utility of the commercial driver's license and enforcement of hours-of-service regulations."

Smart cards, for the purposes of this study, were defined as credit card-sized plastic cards with an embedded integrated circuit chip containing a central processing unit, random access memory, and non-volatile data storage. The research contractor assessed technological, economic, and institutional factors requiring consideration if smart-card applications were to be implemented.

The researchers determined that three smart-card applications were feasible: driver's license, vehicle card (for operating credentials and maintenance purposes), and electronic toll collection. Two others were determined not to be feasible: international border crossing (because data transfer via telecommunications already is in place under the U.S. Customs Service) and driver record of duty status. The contractor noted three obstacles to implementing the latter:

> "Current federal regulations do not require motor carriers to automate the Driver Record of Duty Status. Any proposed regulation specifying the use of smart cards would almost certainly encounter fierce opposition ... All ITS programs are voluntary, and the federal government would jeopardize carrier participation in other ITS activities if it tried to mandate the use of smart cards."

The Fair Information Principles for ITS/CVO adopted in June, 1998 by ITS America include a "secondary use" provision as follows: "Data collected by the private sector for its own purposes through a voluntary investment in technology over and above those data required by law should not be used for enforcement purposes without the carrier's consent."

Finally, Dinges (Dinges, 1997) and others have pointed out major concerns in identifying, developing, and setting standards in the quest to develop technological approaches to managing transportation operator fatigue and vigilance. The approaches must be assessed in terms of sound science and engineering criteria. They must be practical and implementable. Last, but definitely not least, they must be defensible from legal and public policy perspectives. Dinges closes with this statement:

> "Technologies may eventually prevent or limit certain catastrophic outcomes due to fatigued performance, but technologies are not substitutes for setting societal standards for the functional capability of an operator. On the other hand, technologies can help establish and maintain adherence to that standard if they are developed and used in a valid and responsible manner."

We believe the GPS technologies pilot project will demonstrate that the motor carrier industry can use this technology to improve compliance with the hours-of-service regulations in a manner which promotes safety and operational efficiency while reducing paperwork requirements.

We believe drivers are likely to use personal alertness and performance monitors such as the Actigraph to help them plan their own wake and sleep schedules, and to adjust their activities (including taking naps and sleep breaks, if necessary) if their alertness level is not sufficient for them to continue driving safely. Motor carriers might also elect to use them as part of their proactive safety assurance programs, or require drivers to use them as a condition of employment.

REFERENCES

3-G International *Smart Cards in Commercial Vehicle Operations*. Report No. FHWA-MC-97-022 1996.

Belenky, G. "Sleep, Sleep Deprivation, and Continuous Operations." *Army RD&A*, May-June 1995.

Campbell, K., Lang., Smith, M. (1998) *Electronic Recorder Study*. Federal Highway Administration. (Report No. UMTRI-97-34 available from the University of Michigan Transportation Research Institute).

Dinges, David F. "The Promise and Challenges of Technologies for Monitoring Operator Vigilance." Proceedings, *Managing Fatigue in Transportation*. American Trucking Associations Foundation, Alexandria, Virginia, April, 1997.

Federal Highway Administration, *Accident Countermeasures Course*. October 1, 1993 edition.

Federal Highway Administration, *1997 Large Truck Crash Overview*. Publication FHWA-MC-99- 021.

Federal Highway Administration, "Modeling of Driver Performance under Various Work-Rest Schedules" in *Summary of Driver Fatigue Programs (*December, 1998*)*. (Available from Federal Highway Administration, Office of Motor Carrier Research and Standards).

ITS America Staff. "CVO Policy Subcommittee Approves Privacy Principles." *CVO Update*, Spring, 1998.

Johnson, D., Thorne, D., Rowland, L., Balkin, T., Sing, H. et. al. (1997) "The Effects of Partial Sleep Deprivation on Psychomotor Vigilance." *Sleep Research, 26*, 627 (Abstract).

Mitler, M.M., Carskadon, M.A., Czeisler, C.A., Dement, W.C., Dinges, D.F., Graeber, R.C. "Catastrophes, Sleep, and Public Policy: Consensus Report." *Sleep* 11(1):100-109, Raven Press, Ltd., New York. 1988.

Department of Transportation, Office of the Secretary of Transportation, Reports, Forms, and Recordkeeping Requirements; Agency Information Collection Activity Under OMB Review: Federal Highway Administration renewal of OMB Information Collection 2125-0016; Supporting Statement. August 6, 1998 (63 FR 42091).

Penn + Schoen Associates, Inc. *Critical Issues Relating to Acceptance of CVO Services by Interstate Truck and Bus Drivers*. Federal Highway Administration Contract DTFH61-94-C-00182. 1995.

Tepas, D. "Literature Review and Critique of Past Research on the Rest and Recovery Cycles of Commercial Motor Vehicle Drivers." Contract DTFH61-91-P-01179, Final draft report. September, 1992. (Available from Federal Highway Administration, Office of Motor Carrier Research and Standards).

Thorne, D., Thomas, M., Sing, H., Balkin, T., Wesensten, N., et. al. (1998) Driving-Simulator Accident Rates Before, During, and After One Week of Restricted Nightly Sleep. *Sleep, 21* (3 Suppl.), 235. (Abstract).

U.S. Department of Transportation, Federal Highway Administration. 49 CFR Part 395: Driver's Record of Duty Status; Automatic On-Board Recording Devices. Final rule and notice of termination of exemptions. September 30, 1988 (53 FR 38666).

U.S. Department of Transportation, Federal Highway Administration, Global Positioning Systems (GPS) Technology, Notice of interpretation; request for participation in pilot demonstration project. April 6, 1998 (65 FR 16697).

Wesensten, N., Thorne, D., Balkin, T., Redmond, D., Sing, H., et. al. (1998) Actigraphic Assessment of Commercial Drivers Over 20 Consecutive Days. *Sleep, 21* (3 Suppl.), 237. (Abstract).

BIOGRAPHIES

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A VISION OF FUTURE CRASH SURVIVABLE RECORDING SYSTEMS

By
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INTRODUCTION

For more than 40 years recording of flight data has developed from scratches made by stylus on aluminum foil, recording a handful of parameters, to silicon memory chips recording thousands of digital bits. There can be no doubt to the value obtained from airborne crash survivable recorders, however the perpetual enhancements in aircraft systems leads to the need for more data to be recorded as aircraft operation and performance become ever more sophisticated. This creates a moving target for the crash investigation community and recorder manufacturers to contend with. Today many aircraft incorporate centralized processing to automatically present information tailored to flight and operational conditions, and much of this data consists of the parameters processed for airborne recording. As changes emerge to the traditional partitioning of avionics by functionality to a design based on partitioning by flight criticality or operational applications, centralized processing increasingly impacts current systems/subsystems, customers and regulatory agencies. Gains in onboard computational power make more sophisticated onboard diagnostic and prognostic software a reality, but the emphasis tends to be on the ease of use, cost effectiveness, flexibility and integration and little thought to the airborne recording. As new technologies are introduced, it should be as a means to enhance safer air travel and utilize the effect of computational power to provide system flexibility and growth, while maintaining a minimal impact on recording systems and aircraft integration.

EVOLUTION OF FLIGHT SAFETY & DATA MANAGEMENT

In the early 1940s, with the boom in civilian passenger aircraft, the Civil Aeronautics Board (which evolved into the FAA) demanded that a record of the flight be protected beyond the impact of the crash. Several models of recorder designs were tested until in 1953 General Mills produced a yellow sphere – known as the Lockheed 109-C flight data recorder (FDR) - in which 5 Signals were recorded directly from discrete/analog sensors. Some of the significant events in the history of data management and recording include :

In 1957 the CAB mandated aircraft over 12,500 pounds carry a FDR, this was the dawn of the jet age (DC-8, B707 introduction).

In the early 1960s recording of the pilot's voice on the aircraft was initiated.

In 1965 CVRs were mandated on large passenger aircraft.

About 1970 up to 25 Discrete/analog Signals recorded, aircraft digital complexity increased and FDAU systems were introduced.

Early 1970s QAR were introduced, recording the output provided by the FDAU.

In 1975 GPWS required on large passenger aircraft.

In early 1990s TCAS became mandatory.

Early 1992 Solid State recorders were produced.

July 1997, number of mandatory FDR parameter increase (11 to 18 parameters)

24 March 1999 NTSB Safety Recommendations:-

- 2 Hr SSCVR standard
- Independent power supply source (10 minutes)
- Datalink message recording

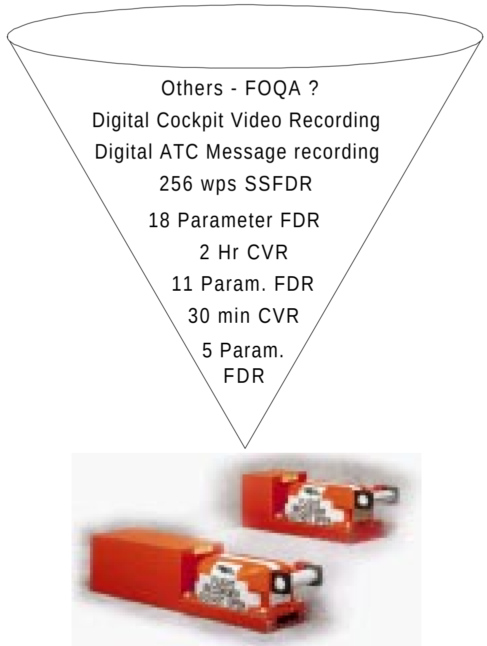

Figure 1 - The Requirements Funnel Effect

The progression of mandated changes to date have necessitated re-design and re-certification costs, for both the recorder and aircraft installation. CVR and FDR recording requirements will, in the near term, be further expanded based on the developing EUOCAE WG-50 specifications for Digital Message recording and possible airborne Video recording. Digital messages are cockpit communications that have replace the traditional voice, i.e. datalink messages.

Current Crash Survivable Recording Systems

Current state of the art airborne recorders are independent and physically separate systems. Solid State flash memory records 4 channels of cockpit audio for a duration of 30 minutes or 2 hours in one unit, and 25 hours of flight data at rates up to 256 – 12 bit data words per second in a separate unit.

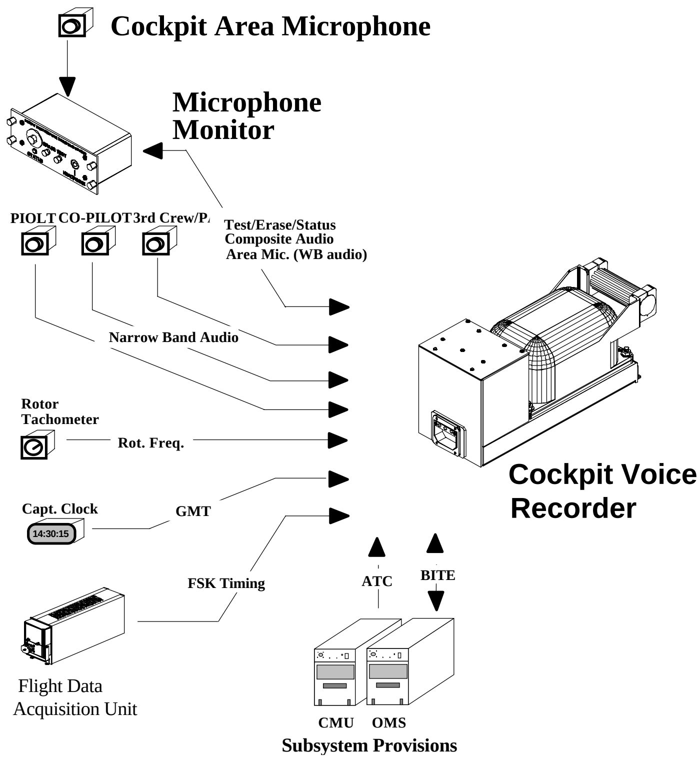

Figure 2 – Cockpit Voice Recorder System

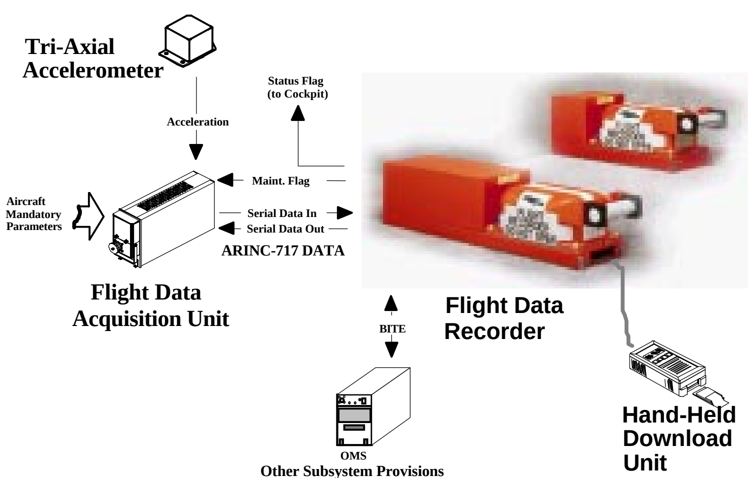

Figure 3 – Flight Data Recorder System

The 12 bit words can adequately manage the required resolution, accuracy and rate of change of modern aircraft systems and sensors. The latest generation of digital aircraft (the B777), using the 256wps rate, records approximately 870 parameters on the FDR. This FDR operates in an identical way to some of the older "11 parameter" FDR installations, where the FDAMS collects the sensor information.

The key element of today's airborne flight data recording systems is the FDAMS, which acts as the central processor for the remotely distributed sensors, discrete inputs and data-busses. As one of its outputs the FDAMS provides mandatory data to the FDR via a single ARINC-573/717 data stream. This data stream may be configured per aircraft type or customer preferences and contains industry standard 12 bit words at rates of 64, 128 or 256 words per second. The FDAMS can typically provide the following inputs to interface with multiple systems and sensors:

60	programmable 3 or 4 wire inputs
127	discrete inputs
48	ARINC 429 DITS Ports
18	identification discretes
3	Marker beacon discretes
1	FDEP/STP Tx/Rx Port (429)

Evolving Systems and Data Availability

Aircraft system configurations are driven by operational, technical and regulatory requirements and further complicated, for international operators, by the fact that FAA and CAA/JAA requirements tend to overlap. Requirements will continue to evolve to enhance the safety of air travel, and safety improvements enforced due to lessons learned from little information on antiquated crash survivable media.

In the transition towards "Free Flight" where the Reduced Vertical Separation Minimum are implemented, the potential exists for an increase in TCAS Traffic and Resolution Advisories, along with Wake Vortex occurrences, hence the need to monitor the aircraft's Altitude Drift. Also, within the Cockpit, displays have evolved from basic round dial instruments to very sophisticated multifunction displays with living color and graphical displays in a bid to enhance aircraft situational awareness. This compounds the need of the Crash Investigator for MORE Data and the further expansion of the recording requirements "Funnel Effect".

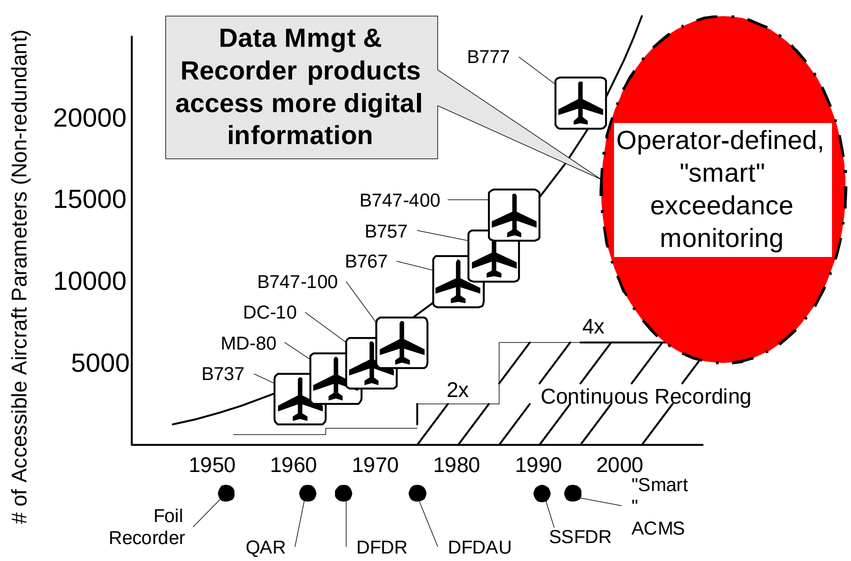

Figure 4 – Technological Advance of Airborne Recording Systems

Many systems have evolved as individual safety systems. In today's technological advanced aircraft, systems and sub-systems are combined within a single Line Replaceable Unit (LRU), for example the FDAU can now contain the ACMS, FDAMS and QAR functionality. The Boeing 777 has a single avionics cabinet containing multiple systems interfaced with a single backplane – this is the future of airborne avionics.

COMBINED COCKPIT VOICE AND FLIGHT DATA RECORDERS

The subject of combining both cockpit voice and flight data information into a single crash survivable recorder has been discussed for some time. As a result of aircraft disasters in the late 1980s and early 1990s where one (or both) of the individual crash survivable recorders were destroyed, the NTSB recommended cancellation of the existing Technical Standard Orders (TSOs) in favor of newer TSOs (C 123 and TSO-C 124). These TSOs were based upon the more stringent crash survivability requirements of ED-55 and ED-56 Rev. A.

In 1992, an industry-wide meeting discussed ways to improve the probability of 100% post crash data recovery for both the cockpit voice and flight data information. AlliedSignal proposed that one way was to have combined recorders in a dual-redundant installation (i.e. two separate crash survivable recorders storing both the cockpit voice and flight data information) on the aircraft. Further, these combined recorders should be installed in vastly different locations on the aircraft, such that in a worst case scenario at least one of the recorders would be subjected to a less severe post-crash environment. Aircraft manufacturers agree with this basic philosophy, but have yet to implement a dual-redundant recorder installation on any commercial aircraft being currently produced.

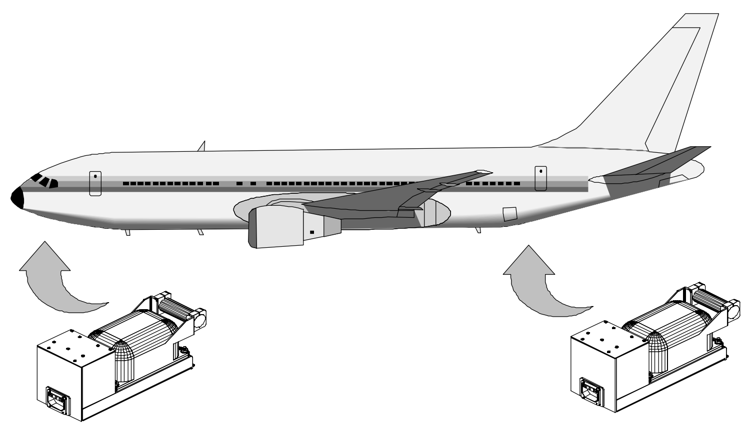

Figure 5 – Dual Redundant Recorders

Enhancing Data Survivability

In the interim, the industry has taken steps to improve the probability of 100% data recovery. First, it had been noted that in the majority of cases where the data has been unrecoverable after an aircraft disaster was due to a post-impact fire. It was also concluded that in many cases, the post-crash fire was not the short, high intensity scenario covered by qualification to the existing TSOs, but due to a much lower intensity, with substantially longer duration fire. Therefore EUROCAE, included the low intensity fire requirement (10 Hours at 260°C) into ED-56 Rev. A. The NTSB and FAA have also acted in increasing the existing high intensity fire survivability from 30 minutes to 60 minutes (50,000 BTUs, 1100°C) in TSO-C123a and TSO-C124a which superceded existing TSOs. in August of 1998

Recording System Maintainability

Another major cause of unrecoverable data (or a "poor" recording) after an aircraft disaster, is due to broken and/or damaged recorders which were unable to record the necessary information due to an internal or system level fault.

Historically, electro-mechanically-based CVRs and FDRs have suffered in terms of overall reliability and performance due to their basic design. Recording head and tape wear, motor belts and bearings, etc. will degrade over time in the severe environments encountered on commercial air transport aircraft. This cause has been dramatically improved by the introduction of all solid-state crash survivable recorders, where non-volatile memory devices have replaced the electro-mechanical tape based recording systems. Since there are no longer any moving parts in Solid State recorders, basic reliability (as expressed in Mean-Time-Between-Failures) has improved dramatically by at least 5-fold. Additionally, since there are no moving parts in the recording system, there is no degradation over time in the quality of the recording. In the past, the quality of the recording has been greatly effected by where in the "maintenance cycle" the recorder is when data is extracted from it (i.e. if it has been a long time since the last overhaul of the unit, head/tape wear, motor bearing wear, etc., will naturally cause a lower quality recording).

Accident Analysis with Solid State Recorders

Several recent accidents of commercial aircraft have demonstrated the effect of the Solid State Recorders. The AlliedSignal SSFDR and SSCVRs have performed flawlessly with 100% recovery and no errors in the data. In one particular investigation the NTSB started with a download of the SSFDR contents at 9:00 am and by 1:00 pm of that same afternoon a full animation of the final moments of the flight were available for review.

As a result of the survivability and maintainability of Solid State recorders the NTSB have released Safety Recommendations to mandate solid-state cockpit voice and flight data recorders by 2005, i.e. retrofitting of all tape based recorders to solid-state. Many commercial airlines are already doing this on their own based on economic (cost-of-ownership) arguments.

ADVANCED DIGITAL DATA RECORDING SYSTEMS

The industry (primarily EUROCAE WG-50) is presently developing specifications for recording of CNS/ATM systems information that, although not currently recorded, may be desirable to be stored in crash survivable recorders on-board the aircraft. Examples include:

- CNS/ATM digital datalink (replacing the historical voice radio link),
- Cockpit Video,
- Increasing number of mandatory flight parameters (to align with FAA requirements),
- Navigation and Surveillance information (future systems).
- Direct Digital Audio Inputs (in lieu of analog conversion and sampling)

There is continuing debate within industry on the benefits of adding some of these new information sources to the airborne crash survivable recorders. As already discussed, combining Flight Data and Cockpit Voice within a single unit is relatively simple, but may be quickly obseleted by any future recording legislation.

To avoid recurring changes to aircraft interfacing and the recorder itself; a new recording system philosophy is required. This new architecture can be an extension of the existing "Data Acquisition System" as the central processing component, accompanied by multiple high-speed serial interfaces to dual Solid State Digital Data Recorders (SSDDR).

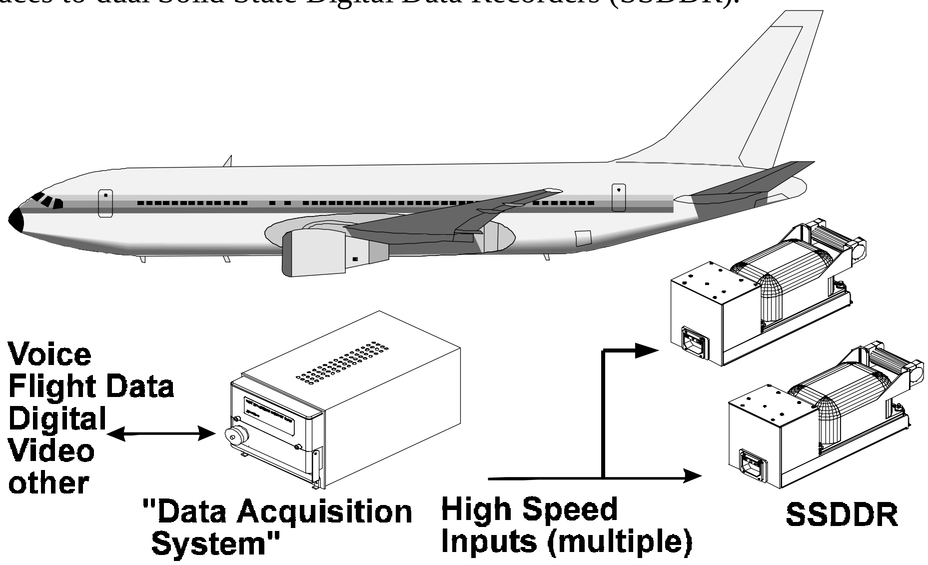

Figure 6 – Solid State Digital Data Recorder (SSDDR) System

In this proposed new system the crash survivable recorders are reduced to simply recording digital information received on high-speed serial interface(s). The recorders need not know the specific source or type of information being recorded, but simply recording the digital data as it is received under a yet to be defined rule set. The processing of information and digitization would therefore take place in other avionics within the aircraft and transmitted to the redundant recorders. If developed suitably, this architecture can provide the following benefits:

1) Dual redundant Crash Survivable Recorders - Reduces airlines spares and logistic support and provides improved probability of 100% data recovery.
2) Crash survivable recorder need not require modification to meet changes in recording requirements.
3) Lower system cost - data processing and digitization process moved to highly integrated avionics subsystems (instead of the recorders themselves, which are subject to more severe operating environments)
4) Minimizing Installation costs by reducing wiring required for growth systems.
5) Eliminating the need to add other crash survivable recorders for additional information storage
6) Minimize cost impact for the recorder itself. The price of two redundant recorders would only be on the order of 50% more than the total price of today's separate FDR/CVR combination.

In this architecture, the crash survivable recorders need sufficient memory capacity and input bandwidth to handle current and future requirements,. Such a proposed architecture is a large deviation from today' s crash survivable recording system. Memory allocation could be software loadable to provide flexibility for operator customization as sub-components are added in future.

The SSDDR memory partitioning could distinguish between data types and thereby enable selective data downloading.

AUDIO INPUTS

For the Cockpit Voice Recorder the audio for each of the 4 Channel Inputs is provided as an analog signal to the CVR input. The source of this is the aircraft's Audio Summing Amplifier that interfaces the Flight Crew's intercom and direct voice communication systems. Within the CVR the analog is sampled, compressed and stored as digital information. Modern airborne audio systems have the capability to provide direct digital audio as the output. Hence the processing from digital to analog to digital can be eliminated and the digital audio fed directly to the CVR thereby providing a superior quality signal.

AVIONIC LOCAL AREA NETWORKS

Recent system architectures and interfaces have employed the use of Local Area Networks, such as Ethernet (as defined in ARINC-646), within the aircraft. These architectures will assist in reducing software modification costs and development time for planned, incremental software upgrades which will provide system growth. It should be possible to update, modify or add functionality with minimal impact on other systems. This is the basis for the next generation of Enhanced Airborne Flight Recorder currently being defined by AEEC. LANs will provide significant growth margins and will utilize the bandwidth more efficiently than current databusses, with expected Data rate of greater than 100kbps.

SUSTAINING DATA RECORDING IN ABNORMAL SITUATIONS

It is always a source of debate as to how much more data could actually be recorded when the aircraft itself is falling apart (breaking wires, etc.). One step in the process is to move the recorder in or near the cockpit area so as to minimize the amount of wiring which could be "disconnected" during such a catastrophe. Operating Solid State Recorders from an independent power source is not an issue, but the major problem arises as to what other equipment must also still be operating in order for the CVR or FDR to be receiving data.

With the current installation, the Cockpit Area Microphone is powered directly from the CVR. Therefore it seems reasonable to assume that there would be a good chance to keep recording from at least the cockpit area microphone . This is possible if the CVR were powered and it was located relatively close to the cockpit area, so as to maximize the probability of the interconnection (between the CVR and Control Panel/Area Microphone) remaining intact. For other audio to be recorded the radio communication panels, audio multiplexer unit, microphones, etc. would need to remain active. This is more unlikely due to the physical distribution of the components in the aircraft.

For the SSFDR, the case is completely different. Since the data is being obtained from a multitude or aircraft systems and sensors (with a lot of wire in-between) through the DFDAU (or equivalent), the likelihood of retaining a lot of the flight data for recording purposes after a major catastrophe (like TWA 800) is much more remote. However, like the CVR, the probability would be greatly improved if the SSFDR were also located near the Electronic Equipment Bay (where the DFDAU is located as well as most of the other LRUs with which it interfaces). In other words, the SSFDR is a very small piece of the flight data recording system, and that many other systems must be powered (with intact wiring, etc.) to get useful information.

Due to survivability characteristics, we know that the cockpit area is not the best place for crash survivable recorders. However, an improved installation would have dual redundant Solid State Digital Data Recorders (SSDDRs) with combined flight data, cockpit voice, digital messages, and video. One would be located in the traditional area (in the aft of the aircraft), and the other near the cockpit area. Both could be supplied with an independent power source to allow for a few more minutes of recording after the main power can no longer be supplied (10 minutes is recommended by the NTSB). To provide maximum installation flexibility, the recorder form factor requires revision.

AlliedSignal have demonstrated, with their AR-Series recorders, which are TSO C-123a and C-124a compliant, that the recorder's physical size and weight, can be reduced dramatically from the current ½-ATR-Long format (19.6"L x 6.1"H x 4.8"W) and 18 – 20 pounds, to one of only 9.0"L x 5.5"H x 4.5"W and less than 9.0 pounds.

Figure 7 - Physical Size Reduction of Crash Recorders

The significant size, weight and power reduction makes the application of solid state recorders for small aircraft particularly appealing. Thereby enabling the safety envelope to be increased.

COCKPIT VIDEO RECORDERS

The development of Flight Instrument Displays and cockpit automation has increased the need of the Crash Investigator for Cockpit Video Recording.

While no doubt more efficient in controlling the aircraft than humans, computers do not ask the questions "Why.?" or "What.?", and could implement inappropriate modes or characteristics under unusual circumstances, and often in high workload situations. In several crashes the crew were either unaware of the systems potential responses or had given the system an incorrect command. There has also been CFIT events where the crew felt that the aircraft was performing in a perfectly normal manner. While all new automated systems follow the same general principles, pilot interfaces vary dramatically. A pilot can no longer "fly the gauges..". Similarly the Crash Investigators no longer have the remnants of the gauges to glean additional information as they try to piece the clues together.

Therefore a need for video recording of the main instrument panel is desired by both pilots unions (IFALPA) and accident investigators in order to correlate what is displayed with that recorded.

From a human factors perspective the cockpit environment would also be informative, however pilot's unions do not as readily accept this. Pilots and safety officials agree that privacy legislation similar to current voice recorder laws would be needed to keep video footage protected from court cases and Freedom of Information Act requests.

The system requirements are being drafted by EUROCAE (WG50) and may be the basis of any future FAA/JAA considerations. Technical issues will include:-

- recording duration,
- resolution (sufficient to read multifunction displays to ensure proper data presentation),
- refresh rate (frames per second recording),
- color or monochrome images,
- number of cameras and coverage (2 or 3 may be needed to view the front instrument panel, and another may view the overhead panel).
- suitable data compression techniques,
- capacity – dependent on the above listed factors.

CRASH RECORDERS GROWTH POTENTIAL

Operator concerns over existing airborne recording systems can be readily accommodated by a new architecture and software functionality, which provides incremental growth and the proposed Solid State Digital Data Recorder system.

Certifying agencies could ensure recording requirements for new systems are established during development. Conceivably as new aircraft systems are developed, the relevant information (from ANY new system that has an airworthiness effect) could automatically be added to the recording system.

Incremental expansion of FDR frame size could take account of increasing memory density, without the need to double the recorder frame size each time expansion is required, as with current philosophy.

Some ARINC 429 labels should be reserved for the output of information to the flight recorder, and FDAMs manufacturers could then ensure the mapping of these labels to spare data words. Designers of new systems would then be required to ensure that flight recorder data was broadcast on these labels. The installer would then only need to connect to the data bus in order to add the parameters to the recorder.

Calibration checks should combine the review and analysis of recorded data with on aircraft calibration checks.

The installation of dual combined units in lieu of the single recorder systems provides a solution to operating with a single unserviceable recorder for extended time periods.

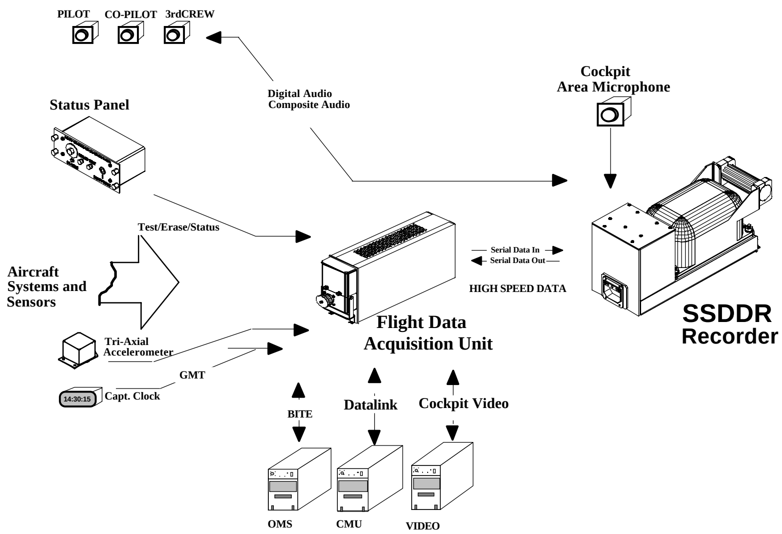

FIGURE 8 - ENHANCED AIRBORNE RECORDING SYSTEM

CONCLUSION

The introduction of much more reliable and crash survivable solid-state recorders into the commercial air transport fleet will greatly improve the probability of 100% data recovery after an aircraft disaster. A new and radical recording architecture can readily include the benefits of identical and redundant crash survivable recorders, and provide growth to add new requirements, and recording systems or components with minimal impact to the overall system. Basing the architecture on a Flight Data Acquisition Management System as the central processing component with multiple high-speed serial interfaces to the Solid State Digital Data Recorder (SSDDR) enables a relatively inexpensive solution.

Solid State technology also provides the potential for increasing the Flight Safety envelope by providing recorders of smaller size, weight and power for smaller aircraft not currently required to carry crash recorders.

Preservation of valuable information is also readily provided by the co-location of the primary Recorder and Cockpit Area Microphone.

Elimination of the frustrating requirements funnel effect of constantly updating the crash recording system can be made simple and straightforward for operators, crash investigators, aircraft manufacturers, installers, designers and recorder manufacturers.

SSCVR
SSFDR

References

1) Proceedings, 14th AIMS Symposium, Sept 15-17, 1987; "The Role Played by FDR in Understanding Windshear Phenomenon" by D.Grossi (NTSB).

2) Royal Aeronautical Society Proceedings; Recording Aircraft Accident Data, 20-21 Oct, 1997.

3) "Black Box" by Vanda Sendzimir; Invention and Technology; Fall 1996

4) National Transportation Safety Board – Safety Recommendation ; A-99-16 through –18; dated March 9, 1999

List of Abbreviations

AIMS	AIRCRAFT INTEGRATED MONITORING SYSTEM
ARINC	Aeronautical Radio Incorporated
ATC	Air Traffic Control
ATM	Air Traffic Management
CAA	Civil Aviation Administration
CAB	Civil Aeronautics Board
CFIT	Controlled Flight into Terrain
CNS	Communication, Navigation and Surveillance
CSMU	Crash Survivable Memory Unit
CVDR	***COCKPIT VIDEO DIGITAL RECORDER***
CVR	Cockpit Voice Recorder
DFDAU	Digital Flight Data Acquisition Unit
DFDR	Digital Flight Data Recorder
DITS	Digital Information Transfer System
EE Bay	Electronic Equipment Bay
EGPWS	Enhanced Ground Proximity Warning System
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FDAU	Flight Data Acquisition Unit
FDAU	Flight Data Acquisition Unit
FDEP	Flight Data Entry Panel
FDR	Flight Data Recorder
GPWS	Ground Proximity Warning System
IHAS	Integrated Hazard Avoidance System
JAA	Joint Aviation Administration
MTBF	Mean Time Between Failures
NTSB	National Transportation Safety Board
QAR	Quick Access Recorder
RNAV	Radar Navigation
RVSM	Reduced Vertical Separation Minimums
Rx	Receiver
SSCVR	Solid State Cockpit Voice Recorder
SSDDR	Solid State Digital Data Recorder
SSFDR	Solid State Flight Data recorder
TCAS	Traffic Alert and Collision Avoidance System
TSO	Technical Standards Order

Tx	Transmitter
WG-50	Working Group No. 50 (EUROCAE)

Title:
How can the VDR prevent accidents and improve the Safety of a vessel ?

Sten Warnfeldt

Keywords
Marine
Safety
Efficient
Quality

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Ladies and Gentlemen,

This paper will present how easy it is to retrieve the information from a shipborne VDR, using the desktop at your office.
You can review *real events* that is recorded and stored on board a vessel.

First, and for all of us the most important information - the radar images- as displayed on the bridge.
Secondly - and as important - you can listen to the communication on the bridge and over the comsystems.
Listening to discussions, orders and radiocom could clarify the handling of the ship at the time.
And - all the important data, as position, course, speed, main alarms ... as presented on the bridge.

All information recorded is time-synchronized for obvious reasons.

Please, give this idea a thought - what can we learn from all accidents/incidents ?

And as important - what what can we learn from successful ship handling ?

How can the VDR prevent accidents and improve the Safety of a vessel ?

Let's start with one important definition -
It says in the **IMO A.861(20)** - which is the Performance Standards for Shipborne VDRs - Information contained in a VDR should be made available to both the Administration and the shipowner. This information is for use during any subsequent investigation to identify the causes of the incident.

The key-question is access to the information.

Appreciating that, let's have a look at the technical features, is it possible to retrieve this information at the offices ?

Yes - daily use of real events can be done by use of your desktop, as the computers that we are using here today.
You need a multimedia equipped computer, loudspeakers and a large monitor, at least 19, or maybe even better - use two large monitors.

We are looking at a computer that could be purchased from all major suppliers, and the prices are approx. USD 3500 or better.

If you have a Windows operating system and the special software package which is available with a VDR - than you should be set.
Utilizing a Windows Menu and Browser should provide an easy to use handling.

Let's appreciate that - if this is going to happen, it has to be an easy handling.

Preferably you will dedicate one exclusive computer for this purpose, required software packages are installed and it's ready for an immediate use.
We don't know when next incident comes up.

But, and this is important - in order to access the recorded information very easy, it might be an idea to include the capability to use your desktop computer.
Understanding that improved reviewing could be achieved by use of the dedicated computers, especially designed for the purpose.

The data is transferred from the vessel, using magnetical or optical disks, tapes, or on line using a secure network.
Again it's vital that it's easy to transfer the information for obvious reasons, and in the same time ensuring that the security is fulfilled.

Security - What about access ?
Who should have access to the information, on board and at the offices ?

This question has already been targeted and it's appreciated that this must be very clear and understood by the Officers and the Management.

Let's appreciate it once again - this is a very sensitive question,
which has been discussed all around the world intensively already today.
This possibility has to be a positive option to the Officers on the bridge,
if you are going to succeed using the information stored to improve the safety.

So again - access is the key-question.

How to use this information ?

Now as we can retrieve the information at the desktop, the most important issue is how to use all this most important and most valuable information to improve safety and quality on board the vessel.
We are looking at a lot of information, and the question is how to select and get a good understanding of the situation on the vessel.

If we are looking for information from an accident or incident, that's easy to decide - we are looking for all information for the time leading up to the event.

But when we are looking for information to improve ship's handling it's not that easy. Either make a spot check, select a time, an operating area or a harbor, and start reviewing. Or ask the Captain to select the information for you.
And please remember that we have to appreciate the IMO wording re this access.

Successful ship handling, again it's easier. The Officers on watch selects the period to review in order to present how they managed and handled the ship.
Here is also the access not that sensitive as the Officers most likely are happy to present how they succeeded.

One example, radar images

Let's have a look at a few radar images - image by image,
and when we are adding the audio files with the communication,
together with all the data files, minute by minute ...
maybe it's easier now to understand that we have to be very restrictive handling this important information.

I hope that you can foresee the huge amount of data that's stored
even only looking at a few minutes, and by that appreciate my statement.

And also that we are now finally looking at the possibility of using real events from the voyages with our own ships, in the safety training.

Technically it can be done - the key-question is related to access and selection of the data to be retrieved.

The most important target is to improve safety handling of the vessels.
Now when we have developed new tools to improve safety training, it's very much up to ourselves to discuss, decide and begin to use these in our safety efforts.

Sum-up - we can retrieve information stored in a VDR, using our own desktop.
And when we are going to retrieve the information for investigational purposes, radar could be reviewed using the high resolution, provided that we have advanced computers with a high resolution capability.

That about the operational use of this most valuable information.

Now, let's focus onto the high-tech use of all this information.

Imagine, that you are participating in a safety training, using a Bridge Simulator.
The session starts with real events, displayed on the screen in front of you, as you remember them from one of your recent voyages.
The Radar images are retrieved from this very voyage, coordinated with all the navigation and safety information, as recorded.
And suddenly the Training officer takes over and the scenario changes.
It's all based on the real events - what can be achieved during a training session including the use of real events ?
I think it's obvious - this training will be far more realistic and by that improve safety handling of the ship.

Bridge Simulation Training is expensive - here is a tool that can give us much more value for money.

This is what's about to happen in Port Klang, at Star Cruises HQ, using their new Bridge Safety Training Center.
First - use the Full scale Bridge Simulator to review information leading up to an incident - what could be achieved when the Officers are reviewing this ?
(And they have experienced to many incidents, or better claims, in the Malacca Straights)

You can recognize main alarms as displayed on the bridge, while you were on watch.

We do think that this Training now will become even more realistic, and we are going to reach new dimensions, using the latest multimedia technology - all to improve safety handling of vessels.

Conclusion, can the VDR improve the Safety of a vessel ?

No, not the VDR itself, but the information recorded and stored in the VDR could improve the Safety of a vessel.

We have seen only the very first steps, and experienced only a very few features to date. There are a lot more benefits coming with new VDRs accordingly with the forthcoming Directives, and all this could be used to improve quality and safety for the shipowner and the ship handling.

And as important - The possibility to retrieve the information at your desktop - you can use this most important and valuable information to improve the quality within your own fleet, provided that you have invested in a multimedia equipped pc.

The technology is here, and it works.
Now it’s up to ourselves to use all these options to improve safety on board our vessels.

Thank you for your kind attention.

Sten Warnfeldt

Acknowledgements
Consilium Marine, Nacka Sweden
Star Cruises, Port Klang, Malaysia
DMI, Lyngby, Denmark
IMO, London, UK
IEC TC 80, WG11. UK

References
IMO A.861(20)
EU Council Directive COM(98) 71 final

Using Operating Data at Natural Gas Pipelines

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KEYWORDS

Pipeline, Gas, Operations, SCADA

INTRODUCTION

Interstate natural gas pipelines are operated using sophisticated supervisory control and data acquisition (SCADA) systems. These systems are used to monitor, control and analyze operations. Software which runs in conjunction with the basic SCADA system expands the usefulness of SCADA data to enhance reliability and efficiency of operations, improve customer service, and minimize undesirable business practices, all in near real-time. Data from such systems are used off-line for the development of planning tools, training and system design studies.

PIPELINE OPERATIONS OVERVIEW

Operating under the jurisdiction of the U. S. Federal Energy Regulatory Commission, interstate pipelines provide open access for shipment of natural gas. Gas enters an interstate pipeline from gathering systems and from interconnecting pipelines. Beginning at individual wellheads, gathering systems usually consist of smaller diameter pipe operating at lower pressure. Gas conditioning is usually performed to reduce contaminants such as water from gathered gas before it is compressed into the transmission system. Gas leaves the transmission system through delivery points to other interstate pipelines, local distribution companies and directly to end users such as industrial facilities and power plants. Local distribution systems deliver gas to residential, commercial and industrial end users.

The basic components of an interstate pipeline include steel pipe, valves, compression, processing and storage facilities. Pipe sizes vary widely with much of the pipe in the 20-inch to 36-inch diameter range and wall thickness of about one-quarter to one-half inch. A typical range of operating pressures for a transmission system is 300 to 1440 psig. Powered by natural gas or electricity, compression is one of two types: reciprocating or centrifugal. Processing facilities extract undesirable contaminants (such as hydrogen sulfide and water) and marketable hydrocarbons (such as propane and gasoline). Storage facilities have been developed from depleted oil fields, coal mines, salt domes, aquifers and reefs. These facilities can be used for peak-shaving hourly demands and short-term, as well as, seasonal storage of gas.

Much of the gas that is transported on interstate pipelines is nominated, that is, scheduled in advance of actual gas flow. Deliveries into local distribution companies that serve weather-sensitive markets, however, cannot be known with absolute certainty. Such demand is met in part with “no-notice” service, which is usually supplied from inventories of the customers’ gas, which is stored in the pipeline’s storage facilities.

OPERATIONAL DATA

Gas pipelines are operated with a three-fold objective of ensuring safety of persons and property, reliability of service and cost-effectiveness. Operations are monitored and controlled by use of SCADA systems that provide thousands of data to pipeline controllers and operators. Some data are provided at intervals of a few seconds, other data are provided at intervals of a few minutes and still others on an hourly or daily basis.

Operational data include pipeline pressure, flow rate, gas composition, and equipment status. Maintaining appropriate pressures in the pipeline is essential to ensure safety, maximize throughput and provide reliability of service. Flow rates are determined on the basis of energy as well as volume and are used to balance system demands and supplies. Gas composition is required to maintain appropriate combustion characteristics, screen for undesirable contaminants, and balance gas transmission on a thermal basis. Equipment status, such as valve position and compressor information, is used to confirm that the system is configured to meet operational objectives.

SCADA SYSTEMS

SCADA system designs vary widely but there are elements common to all. For an interstate pipeline, data must be gathered from locations that are distributed widely across large geographical areas. Measurement transducers are polled frequently, often every two to five minutes. In a limited number of highly critical operations that are performed on-site at field locations, polling frequencies are measured in seconds. To efficiently perform basic functions, data must be accessible by operations personnel located in the field and at a central pipeline control center. As data are updated, the older data that have been superceded over time must be stored for audit trails, trending, and maintaining a historical operating record.

HARDWARE

SCADA systems are configured with a variety of instrumentation. Flow rates can be measured using orifice plates, annubars, or ultrasonic measurement devices. Gas quality is measured using thermal titration or gas chromatography. Where necessary, instrumentation is installed to sample for various contaminants including oxygen, water, and hydrogen sulfide.

Electrical signals from measurement devices are typically converted to engineering units in computers, referred to as remote terminal units (RTU), which are located at the measurement site. Communication links are provided by radio, cell phone, private microwave, leased line or satellite. Polling frequencies can be predetermined or on-demand.

Data from a given area of operations is often concentrated in computers at field offices, which are distributed throughout the pipeline system. SCADA software running on these field computers provides operational data and control to local operations personnel. Central computers located at a company’s pipeline control center, in turn, poll field computers. SCADA software runs on the central computers to provide pipeline controllers with displays of operational data and remote control capabilities.

LEVEL OF INSTRUMENTATION

For locations where gas is received or delivered, the level of instrumentation and telemetry is often dependent upon volume rates. At low rates, e.g., below 1 MMcf/d, gas flow is recorded locally but not telemetered by way of the SCADA system. At somewhat higher rates, pressures and flow rates are recorded locally and telemetered via the SCADA system. Above a certain threshold, perhaps 5 MMcf/d, pressures, flow rates, and gas quality are continuously measured and telemetered via the SCADA system.

Measurement facilities, hence SCADA data, are located at points where gas is received and delivered, at compressor stations, and at other remotely actuated equipment such as valves. Distribution of measurement points is thus facility-driven and is rarely uniform across the system; that is, measurement is not generally installed at regular increments of pipeline length.

DATA PRESENTATION

With so much data available at such high frequency, the effectiveness of the SCADA system hinges on appropriate data presentation, analysis and alarming. A variety of data presentations are used to transform basic data into information. Trends, schematics and other graphics are used to convey large amounts of data, which vary over time, in a concise and informative format.

TABULAR

Original SCADA systems made extensive use of tabular formats for data presentation. If the objective is to maximize the amount of data on one screen, tables of numbers are a good way to do it. Apart from being visually boring, tables can be difficult to decipher. New employees often struggle to put tabular data in the appropriate spatial and operational context.

SCHEMATICS

Superimposing operational data on facility schematics is an alternative method of data presentation. While potentially less efficient than tables in the use of screen space, schematic presentation offers several advantages. New employees can more easily put data in the appropriate operational context. Internal consistency of data can be assessed more readily. Color schemes can be used to convey equipment status, e.g., red for closed/off and green for open/on. With pipelines and color coded valves indicating open and closed positions, flow paths are more readily apparent. Managing emergencies is facilitated by presenting receipt and delivery information in the context of operating equipment such as compression and valves, which are used to mitigate the impacts of emergencies.

In some SCADA system installations, file compatibility has been established between SCADA system displays and standard drafting software. Using files developed by a firm’s drafting or GIS department offers numerous advantages, not the least of which is, the most recent revisions of drawings can be put to immediate use by operating personnel. Current schematics are essential to the effective management of all pipeline operations from routine daily operations to emergencies.

TRENDING

Ambient temperature fluctuations lead demand profiles where weather-sensitive loads are served. This is but one example of another effective means of data presentation, namely, trending. Trends are especially useful in monitoring pipeline operations because the vast majority of data, including flow rates, pressures and gas quality continuously vary with time. Trends are useful in assessing what has happened and in projecting what might happen. In an emergency situation, trends are extremely useful in corroborating incident reports and providing initial indications of affected locations.

REAL-TIME ANALYSES

SCADA systems are designed to provide for continuous calculations using telemetered quantities. Combining multiple data into meaningful aggregated and calculated quantities provides an effective means of synthesizing data and conveying information. Key aspects of pipeline operation can thus be quantified and trended. The pipeline controller is relieved of reviewing large amounts of raw data, performing calculations, keeping log sheets and making inferences. More of the controller’s time can be spent analyzing current operation, making projections and proactively coordinating system changes.

SYSTEM BALANCE

Many pressure measurements are combined with the physical description of the pipeline to render the inventory of gas in the pipeline as a whole and in its various segments. The result is called linepack, and this one number conveys much information about the state of the pipeline. A mid-size interstate pipeline consisting of 3000 to 5000 miles pipe in the 20-inch diameter range will contain two to three billion cubic feet of linepack. As much as five to ten percent of linepack may be available for packing or drafting, i.e., increasing or decreasing gas inventory in the pipeline. Used in such a way, linepack provides a significant amount of short-term storage.

Interstate pipelines have hundreds of locations where gas volumes are received and delivered. Aggregating some or all of these receipt volumes and delivery volumes provides essential information about the "balance" of the system and the performance of key segments. Trending the total receipts and total deliveries, along with system linepack, provides pipeline controllers with a near real-time system balance. Such information can be used to assess the proper level of storage field activity versus linepack utilization.

PIPELINE PERFORMANCE

When pressures at both ends of a pipeline segment are known, standard steady-state pipeline flow equations can be used to estimate flow through that segment. Comparisons between theoretical and measured gas flow allow for real-time assessment of pipeline performance. Gas flow equations for pipelines include a term such as roughness, typically in microinches, or efficiency, typically in percent. These terms have been empirically derived for new "smooth" pipe.

Flows that are calculated for ideal conditions can be used as a benchmark for performance analyses. Over time, contaminants in the gas stream are either deposited on the wall of the pipe or, in the case of liquids, settle into low spots, creating excessive pressure losses, thereby degrading the performance of the pipeline. Measured gas flow inherently describes the actual, somewhat degraded, performance of the pipeline. A simple comparison with the appropriate benchmark provides information that can be used to schedule cleaning of the lines. Predetermined limits can be established such that when the measured flow through the pipeline segment falls, say, 10 percent below "ideal" conditions, cleaning is mandated. The tolerance might be narrowed for pipelines operating at or near capacity and widened for slack lines.

Comparisons between calculated and measured flow rates can indicate, in extreme cases, the formation of blockages such as a line freeze or stuck pig. ("Pig" is a rather humorous moniker applied to devices used for cleaning and internal inspections of pipelines. One story has it that the original devices made a squealing noise as they exited the pipeline. Another story is that the name refers to the appearance of the devices as they were originally designed, however, devices currently in use have shapes ranging from spheres to torpedoes. Regardless, even veteran pipeliners have to smile at the images conjured up by "pig launchers" and "stuck pigs".) Freezes are the result of a combination of hydrocarbon vapor and water vapor entrained in the gas stream. Otherwise minor restrictions in flow can cause enough pressure reduction and corresponding temperature drop to precipitate liquid formation which in turn freezes. Using trends, departures between measured and calculated flow rates are graphically and effectively presented to pipeline controllers so that accurate problem identification can be made.

GAS BLENDING

"Natural gas" is a generic term applied to a mixture of hydrocarbon gases, with methane as the predominant constituent. Most natural gas contains at least some impurities. Quality specifications, which are detailed in an interstate pipeline's tariff, are established to protect the pipeline and compression against physical damage and performance degradation. When tolerances for impurities are exceeded, decisions must be made as to how much, if any, gas of substandard quality can be accepted.

Volumetric flow rates and gas qualities obtained from the SCADA system can be used to predict the gas quality of blended streams. As gas quality problems are encountered, expected blends can be calculated. While not always chemically correct, simple volume-weighted averages often provide reasonable estimates for operational decisions. Allowable flow rates from an offending source can thus be estimated based upon the concentration of contaminant relative to the volume and quality of the stream with which it will be blended. Such an approach protects the pipeline, minimizes disruption to production and can materially assist a producer or processor as they remedy gas quality problems.

ALARMS

Alarms are used to indicate that operating conditions are approaching or have exceeded prescribed tolerances. Attention can then be focussed on problem diagnosis and appropriate actions. However, too many minor alarms can have the reverse effect by desensitizing pipeline controllers to all alarms, important and trivial.

BASIC

Basic alarm types include high and critical high alarms, low and critical low alarms, and changes of status (on or off, open or closed). High limits can be applied to any type of data but are most often used for pressures and gas quality problems. Low limits are typically used for delivery pressures and volumes, particularly when volumes trend to zero. Status change alarms alert pipeline controllers to changes in system configuration. Changes may include an increase in compression, redirection of gas flow, or changes to gas quality.

The next level of alarm sophistication includes “rate of change” alarms. Abnormal variation of data with respect to time, such as a sudden increase or decrease of pressures, can trigger rate of change alarms. While data may not be high or low enough to trigger a basic alarm, unusually rapid fluctuation in value can indicate abnormal operating conditions. Major pipeline incidents are often detected quickly with appropriately set rate of change alarms.

ADVANCED

A third level of sophistication includes conditional alarms, which combine multiple data to warn the controller of specific abnormal conditions or to eliminate some nuisance alarms. An example is alarming gas quality which exceeds prescribed tolerances only when the receipt volume is non-zero. It makes little sense to issue a gas quality alarm for a source that is flowing no gas.

The most sophisticated alarms require numerous calculations involving multiple data points. Using near real-time analyses of pipeline performance, alarms can be employed to detect abnormal pressure drops associated with flow restrictions. Excess pressure loss would equate to higher calculated flow rates through the pipeline as compared to measured flow rates. Significant differences between calculated benchmark flow rates and measured flow rates can indicate some type of obstruction, such as hydrate formation or some other degradation in pipeline performance.

PIPELINE CONTROL

Pipeline operations are managed with a balance of automated and mechanical devices that are operated with local and remote control. For the most part, pipelines are controlled by regulation of pressure and volume through the use of compression and modulating valves. Pipeline facilities are protected from overpressure through the use of mechanical relief valves, which are completely independent of any control systems, including the SCADA system.

Volumes for receipt and many delivery points are set with modulating valves, often by remote control from the pipeline control center. Locations at which deliveries are made to local distribution companies, which serve weather-sensitive demand, are controlled locally with mechanical pressure regulation. The delivery pressure is maintained at nearly constant levels while demand varies significantly throughout the day. Delivery pressures are monitored and alarmed to ensure reliability but there is typically no remote control to such locations.

Compression is controlled with a combination of local and remote control. Suction or discharge pressures are determined for compressor stations based upon scheduled throughput. Pressure setpoints are sent from the pipeline control center to individual compressor stations via the SCADA system. The setpoints are relayed to local station automation equipment, which select units and set their speed and loading. As discharge pressures approach maximum allowable operating levels, local automation equipment slows and subtracts units as necessary.

LEAK DETECTION AND RESPONSE

Pipeline ruptures are rare and often the result of unreported third-party damage. They are very noisy affairs as gas at 500 to 1000 psig is blown to atmospheric pressure. The noise rapidly draws the attention of any people in the area. The first notification of such a pipeline incident is frequently a phone call from someone near the incident site. (Pipeline markers, which are liberally distributed along the pipeline right of way, provide the telephone number of the central pipeline control office.) Meanwhile on the SCADA system, the first indications of a problem include a rapid loss of pressure at nearby points. Rate of change alarms are typically issued by the SCADA system. Pipeline controllers usually identify incidents of this magnitude rapidly. Confirmation comes in the form of a phone call from an eyewitness and the receipt of additional scans that are sufficient to develop a trend.

RESPONSE

Responding to a rupture involves calling local field personnel and directing them to the block valves upstream and downstream of the site. If the site is located in an area of the pipeline where valves can be remotely actuated, the SCADA system can be used to isolate the damaged segment. After field personnel positively identify the location of the rupture site, pipeline controllers can be directed to remotely close valves immediately upstream and downstream of the rupture site. In areas where valves cannot be actuated through the SCADA system, operations personnel must travel to appropriate valves and isolate the damaged segment.

Some interstate transmission pipelines have installed “excess flow valves” which sense abnormal changes in flow and automatically close. In theory these locally controlled valves offer the fastest response time to isolation of the affected segment. Experience has shown, however, that these valves close in error as much or more than they close at appropriate times. When these valves are located immediately downstream of compression facilities they can pose as much hazard as help.

REAL-TIME SIMULATION

Coupling simulation results from real-time models with SCADA system data has long been proposed as an effective means to detect pipeline leaks [1]. Real-time models are a special application of simulation programs that describe transient pipeline operation as opposed to steady-state analyses. These simulation programs run in “lock-step” with pipeline operations as described by SCADA data. Deviations of simulated results from measured results can indicate leaks or errors in SCADA data.

The advantages of using a real-time transient model over a steady-state model for leak detection include a wider range of application and increased sensitivity. No longer must steady-state conditions apply as real-time models can be extended to cover the entire range of operating conditions. Sensitivity to detect smaller leaks is improved because systematic departures between calculated and measured results can be tracked through continuous operation.

While real-time models have been proposed for leak detection for some time, their application at gas pipelines has been very limited. Building and maintaining such a model is labor intensive. Response time for pipeline ruptures cannot be shortened appreciably and improvements in detection of small leaks will be limited by the extent to which a pipeline is instrumented. Measurement spacing is a factor in leak detection sensitivity. Miles of uninstrumented pipeline typically lies between clusters of measurement sites. Finally, where numerous small receipt and delivery points are not instrumented to provide pressure and flow data to the SCADA system, as is frequently the case, detection sensitivity is further eroded. The expense of the simulation program, additional telemetry and the resources to maintain both is simply not justified in many instances.

ACCIDENT PREVENTION

The excellent safety record of interstate pipelines is not a matter of chance. System designs are conservative with maximum allowable operating pressures mandated to be considerably below the yield strength of the pipe. Simple but effective pressure relief devices vent gas to prevent overpressure situations. Compressor station controls throttle back horsepower as pressure approaches the maximum allowable. Pipeline controllers schedule volumes and adjust system operations to avoid excessive pressure.

Pipeline companies aggressively pursue corrosion prevention. Gas quality specifications are established to prevent internal corrosion. Gas composition is monitored with the SCADA system and sources of potentially corrosive contaminants are limited in their flow rates, if not, shut in altogether. The exterior of pipelines is coated with corrosion inhibiting materials and cathodic protection is used extensively.

Most pipeline damage is caused by third parties encroaching on pipeline right-of-way. Damage prevention activities include public education efforts and encouragement to use “one-call” systems for the location of buried utilities, including gas pipelines. Field personnel on the ground and from the air routinely perform surveillance of pipeline right-of-way. Internal pipeline inspections are performed by smart pigs, which pinpoint locations of anomalies in the pipe wall. SCADA systems have little or no role in such accident prevention efforts.

In a limited number of applications, SCADA systems can be employed to alert pipeline controllers of a potential for pipeline failure. When a pipeline is located in an area of potential landslide, washout, or fault lines, instrumentation can be installed to provide early warning of soil movement and excessive strain on the pipeline. One approach involves the installation of strain gages directly on the pipeline. When telemetered values exceed the allowable tolerance, alarms are issued by the SCADA system so that appropriate action can be taken.

Research has been done to develop sensors to be used with appropriate signal conditioning and analysis to detect damage as it occurs. Even more ambitious are efforts to detect impending damage due to excavation near the pipeline. Presumably, such information would be communicated to pipeline controllers through the SCADA system. While promising, these efforts still have technical challenges to overcome. For a technical review of the subject see Francini et al. [2,3].

PLANNING AND SCHEDULING

For pipelines that serve weather-sensitive demand, load forecasting is an integral part of planning daily operations. Archived SCADA data, specifically flow rates, for deliveries into weather-sensitive areas are correlated with ambient temperature, wind speed and other weather variables. The resulting correlations are then used with weather predictions to quantify expected hourly and daily demand.

Currently, shippers can nominate their gas transactions four times per day. At the close of each nominating cycle, the demands for capacity on all segments of the pipeline are assessed with simple network models. Nominations are scheduled up to the sustainable capacity of the pipeline. Capacity limitations are determined by experience and review of historical SCADA data. Minor facility problems on the pipeline and on interconnecting systems will combine to render sustainable capacity somewhat below theoretical limits. To schedule volumes at theoretical limits is to invite the accrual of significant shortfalls from nominated levels.

In some instances, computer simulations are used to predict the pipeline system's physical response to expected demand and supplies. Simulation results are used to assess the feasibility of proposed operating plans. A key step in the simulation process is the comparison of recent SCADA data to calculated results. Based on these comparisons, modeling parameters are adjusted until simulation results reasonably approximate measured pipeline performance and an initial pipeline state is defined. Only then can the model be used in a predictive mode to test the feasibility of an operating plan.

BUSINESS PROCESSES

Integration of SCADA systems with business applications has long been done. These efforts took on added importance as regulatory changes during the last decade dramatically altered the role of the interstate pipeline [4]. To cope with the changes, interstate pipelines invested considerable resources into upgrading their SCADA systems and increasing the number of points at which telemetered measurement is installed. SCADA data have proven to be an important resource not only for managing pipeline operations but managing the business, as well.

SCADA data are useful in minimizing the impacts of measurement malfunctions that can lead to accounting mistakes and errant customer billing. The same measurement facility is typically used to provide SCADA data and electronic measurement data used in custody-transfer calculations. Pipeline controllers can respond timely to alarms that indicate flow rates are outside the optimal range for measurement accuracy. Other measurement and communication failures are alarmed as well. Responding to these failures early on minimizes inefficiencies later in the business process.

Nominated receipts and deliveries are compared with measured quantities from the SCADA system to determine variances between actual and scheduled activity. At times these variances are planned so as to mitigate the impacts of facility work or to offset imbalances that have accrued over time. At other times, these variances aggravate existing imbalances, in which case adjustments to nominations may be required.

During critical operating conditions, for instance extremely cold weather, variances take on added significance for pipeline and customer alike. Pipelines must receive all scheduled receipt volumes to ensure adequate supply to meet demand. Customers must be apprised of failing supplies and excessive deliveries so attempts can be made to avoid potential penalties. Instead of simply reviewing the previous day's and month-to-date activity, variances are calculated based upon current flow rates and projections for the balance of the day.

TRAINING

A promising approach to training pipeline controllers is to use the SCADA system in conjunction with transient simulations. The trainee interacts with the same SCADA displays and control systems used in actual operations. Simulation results take the place of measured data but all else remains the same. A single training environment meets multiple objectives including familiarization with SCADA system functional capabilities, pipeline operating characteristics and problem solving strategies.

DESIGN

Design studies are based upon simulations that are run with pipeline models. SCADA data are used in model preparation and tuning as well as in design simulations. Simulation results are compared to archived SCADA data to verify the consistency of the model with the physical system and to tune modeling parameters such as pipeline and compressor efficiencies. Projected system modifications are incorporated into the model and design simulations are run. Oftentimes archived SCADA data are used to develop typical demand profiles and other operating conditions to evaluate the response of the modeled system to expected operating conditions.

CONCLUSIONS

The data from supervisory control and data acquisition systems are indispensable to monitoring and controlling operations of interstate natural gas pipelines. Beyond these basic functions, however, the data gathered by these systems are used extensively directly and indirectly in a variety of business applications from design to invoicing.

REFERENCES

1. Rachford, H. H. et al., “Detection of Leaks in Pipeline Networks Using Standard SCADA Information,” Pipeline Simulation Interest Group, 1986
2. Francini, R.B. et al., “Real-Time Monitoring to Detect Third-Party Damage”, GRI Document Number: GRI-96/0077, 1995
3. Francini, R. B. et al., “Real-Time Monitoring to Detect Third-Party Damage: Phase II.,” GRI Document Number: GRI-97/0141, 1997
4. Westhoff, M. A., “System Integrates Scheduling, Modeling and Monitoring,” Oil and Gas Journal, March 5 and 12, 1990.

BIOGRAPHY

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Accident Reconstruction/Simulation With Event Recorders

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Introduction

In 1997, 42,000 people were killed in highway accidents in the United States. The exact cause of an accident is often unknown and, therefore, conclusions relating to the safety afforded by the vehicle to the occupant cannot be made. In addition, safety hazards in the highway environment are often not discovered due to the lack of information. Accident reconstruction is a tool commonly used by the National Transportation Safety Board (NTSB) to investigate the accident sequence, but data are often lacking and accurate reconstructions are difficult and time-consuming. Because many assumptions are made in this process, the reconstruction is not exact, making it difficult to accurately predict occupant kinematics and to identify potential safety hazards within the vehicles. Vehicle recorders would eliminate much of the guesswork involved in reconstructing accidents, enabling a more accurate assessment of occupant injuries, driver performance, and safety hazards within and around a vehicle.

Vehicular Data

Much information concerning the accident vehicles is needed to reconstruct an accident accurately. This information includes both driver inputs and vehicle outputs. The driver inputs would include steering angles; application of brakes and throttle; gear selection; engine braking; and use of lights, turn signals, cruise control, wipers, and horn at various increments prior to and during the accident sequence. Information is also necessary on driver restraint use and occupant seating location. The vehicle output parameters that are needed include the pre-impact speed, engine rpm and gear selection, acceleration history, braking efficiency, the use of cruise control and anti-lock braking systems, and activation of passive restraints.

Typically in highway accidents, the driver inputs and the vehicle outputs are derived from witness statements, or physical evidence such as the impact location, tire marks, and the final resting position of the vehicles. Unfortunately, witness statements are often in conflict, biased, and perhaps based on past experience, adding confusion to variables such as initial speed or speed at impact. Further, the accident typically occurs within 0.10 seconds, a speed at which witnesses cannot always accurately comprehend vehicle interactions. Furthermore, physical evidence can be limited if road considitions are not ideal or if evidence is not collected immediately after the accident.

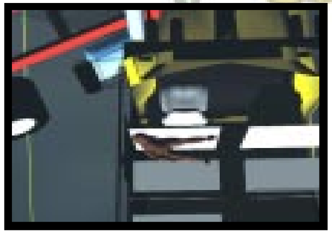


Figure 2: Occupant kinematics during a simulated accident between a tractor-trailer and a school bus.

Methods for Accident Reconstruction and/or Simulation

Several programs have been developed to aid in accident reconstruction/simulation. These developers include McHenry Software (m-smac,m-hvosm, m-crash, ATB/cvs); Engineering Dynamics, Inc. (EDCRASH (reconstruction), EDSMAC, EDVDS, EDVSM, EDHIS, EDVTS, EDGEN); MacInnis Engineering (PC-Crash); Mechanical Simulation Corporation (TruckSim, AutoSim); AR Software (Slam, WinSMAC); Accident Reconstruction Software (REC-TEC); Fonda Engineering Associates (CRASHEX); and others. These programs use the driver inputs and the vehicle outputs to reconstruct/simulate the accident. Crash pulses detailing the acceleration-time history of a vehicle can be calculated from these inputs, the damage profiles of the vehicles, and the vehicle stiffness, as shown in Figure 1.

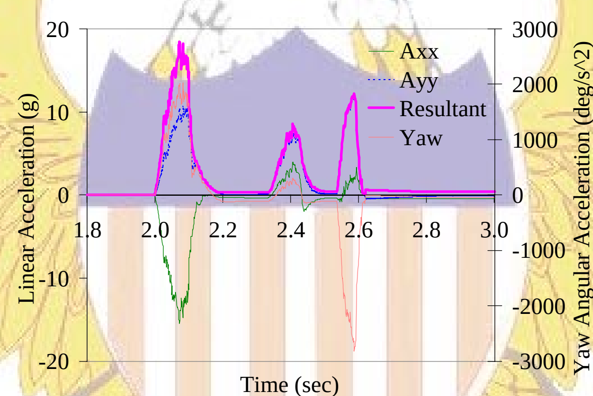


Figure 1: The crash pulse on a school bus from a simulated accident between a tractor-trailer and the bus.

Human Performance: Recorded information could help investigators determine the drivers' actions before and during the accident. These inputs will help to refine the vehicle and occupant dynamics during the accident. The recorded information may also help to assess if the driver was fatigued, impaired, or not making evasive maneuvers. For example, a lack of steering reversals may indicate fatigue. Such information will help to assess countermeasures for preventing accidents.

Biomechanics: Once accurate information on vehicle performance and driver response is known, the reconstruction may then be used to assess occupant kinematics (Figure 2) and occupant protection within the vehicle. The more accurate the vehicle dynamics, the more accurate the occupant simulation. Better occupant simulation will result in more effective design changes that improve occupant safety.

Accident Reconstruction Examples

Collision of a Van and a Train: Event recorders may be used to facilitate the accident reconstruction process. For example, in 1998 in Wagner, Oklahoma, a van was struck in the rear by a train. Witnesses in the van reported that the driver stopped at the railroad crossing and then proceeded into the crossing. The train engineer reported that the van did not stop at the crossing. An event recorder was present on the train, so the train speed at impact was known to be 46 mph. Based on the damage profile on the van and the final resting location of the van, reconstructionists at the NTSB varied the speed of the van at the point of impact to determine the most accurate trajectory and the related initial speed of the van. (Figure 3)

The conclusion drawn, based on the reconstruction, was that the van had to be traveling about 35 mph at impact to sustain the damage and reach the final resting location. The train's event recorder enabled this iterative process to occur. Without the recorder, there would have been an infinite number of train and van speed combinations that would have resulted in a similar damage profile and rest location for the van. Furthermore, the cause of the accident would have been unknown and potential safety hazards might not be identified.

Collision of a Tractor Semi-Trailer and a School Bus: Another simulation being developed by the NTSB involves a school bus that was struck from behind by a tractor semi-trailer in Holyoke, Colorado, in 1998. Vehicle recorders would have greatly helped the simulation and reduced the number of simulation runs required. A bus recorder would have indicated if the bus was stopped or had just started to accelerate when struck by the truck. A truck recorder would have provided information on the truck's initial speed, gear in use and rpm, when the truck driver started to brake, how hard he braked, and which brakes (semi-trailer only or full truck) he initially used. The driver added steering input just before the crash; knowing when he started to steer and the rate at which he steered would have helped in the simulation. Furthermore, both bus and truck driver inputs prior to the crash would help determine a potential cause of the accident.

Summary

Accident reconstruction/simulation is a difficult and time-consuming process. Event recorders not only simplify the reconstruction process, but they also increase the accuracy of the reconstruction resulting in more detailed conclusions concerning safety.

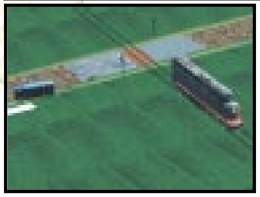
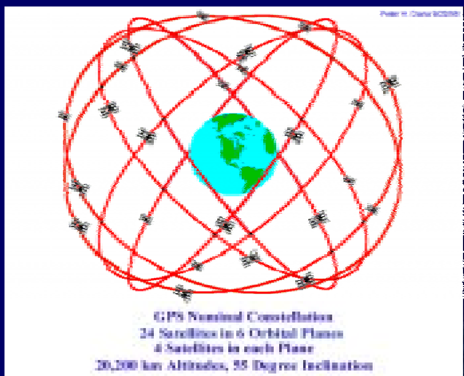


Figure 3: The simulation of the train and van in Wagner, Oklahoma.

Seat Belt Event Data Recorder (SB-EDR)

Click Incorporated - Transportation Safety Technologies

Southern Pines, North Carolina, USA 910-692-5209



WARNING: VEHICLE CONTAINS MEANS TO MONITOR, RECORD, AND TRANSMIT CRASH DATA ELEMENTS FOR POST-CRASH ANALYSIS. OWNER RETAINS OWNERSHIP OF ALL DATA COLLECTED.

Internet

Pre-Crash

Monitor

Transmit

Crash

Record

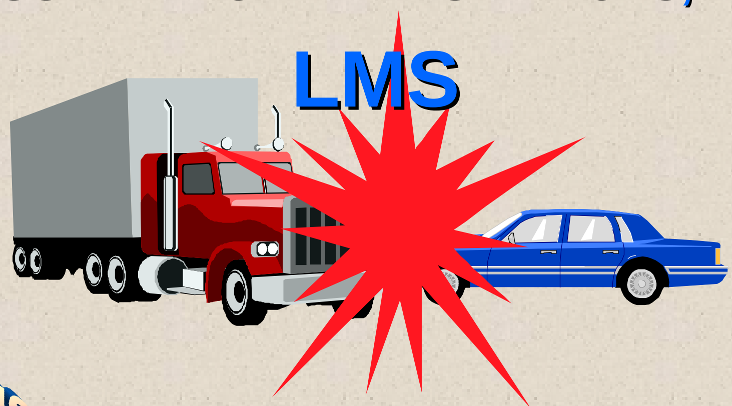
Post-Crash

CRASH DATA ELEMENTS OCCUPANTS TIME LOCATION VELOCITY DIRECTION SEAT BELT USAGE

The Future is Now...

LOSS MANAGEMENT SERVICES, INC.

LMS



Introduction

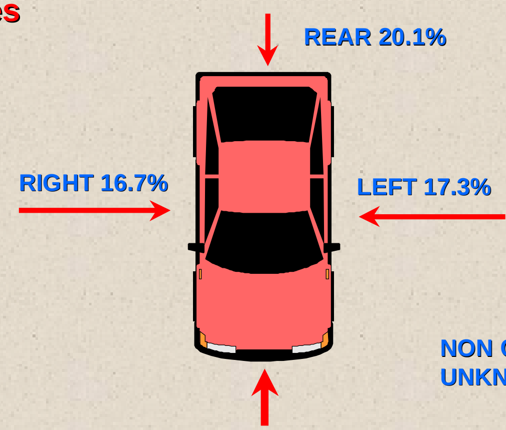
- For more than three years, LMS has been involved in field investigation, adjusting and managing transportation insurance claims.
- LMS is dedicated to developing cost effective ways to service the insurance claims industry's investigation and litigation procedures through 21st century technology.
- By combining high-tech sensors and digital imaging, LMS could solve the most vexing questions today involving automobile accidents....

What Happened?
Who is at fault?

Loss Management Services, Inc.
36 Surf Road, Lindenhurst, New York 11757

Accident Statistics

Collision point of contact percentages

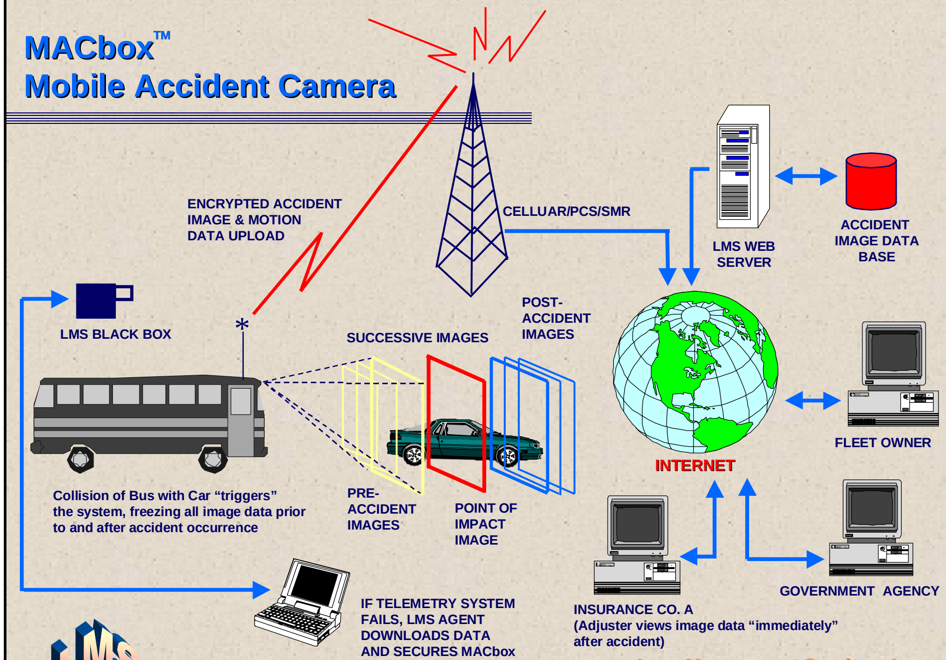


Solution

The Mobile Accident Camera, "MACbox™" will:.

- **Secure a "driver's eye view" of *valuable* digital imagery.**
- **Provide a repository of information, including in-cabin acceleration data, for customers, insurance carriers, government agencies, and auto manufactures.**
- **Provide telemetry data.**
- **Better control and manage claim expenses and pay outs.**

MACbox™
Mobile Accident Camera



Benefits

- Accurate Assessment of Liability
- Reduce the Cost of Litigation
- Reduce the Need for Expert Witnesses
- Reduce Costs Associated with Claims Investigations
- Assist with Accurate Claim Reserving
- Deter "ROAD RAGE"
- "G-Force" Comparison to the Extent of the Injury
- Acceleration data used improve cabin safety

Applications

- Municipal Transportation Environment (Buses - Emergency Vehicles)
- Long Haul / Short Haul Trucking
- Taxi / Livery Services
- Commercial Passenger Transportation Fleets

Business Partners

Phoenix Group Inc. (PGI), Hauppauge, NY, is a designer and manufacturer of ADVANCED RUGGED MOBILE COMPUTERS for industrial and government field applications.

PGI has designed a roster of impressive portables that feature innovative use of today's technology components. PGI products are presently are used by industrial and military customers.

Instrumented Sensor Technology (IST), a world leader in portable PC-programmable, high speed data recorders, supplies recording systems and data analysis software for numerous applications including transportation monitoring, flight testing, crash recording, industrial package testing and accident reconstruction.

Business Affiliates

By having the PGI and IST manufacturing partnerships, LMS possesses the development and manufacturing capability that can deliver a system that addresses the needs of the insurance related risks.

The Future is Now...

LOSS MANAGEMENT SERVICES, INC.

LMS

Loss Management Services, Inc.
36 Surf Road, Lindenhurst, New York 11757

The Benefits of Vehicle-Mounted Video Recording Systems

R. Jeffrey Scaman

Evicam International, Inc.
600 17th Street, Suite 2008 South
Denver, CO USA 80202

The introduction of Vehicle-Mounted Video Recording Systems will have a positive impact on the way transportation accidents are investigated and mitigated. Here's why…

CURRENT METHODS

Currently, investigators must rely on second-hand information, physical evidence and limited data collected from transportation recorders. The data collected by present recorders is useful however, it only provides partial data of the circumstances surrounding an accident. Present methods of investigation are out-dated and inefficient based on available technology.

DEVELOPING TECHNOLOGIES

Technologies currently under development will soon allow the use of Vehicle-Mounted Video Recording Systems. These Inter-modal systems will be capable of capturing live video and other vital data of vehicular accidents as they occur. This new technology will concentrate on accident event construction, versus **re**-construction.

POTENTIAL BENEFITS

Some of the potential benefits of Vehicle-Mounted Video Recording Systems are: more accurate and efficient investigations; savings of time, money and manpower associated with investigations; a reduction in accident fraud, and future mitigation of human and economic loss associated with transportation accidents of all types.

COMING SOON TO A VEHICLE NEAR YOU!