PARTY SUBMISSION OF NASCAR, INC.

To the National Transportation Safety Board

Regarding the Accident Involving

Cessna 310R, N501N

Sanford, Florida

July 10, 2007

NTSB# NYC07MA162

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I. EXECUTIVE SUMMARY:

On July 10, 2007 a Cessna 310R aircraft, N501N, collided with trees and residential homes in the vicinity of the Sanford Orlando International Airport (SFB) in Sanford, Florida. The aircraft was being operated on an instrument flight plan under 14 CFR Part 91, from the Daytona Beach International Airport (DAB) in Daytona Beach, Florida to Lakeland Linder Regional Airport (LAL) in Lakeland, Florida. When the aircraft was approximately seven miles north of SFB, the flight crew advised ATC that they were declaring an emergency because of “smoke in the cockpit” and asked to divert to SFB. The aircraft then turned directly toward SFB. Approximately one minute before reaching the airport, witnesses saw the aircraft make an approximate 70 degree bank to the right[1], descend, and collide with trees and residential homes. Both occupants of the aircraft, a certificated commercial pilot and an airline transport pilot, were fatally injured. Three persons on the ground were fatally injured, and four were seriously injured.

The aircraft crashed approximately three minutes after the crew first reported smoke in the cockpit, and only about one minute[2] before its anticipated touchdown at SFB. The 70 degree right bank and turn of the aircraft resulted in contact with trees and residential homes. This last sequence of events and the fact the plane was not configured for a landing show that the cockpit crew was not in control of the aircraft during this final period. The most likely cause of this inability to control the aircraft was smoke in the cockpit from burning PVC electrical insulation.[3]

The evidence developed during the course of this accident investigation showed that the smoke in the cockpit was caused by an electrical fault in the aircraft wiring installed in the aircraft by the manufacturer in 1977. The electrical fault (arc) and melted electrical wires were located behind the instrument panel. Based on the sequence of events that lead to this accident, it appears that one or two or both factors was the cause of this accident; (1) the wire insulation did not meet certification standards[4] requiring a “slow burning” type of wire and/or (2) the circuit protection devices (fuses and circuit breakers) installed as a part of the electrical system by the manufacturer did not arrest the arcing which caused ignition of combustible materials, principally, the PVC electrical insulation.

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[1] According to the Board’s analysis of the radar returns (primary and secondary), as compared with the wreckage distribution path, when the aircraft was approximately seven-tenths of a nautical mile to the northeast of the crash site, it made a right turn from a ground track of approximately 155° to a track of 251°. Performance calculations performed by the Board investigators as part of the Aircraft Radar Performance Study established that the aircraft would have had to have banked at approximately 68 degrees, at a groundspeed of approximately 180 knots, to achieve this turn. This is consistent with observations of ground witnesses who indicated that they saw the aircraft enter a “steep bank” and a sharp turn and descent quickly just before the crash; and with the statement of witness Kunzer who described the maneuver as “a hard bank, about 70 degrees.”

[2] The radar track of the aircraft shows that the turn took place approximately three nautical miles north of SFB, at a time when the groundspeed of the aircraft was approximately 180 knots (3 nautical miles per minute).

[3] See discussion of crew incapacitation in Section VI. below.

[4] See discussion of certification in Sections V.A. and V.B. below.

The pilot who flew the aircraft on the previous day had logged a discrepancy report concerning malfunction of the weather radar display unit mounted in the aircraft instrument panel. In operating the unit, he had smelled what he described as overheated electrical equipment. That pilot deactivated the unit by switching it off and removing electrical power to the unit by pulling its circuit breaker. The accident flight crew were made aware of this discrepancy by both direct communication, and by a discrepancy notice prominently placed on the throttle quadrant of the aircraft. The radar was not in use during the accident flight. Further, the arced and beaded electrical wiring found as a part of the post-crash investigation was not associated with the radar unit deactivated the previous day.

The event which was the probable cause of this accident was a fire in the aircraft wiring unrelated to the radar display unit. The crew reacted appropriately to this fire, by using the master electrical switch and alternator switches to interrupt electrical power to the aircraft electrical system, and by diverting to a nearby airport. Despite these actions, however, the electrical fire continued, because the insulation of the aircraft wire did not meet the certification requirements of CAR Section 3.693 and was flammable, allowing the fire to become self sustaining; because the circuit breakers and master switch did not accomplish their intended purpose of interrupting electrical power to the damaged circuit (contrary to CAR Section 3.688 and Section 3.690); or because of a combination of both of these factors.

If the electrical fire had been interrupted early enough, either because the wire was of a nonflammable type, or because the electrical current to the fire could be interrupted by the master switch and/or circuit breakers, the accident would not have occurred because, at the time the fire began, the crew was approximately three and one-half minutes from landing at SFB. It appears from the evidence that the crew was incapacitated approximately two and a half minutes after the onset of the fire, and only about one minute from landing, by combustion byproducts from the flammable PVC wiring.

II. THE AIRCRAFT:

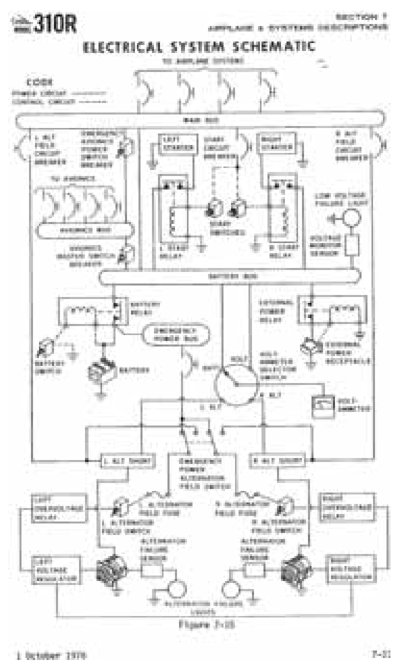
N501N was a Cessna 310R aircraft, manufactured in 1977 and certificated under CAR (Civil Air Regulations) Part 3. Competitor Liaison Bureau, Inc., (CLB) acquired the aircraft in March 1995. Between initial delivery of the aircraft by the manufacturer and its acquisition by CLB, the navigation and communication (nav/com) radios were replaced and a Bendix-King radar unit was installed, in 1988.

Figure 1.
Pre-accident photograph of accident aircraft

A. Aircraft Electrical System:

The aircraft's electrical equipment and accessories are powered by direct current electricity. This electricity is provided by a 24 volt battery, mounted in the left wing, and by two engine-driven alternators, one mounted on each engine. Each alternator is part of an independent electrical generating system, with its own voltage regulator and overvoltage protection relay. A cross-tie bus connects these two systems together to supply power to the various load demands throughout the airplane. Normally both systems operate in parallel. In the event of a power loss of one alternator system, electrical power is supplied from the opposite system through a cross-tie bus. Electrical load distribution, from the power sources of the various electrical accessories in the airplane, is accomplished by wiring, buses and circuit breakers. The circuit breaker panel is located on the left cabin wall forward of the pilot's seat. Reprinted below as Figure 2. is a copy of the electrical system schematic from the Manufacturer's Pilot's Operating Handbook (POH) for the accident aircraft, in which the manufacturer explains to the operators of the aircraft the general configuration of the electrical system.

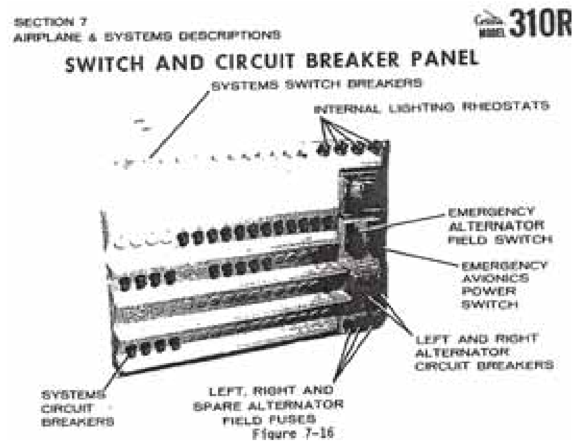
Figure 2.
Electrical schematic diagram from Manufacturer's POH



The aircraft avionics, including the aircraft's nav/com radios, receive electrical power through an avionics buss routed through the "main buss" shown at the top of Figure 2. An electrical plug, with burned and beaded electrical wiring, found in the post crash investigation was determined by the manufacturer to be of a type which would have been installed as part of the original wiring from the avionics buss to the nav/com radios.

The aircraft wiring is primarily protected from overload current by a series of circuit breakers. These breakers are mounted to a circuit breaker panel located on the left-hand cabin wall, forward of the pilot's seat. The breakers are individual "push-pull" breakers, which allow the operator to individually pull a dedicated breaker to deactivate a specific electrical device, system or systems. This panel also contains switches which are designed to allow the crew to deactivate the charging function of either or both alternators, by electrically interrupting their field circuit or, alternatively, to allow the crew, by use of a separate switch, to completely isolate electrical power from the aircraft electrical system. Figure 3. below is a copy of figure 7-16 from the Manufacturer's Pilot's Operating Handbook, depicting this circuit breaker panel and those switches.

Figure 3.
Diagram of switch and circuit breaker panel from Manufacturer's POH



In the POH, the manufacturer's instructions to the crew on the management of electrical circuit breakers is as follows:

> **CIRCUIT BREAKERS AND SWITCH BREAKERS:**
> All electrical systems in the airplane are protected by push-to-reset type circuit breakers or switch breakers, see Figure 7-16. Should an overload occur in any circuit, the resulting heat rise will cause the controlling circuit breaker to "pop" out, opening the circuit or allowing the switch breaker to return to the OFF position. After allowing to cool for approximately three minutes, the circuit breaker may be pushed in (until a click is heard or felt) or the switch breaker may be returned to the ON position to reenergize the circuit. However, the circuit breaker should not be held in nor the switch breaker forced to remain in the ON position if it opens the circuit a second time as this indicates a short circuit.[5]

This advice is contrary to industry best practice. Heat from excessive current causes the breaker to physically "pop out," which mechanically removes electrical power from the failed circuit. Manually pushing the breaker back in after it cools reenergizes the

[5] Page 7-24, Pilot's Operating Handbook for the 1977 model 310R, published by Cessna Aircraft Company.

damaged circuit, serves as a source of further ignition for an electrical fire, and can potentially cause the circuit breaker to fuse closed, overriding its circuit protection.[6]

B. Configuration of Accident Aircraft:

Reproduced below are photographs taken before the accident showing the aircraft instrument panel (Figure 4.) and the circuit panel breaker (Figure 5).

Figure 4.
1. Radar Display Unit
2. Circuit Breaker Panel
3. Throttle quadrant

Figure 5.

III. OPERATION OF ACCIDENT AIRCRAFT ON JULY 9:

A. Deactivation of the Radar Display Unit:

On the day before the accident flight, July 9, 2007, another pilot operated the aircraft, flying it from Daytona Beach, Florida to Concord, North Carolina, returning to Daytona Beach that same day. The flight from Daytona Beach to Concord was uneventful. On the return flight, the pilot had some difficulty with the operation of the radar display. Approximately one hour into the flight, the radar screen went blank. The pilot "recycled" the radar display, turning it off with the intention of turning it back on again but, before he turned it back on, he noticed a smell that reminded him of a "burnt amplifier." There was no smoke, and the smell did not cause the pilot any discomfort or irritation. The pilot then left the display switched off and pulled the circuit breaker governing electrical power to the radar unit. Within two minutes, the odor dissipated. The pilot continued his flight back to Daytona Beach and during the remainder of the trip, lasting approximately one and one-half hours, the aircraft operated normally. Upon landing, he prepared a discrepancy notice advising of the radar display malfunction,

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[6] See Paragraph 6, Advisory Circular 25-16, Federal Aviation Administration, (April 15, 1991) below, in which it is recognized that "push-pull" circuit breakers are inadequate to protect the wiring in many instances.

which he prominently placed on the aircraft throttle quadrant, and further directly informed the operator's Chief Pilot and the Director of Maintenance of this discrepancy.[7]

The pilot's actions in this regard were consistent with the Federal Aviation Administration's advice contained in its publication "Airplane Flying Handbook," published for the education and guidance of pilots. Chapter 16 of that book advises a pilot, in the event of an electrical fire, to attempt to identify the faulty circuit by checking circuit breakers, instruments, avionics and lights," and to "detect and isolate" the faulty circuit.[8]

B. Documentation of Deactivation of Radar Display Consistent with 14 CFR 91.213:

The accident flight was operated under 14 CFR Part 91 of the Federal Aviation Regulations. Operation of this aircraft with the deactivated radar unit is allowed by 14 CFR Section 91.213(d). This regulation allowed operation of the accident aircraft with the deactivated radar display unit so long as:

(a) The display unit was "deactivated and placarded 'inoperative'"; and

(b) A determination is made by a pilot that the inoperative instrument or equipment does not constitute a hazard to the aircraft.

The regulation goes on to say that "an aircraft with inoperative instruments or equipment as provided in paragraph (d) of this section is considered to be in a properly altered condition acceptable to the Administrator."[9]

C. Deactivation and Placarding:

The pilot who flew the aircraft on July 9 deactivated the radar unit by both turning off the unit at its power switch and by deactivating electric current to the radar display unit, by pulling the circuit breaker which controlled electrical power to that unit. The manufacturer's design of the electrical switches and breaker panel facilitated this activity, allowing the deactivation of only the electrical supply to the radar.[10]

The purpose of "placarding," as required by the regulation, is to advise others using the aircraft of the fact that the equipment is inoperable and has been deactivated. The pilot deactivating the radar control unit accomplished this by filling out a discrepancy notice which he placed prominently on the throttle quadrant of the aircraft, which meant that the aircraft could not be operated without the accident pilots removing the notice from that location. The notice advised the accident pilots as follows:

> "Radar went blank during cruise flight, recycled – no response . . . smell of electrical components burning.

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[7] The discrepancy is discussed in detail in Section III.C. below.

[8] Federal Aviation Administration, US Department of Transportation, *Airplane Flying Handbook*, FAA-H-8083-38 (2004), p. 16-7.

[9] 14 CFR Section 91.213(d).

[10] See Section II.A. above. The circuit breaker pulled to deactivate the radar was in the bottom row of the circuit breaker panel shown in Figures 2., 3. and 4.

> Turned off unit – pulled radar C.B. [circuit breaker] – smell went away. – Radar inop [inoperative].

The throttle quadrant (see Figures 4. and 5.) contains the levers for the pilots to operate the aircraft engines, containing controls for the throttles, the fuel mixture, and the propeller pitch for each of those engines. The pilot logging the discrepancy physically placed the discrepancy notice on top of these levers, and it would have been impossible for the pilots on the accident flight to have started the aircraft or, indeed, to have flown it at all, unless they physically moved this discrepancy note. (See Figure 6. below)

Figure 6.
Showing position of discrepancy notice on throttle quadrant

Beyond this, the Chief Pilot of the operator personally telephoned the ATP accident pilot during the afternoon before the accident flight, to inform him of the problem that the previous pilot had experienced with the radar display unit.

D. Determination by Flight Crew that Flight Could Be Conducted Without Radar:

The accident flight took place in the early morning, during visual flight conditions, and was to be a short flight from Daytona Beach, Florida to Lakeland, Florida and return. The two pilots on board the accident aircraft determined that the flight could be conducted safely without the use of the deactivated radar. In fact, the ATP rated pilot occupying the aircraft at the time of the crash commented to an aircraft mechanic employed by the operator before embarking upon the flight that he would not need the radar for the flight. The flight was a short flight, conducted in visual conditions and without significant weather.[11]

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[11] Aircraft Technician Juan Solis, in his statement given to the Board investigator, continued that the ATP pilot told him before embarking that he knew about the radar discrepancy.

IV. THE SOURCE OF THE AIRCRAFT ELECTRICAL FIRE WAS NOT THE RADAR DISPLAY UNIT.

Radar data from the accident flight shows that its departure and climbout from DAB were normal and uneventful. Approximately ten minutes after takeoff, the crew reported to ATC that they were declaring an emergency because of "smoke in the cockpit." The radar data shows that approximately two minutes after this report the aircraft veered off course consistent with crew incapacitation by toxic fumes emitted from burning PVC electrical wiring.[12]

The only physical evidence of electrical malfunction or fire found in the post-crash investigation was a portion of an electrical wiring harness and connector, *which did not appear to be in any way associated with the radar display unit*. This wiring showed evidence of electrical arcing and melting, which indicated that it may have been the source of the electrical fire.[13]

A. General Description of the Radar Display Unit:

The radar display unit (depicted in the photographs of the aircraft instrument panel, Figures 4. and 5.), was manufactured by Bendix-King and bears manufacturer model number KI-244. Figure 7. below is a photograph of an exemplar unit, and is not the one installed in the accident aircraft.

Figure 7.
Exemplar Bendix-King radar display (left) and radar sensor (right)

Manufacturer's installation and maintenance manuals state that this unit operates at 28 volts, at a current of 3 amperes maximum. This means that the unit would draw a maximum of 84 watts of power; it does not draw significantly more power than an ordinary household light bulb.

Electrical power of the radar display unit is guarded by a circuit breaker with a rated capacity of 5 amperes. The expectation of the operator is that the breaker will trip, shutting off electrical power to the radar display unit, if the electrical current drawn by the unit and its associated wiring exceeds 5 amperes.

The pilot operating the aircraft on the day before the accident confirmed in his interview with Board investigators that following the radar display malfunction he deactivated that circuit by pulling the 5 ampere circuit breaker, thereby eliminating the delivery of electrical power to the radar display unit. Therefore, the radar display unit on the day of the accident had no source of electrical power and could not have been the source of the electrical fire.

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[12] Crew incapacitation is discussed in Section V.C. below.
[13] See discussion of this wiring harness and plug at Section IV.B. below.

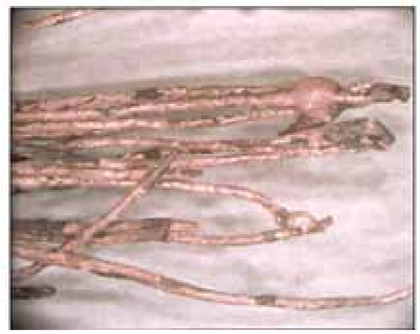
B. Beaded Wiring Found at the Accident Scene Involved in the Electrical Fire Was Not Related to the Radar Display Unit:

Following the crash, Board investigators examined all aircraft electrical wire and wire bundles for evidence of electrical arcing or damage. The only abnormally found was “beading” on the ends of several discrete pieces of wire, and extensive “beading” on the ends of a wire bundle wires with a plug connector on its end. This connector was of a type which would have been installed by the manufacturer as part of the original wiring to the aircraft’s nav/com radios.[14]

Figure 8. is a photograph of the burned wiring harness. Figure 9. is a photograph showing the beading and strand fusing on the wire ends of that harness.[15]

Figure 8.
Burned wiring harness

Figure 9.
Showing beading and strand fusing



Beading of wire ends is considered to be consistent with the wire end being close to the ignition point of the electrical fire, as beading typically only occurs close to the source of the fire, in conditions of low oxygen. Strand fusing means that the individual strands, which are typically braided together to make a wire, are fused together by heat.[16]

The manufacturer’s representative confirmed that this connector plug and wiring was of a type that would have been installed as part of the original wiring of the aircraft.[17] According to the manufacturer, the connector was a Winchester or Amp connector, part number 200-512-2 and in an original installation, would connect to the back of the nav/com (navigation/communication) radio rack. This rack is not where the radar display unit was mounted.

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[14] Page 2, Fire Group Field Notes. The connector was identified by the manufacturer’s representative as a Winchester or AMP connector part number 200-512-2 and, in a standard Cessna installation, would be plugged into the back of the nav/com radio rack. See Sept. 25, 2007 email of manufacturer representative Jan Smith, Cessna Airplane Company, to Board Investigator Michael Huhn.

[15] These photographs were taken in connection with the Board’s Materials Laboratory examination of the failed electrical wiring.

[16] Fire Group Field Notes, page 2, footnotes 1 and 2.

[17] September 25, 2007 email of Jan Smith, Cessna Airplane Company to Board Investigator Michael Huhn.

C. Soot Accumulation on Cockpit Interior Components was Inconsistent with Involvement of the Radar Display Unit as the Source of the Electrical Fire:

While most of the aircraft wreckage was consumed in the post-crash fire, portions of the aircraft interior fell free of that fire, were unaffected by that fire, and were available for examination. The most significant of these was a sheet metal panel which served as the airplane's glareshield, being mounted just under the windshield and just over the radios, serving as the top of the instrument panel.[18] Figures 10 and 11 are photographs of that glareshield panel. A photograph of the instrument panel is also included as Figure 13. for convenient comparison. The sheet metal panel shown in Figures 10., 11. and 12. would have wrapped around the top of the instrument panel shown in Figure 13, just behind the vinyl glareshield eyebrow apparent in that photograph. The vinyl glareshield eyebrow was also essentially undamaged by fire.

Figure 10.–Underside of glareshield panel (left)

Figure 11.-Underside of glareshield panel (right)

Figure 12.-Underside of glareshield panel and eyebrow

Figure 13 →
Aircraft instrument panel photograph for comparison

It will be noted from a comparison of Figures 10., 11. and 12. with Figure 13 that the radar display unit is mounted just below the center of this glareshield panel; therefore, any burning or malfunction in the area of that radar display unit would have deposited sooting on the glareshield panel, just above that unit. There is no such

[18] This panel has been identified as Cessna part number 0813678-1, called "Panel Assembly – Deck Skin."

sooting. The panel does contain soot deposits, but these are primarily on the left of the glareshield panel, and are consistent with burning other than from the radar display unit. It is consistent with burning near where the engine instruments are installed.[19] The cabin door, which would have been located at the right-hand (co-pilot's) seat, was also undamaged by fire. See Figure 14 below. Investigators noted black clumped residue at the midpoint of the door and below, indicating deposits from the cabin electrical fire. (Figure 15.) Although these deposits have not yet been analyzed by the Board, they visually appear to be a similar material to the sooting deposits on the glareshield panel shown in Figures 10., 11. and 12. No such deposits were found near the radar display either on the metal glareshield panel or on the vinyl glareshield eyebrow.

Figure 14.
Cabin door

Figure 15.
Deposits on cabin door

V. ELECTRICAL WIRING ISSUES:

A. Certification Requirements:

This aircraft was certificated under CAR (Civil Air Regulations), Part 3. Regarding the electrical system, this regulation mandates the following:

1. "Electrical systems in airplanes shall be free from hazards in themselves, in their method of operation, and in their effects on other parts of the airplane." (Section 3.681);

2. "If electrical equipment is installed, a master switch arrangement shall be provided which will disconnect all sources of electrical power from the main distribution system at a point adjacent to the power sources." (Section 3.688);

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[19] Following the crash, the Board was contacted by another aircraft operator who advised that he had experienced an electrical fire "behind the ammeter" in his similar model aircraft. This is a location that corresponds well with the sooting patterns shown on the glareshield sheet metal panel.

3. A section entitled "Protective Devices" mandates that "if electrical equipment is installed, protective devices (fuses or circuit breakers) shall be installed in the circuits to all electrical equipment, except that such items need not be installed in the main circuits of starter motors or in other circuits where no hazard is presented by their omission." (Section 3.690).

4. With regard to electrical wiring, the regulation provides that "the connecting cables used shall be in accordance with recognized standards for electric cable of a *slow burning type* and of suitable capacity." (Section 3.693) (emphasis added).

B. PVC Wiring Installed in the Aircraft as Part of its Original Wiring Was Not the Required "Slow Burning Wire":

CAR Part 3 under which this aircraft was type certificated requires all electrical wiring to be of a "slow burning type." At the time this regulation was adopted in the 1940's, "slow burning wire" was long accepted as a term of art, referring to wire which was treated with fire resistant materials so as to be not flammable.[20]

C. Composition of Aircraft Wiring Insulation Contributed to Crew Incapacitation:

The wire installed in the aircraft upon its manufacture was insulated with a PVC (polyvinyl chloride) material, rather than being of a "slow burning type," as required by the regulations applicable to the certification of this airplane. This insulation material is flammable and burns readily, creating copious amounts of thick, toxic smoke, rendering it virtually impossible for pilots to see their flight instruments or to breathe.[21] Similar wire was used in both airline and military aircraft of similar age to the accident aircraft. Government and Industry studies have documented the deterioration of this wire insulation material with age, as well as the propensity for the deteriorated wiring to become susceptible to electrical fires and consequent crew incapacitation.[22] These studies include the analysis of similar wiring in decommissioned airline aircraft (ex.: the

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[20] *See, e.g.,* Cook, A., *Interior Wiring and Systems for Electric Light and Power Service*, John Wiley & Sons (1917); Horstman, H and Tousley, V., *Modern Electrical Construction*, p. 181, Frederick J. Drake & Co. ("slow burning wire has a covering specifically designed to withstand heat or fire . . ."); §556, New Code of Ordinances of the City of New York (1922) (requiring "slow burning wire" to have an insulation impregnated with fireproofing compound or material having "equivalent fire-resisting properties"); §21, Ordinances Relating to Buildings, City of Seattle (1910) (same definition as New York Code).

[21] *See, Section VI.B.* below*,* Seher, Chris and Smith, Federal Aviation Administration*, Managing the Aging Aircraft Problem*, paper presented to the AVT Symposium on Aging Mechanisms and Control and the Specialists Meeting on Life Management Techniques for Aging Air Vehicles, Manchester, England, October 8, 2001; Bai, T., Brenson, C. Car, S., Mason, T., Nunalee, F., Ramanathan, T., Shull, K., Departments of Mechanical Engineering and Material Science and Engineering, Northwestern University, *Aging Characterization of Polymeric Insulation in Aircraft Wiring*, paper presented at the proceedings of the Second Joint Annual COE [Centers of Excellence] Meeting, Federal Aviation Administration, Wichita, Kansas October, 2002.

[22] The Federal Aviation Administration is conducting research into this area under its Continued Airworthiness/Aging Aircraft Program, AAR-400 (See http://AIR400.TC.FAA.Gov\Programs\AgingAircraft\).

FAA's "Transport Aircraft Intrusive Inspection Project"). These inspections have documented numerous age-related wiring failures in PVC wiring in retired air transport aircraft of similar age.[23] The military has made similar findings with regard to the wiring in its older aircraft.[24]

Unfortunately, this information was not shared with the owners and operators of general aviation aircraft including the accident aircraft. Although the average general aviation aircraft is of similar age to the accident aircraft (manufactured in 1977), information regarding deterioration of PVC wiring installed in general aviation aircraft, as well as the hazardous nature of this deterioration, has not been communicated to owners and maintainers. While the manufacturer's maintenance manual of the accident aircraft generally advises the maintainer to "check wiring" as a part of the aircraft's annual inspection, deterioration of aircraft wiring insulation leading to electrical fires cannot usually be discovered through visual inspection:

> Aircraft were designed to be inspected visually, but certification testing and service experience often results in specific directed inspections. The requirements for these directed inspections may be established at the aircraft's time of introduction to service (as a certification maintenance requirement), but more likely are the result of service experience. As the aircraft ages, these inspections become increasingly more problematic. Inaccessible areas, multiple failure modes, and unique structure all complicate the inspection.
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> Seher, *supra*. at 4. *See also* Collins, *infra,* at page 5.

The Federal Aviation Administration, in its Advisory Circular AC25-16, recognized that wiring with PVC insulation does not meet the flammability standards for transport aircraft type certificated after May 1, 1972.[25] General aviation aircraft such as the accident aircraft have the same type of wiring, carrying the same current, as similar wiring in transport category aircraft. This wiring in general aviation aircraft is subject to the same deterioration as in transport aircraft and that deterioration exposes occupants to the same hazards of fire and incapacitating fumes and smoke.

Despite these similar hazards, owners and operators of general aviation aircraft have not been warned of what has been well documented in military and transport aircraft. These flaws and deterioration are not apparent upon visual inspection. Since the electrical fire started at a point remote from the radar display unit, it would seem that

[23] *See* Seher, *Managing the Aging Aircraft Problem*, at Chapter 6. The statistics published in this chapter show that PVC insulated wiring has a higher incidence of failure than that of types of wire with different materials used later by manufacturers.

[24] *See, e.g.,* Collins, Jerome, Manager, Wiring Systems Branch, Naval Air Systems, *The Challenges facing U.S. Navy Aircraft Electrical Wiring Systems* (paper presented to the Ninth Joint FAA/DOD/NASA Aging Aircraft Conference).

[25] "Certain types of insulation, including polyvinyl chloride (PVC) insulation, do not comply with the §25.1359(d) flammability requirements." AC 25-16, paragraph 5a.

the flaws in the aircraft wiring harness which gave rise to the electrical fire would not have been apparent upon visual inspection of that radar display's wiring.[26]

D. Circuit Protection/Master Switch:

Immediately after reporting smoke in the cockpit, the flight crew followed accepted procedures by turning off the electrical master switch and alternator switches. In their last transmission to ATC the accident pilots advised that they were "shutting off all radios and electrical." Immediately thereafter, secondary radar returns disappeared. These actions *should* have removed electrical power from *all* of the aircraft wiring. The fact that the fire continued to burn shows that either the circuit protection installed by the aircraft manufacturer did not operate as designed, or that flammable materials, including electrical insulation on the aircraft, continued to burn after electrical power was removed thereby becoming a self sustaining fire. Failure of the master switch and protective devices to remove electricity from the aircraft wiring would establish that the design did not comply with CAR Section 3.688 or Section 3.690. Burning of the flammable PVC wiring insulation after electrical power was removed would show that the wiring did not meet the certification requirements of CAR Section 3.693.

The Federal Aviation Administration in its Advisory Circular AC25-16 (April 5, 1991) has noted that:

> "Historically, the FAA criterion for circuit protective device (e.g. circuit breaker or fuse) selection can simply be expressed as: 'to protect the aircraft wiring but not the equipment. This limited criterion is based on designing electrical components to be as fire-resistant as practicable and either enclosing them in metal cases that will contain an internal fire or are sufficiently airtight that internal ignition sources cannot cause a fire, or isolating them from flammable materials and safety-related parts."
>
> AC25-16, Paragraph 6, Federal Aviation Administration (April 15, 1991).

However, in making this observation, the Administration noted that field experience had shown that:

> "Protecting electrical system installations by using CPD [circuit protective devices] to protect wiring and through component design to protect the rest of the system is not adequate. Circuit protection devices (circuit breakers and fuses) are considered to be slow-acting devices and may not offer sufficient disconnect protection from events such as arc tracking or insulation flashover.

[26] Despite an aggressive inspection and maintenance program, the US Navy, from the years 1995 to 2002, experienced a total of 31 aircraft mishaps attributed to aircraft electrical wire system failures. Collins, *supra* at page 4.

> AC 25-16, paragraph 26, Federal Aviation Administration (April 15, 1991) (emphasis in original).

This was felt by the Administration to be because traditional circuit breakers would not react appropriately to some over-voltage events that were prone to ignite wiring.[27]

VI. CREW INCAPACITATION:

A. Radar Track and Witness Evidence of Incapacitation:

During the accident flight, the aircraft was crewed by two qualified certificated and current pilots. Upon being confronted with the emergency posed by the electrical fire, the crew acted appropriately in immediately declaring an emergency and asking for a diversion to the nearest airport, SFB. At the time the emergency was declared the aircraft was approximately seven miles from SFB. Radar data shows that immediately after the crew declared the emergency, the aircraft made a left turn, from a southwesterly heading to a southeasterly heading, and the radar ground track shows the aircraft proceeding from that point directly toward SFB for landing. During the descent and the approach to SFB, the aircraft ground speed, as shown by analysis of the radar data, was 180 knots.[28] At a ground speed of 180 knots, the aircraft, at the time it made its turn to divert to SFB, would have been only a little more than two and one-half minutes from reaching the airport.

Figure 3b of the Board's aircraft performance radar study is included with this submission as Figure 16. This figure shows that the crew, immediately after declaring the emergency and announcing their diversion to SFB, began tracking a direct course to SFB (which shows precise navigation and situational awareness), and proceeded as expected until approximately one minute before they would have reached that airport. At that point, the aircraft entered a severe bank to the right (estimated at approximately 70 degrees)[29] and turned more than 90 degrees to the right (estimated turn of approximately 96 degrees) to crash in the subdivision. Witnesses saw the wings of the aircraft "seesawing" back and forth.[30] The aircraft crashed at a high rate of speed, with the gear stowed and the flaps up. The turn away from the airport, the extreme bank, and the right turn beyond 90 degrees indicates that the aircraft was not under the control of the cockpit crew during this short period before the crash. The investigative

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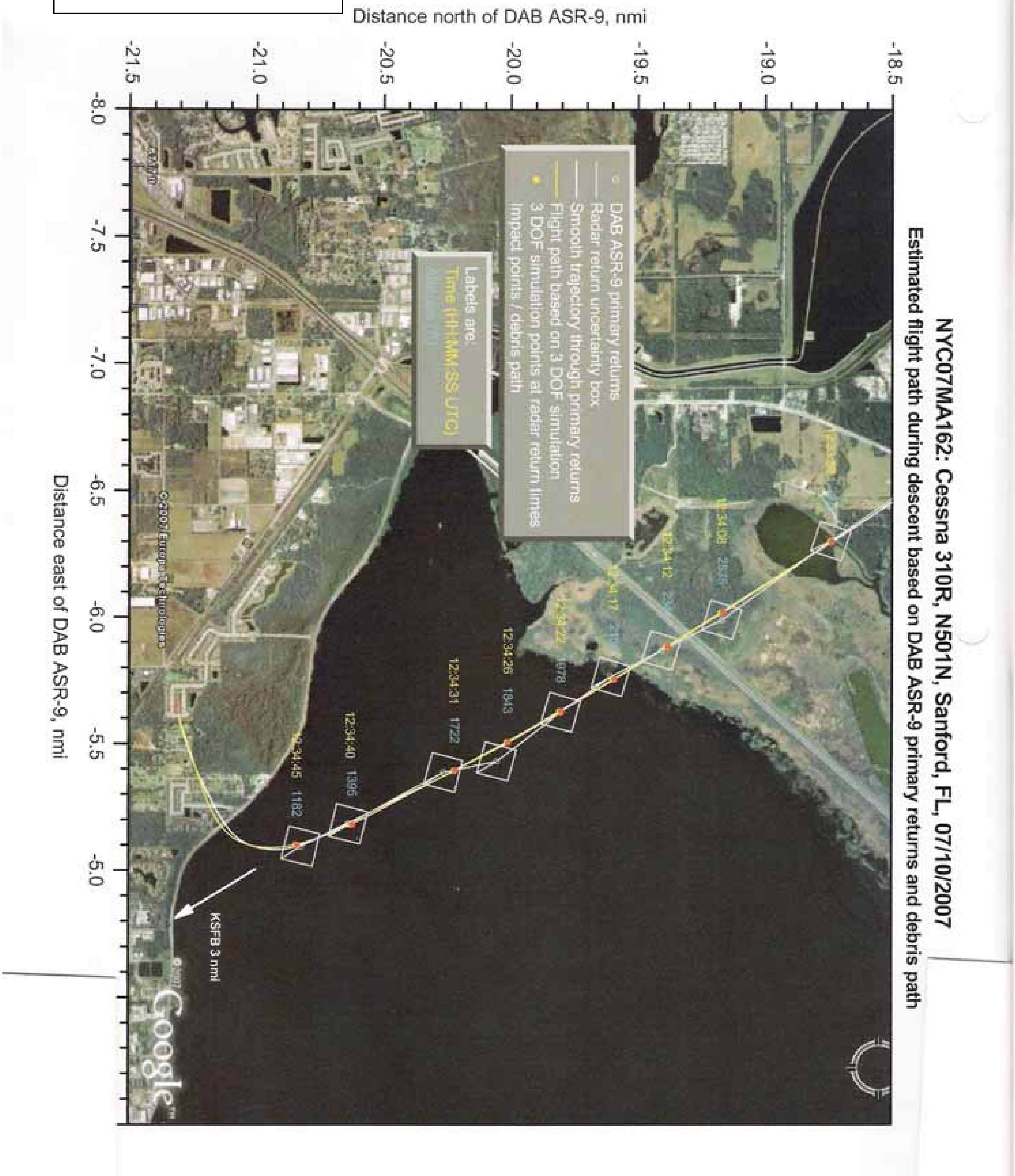
[27] AC25-16, Paragraph 6., Federal Aviation Administration: Section "Circuit Protection Device (CPD) Information."

[28] These tracks and speeds are taken from the Board investigators' December 20, 2007 "Aircraft Performance Radar Study" authored by John O'Callaghan, National Resources Specialist – Aircraft Performance, Office of Research and Engineering.

[29] The conclusion of the Aircraft Performance Radar Study was that the aircraft would have had to have banked approximately 68 degrees to make its final right turn. Eyewitness Kunzer, who observed this turn, described it as a "hard bank, about 70 degrees." See July 11, 2007 summary of Kunzer statement.

[30] Witness Kunzer said the "wings were rocking." July 11, 2007 summary of Kunzer statement. Witness Black said that the aircraft was "teeter tottering." July 16, 2007 email from witness Black to Investigator Brian Rayner. Witness Rocklein described the "wings wagging." July 4, 2007 Witness Hotline synopsis, National Transportation Safety Board.

Figure 16.
(Figure 3b. of Board's aircraft performance radar study)



facts showed that an electrical fire occurred behind the electrical equipment in the forward cockpit area. This suggests that the crew was impaired by smoke or fumes in the cockpit. This incapacitation from burning electrical insulation (polyvinyl chloride) is caused by the release of hydrogen chloride and other smoke products that are strong sensory and pulmonary irritants that will force the pilot(s) to keep their eyes closed and/or prevent respiration.

B. Toxic Effects of Burning of PVC Wire Insulation:

Hydrogen chloride (HCI) is the principal product released during the combustion of poly(vinylchloride). It is classified as a sensory and pulmonary irritant. Because the HCI is released at a relatively low temperature, it will be present in the early stages of the fire. Toxicity studies on smoke from PVC used a variety of animals and animal models in an effort to try to understand the effects of irritants on human performance or incapacitation. The animal studies range from rodents to non-human primates. These studies have been reviewed in an effort to elucidate the incapacitating effects of fires involving poly(vinylchloride).[31] The non-human primate studies[32] were not very definitive because the animals were able to perform the escape paradigm with their eyes closed. This is a normal (and involuntary) human response to exposure to a strong irritant. Everyone has experienced this phenomena during exposure from a typical wood ("bon") fire. Obviously, one cannot control an aircraft with their eyes closed. One can conclude from these studies that the smoke from the electrical fire on board the fatal flight caused the crew to lose control of the aircraft. The evidence developed during the investigation showed the flight diverted from its planned trajectory to the airport totally unconfigured for a landing. It can be only concluded that the crew was unable to control the aircraft due to incapacitation during the final moments of flight from the smoke of burning electrical insulation.

Toxicological tests on the crew did not reveal any evidence of carbon monoxide or sooting in the lungs or trachea which would have been a clear indication of incapacitation due to smoke inhalation. However, the autopsy on the pilot in the left seat showed "mild edema" on the cut surface of the lung tissue. This is consistent with the inhalation of a strong irritant such as HCI. The short time span between the initial report of the emergency and the crash (approximately three minutes) suggests that the crew were incapacitated by the irritant properties of HCI combustion byproduct from the burning PVC wire insulation that interfered with vision as the initial incapacitating effects leading to the loss of control of the aircraft in the final few seconds of flight.

C. Crew Attempt to Evacuate Smoke/Fumes by Opening Cabin Door:

The aircraft cabin door was found separated from the main aircraft wreckage and was undamaged by fire. (See Figure 14 and Section IV.C. above) When closed, the door is latched in place by pins which insert into the aircraft door frame. These pins are latched and unlatched by handles on both the interior and exterior of the door. These latching pins appear undamaged, and the door appears to have been torn from the

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[31] M.M. Birky, *Toxicity and Incapacitation due to Hydrogen Chloride, Fire and Materials*, Vol. 18, 125-132 (1986).

[32] H.L. Kaplan, A. F. Grand, W.R. Rogers, W. G. Switzer and G. E. Hartzell, *A research study of the assessment of escape impairment by irritant combustion gases in postcrash aircraft fires*. DOT/FAA/CT-84/16, September (1984).

airframe at its hinges. This suggests that the crew unlatched and partially opened the cabin door after declaring an emergency, to aid in evacuating smoke and fumes from the cockpit. This is further evidenced by deposits of soot that trail along the lower half of the cabin door, with no corresponding deposits on the upper half of the door, consistent with smoke being drawn from the cabin, past the open door, in flight.[33]

The cabin door is located on the right (co-pilot's) side of the airplane. Opening this door in flight would create drag on the right side of the airplane, which, if uncorrected, would cause a tendency for the aircraft to turn and bank to the right. The crew could, and did, override this right-turning tendency by use of the flight controls, primarily by use of the rudder and ailerons. However, once the crew was incapacitated by the smoke and fumes, they were no longer able to override the airplane's right-turning tendency, and the aircraft rolled and turned to the right, as seen by the ground witnesses, and as exhibited by the analysis of the radar data.

VII: CONCLUSION:

The probable cause of this incident was an electrical fire which began within three and four minutes before the aircraft crash. Evidence collected during the accident investigation shows that this fire ignited in electrical wiring which would have been installed behind the aircraft instrument panel by the aircraft manufacturer upon original manufacture of the aircraft in 1977. The crew reacted appropriately to this fire, by using the aircraft master electrical switch and alternator switches to remove electrical power from the aircraft electrical system, by immediately declaring an emergency, and by immediately diverting to an airport approximately three minutes away for landing.

However, approximately two to three minutes after the fire began, and only about one minute from reaching their alternate airport, the crew was incapacitated by toxic fumes from the burning electrical wiring. These fumes continued to collect in the aircraft cockpit, because the electrical fire continued to burn after the crew had positioned the master electrical switches and alternator switches to shut down all electrical power. This fire continued because the insulation on the burning wire did not meet certification standards; because the electrical circuit protection devices installed by the manufacturer did not act appropriately to arrest the electrical current which was causing the fire; or because of a combination of these factors.

The fumes and smoke emitted by the burning wiring contained hydrogen chloride (HCl), which is a highly toxic sensory and pulmonary irritant. The crew attempted to evacuate the fumes from the cabin through opening the cabin door, without success. These fumes interfered with the crew's ability to control the aircraft to the planned diversionary landing, and ultimately incapacitated the crew approximately one minute before they landed at the airport. If the aircraft wiring had been of the "slow burning" type required by regulation, or if the fumes from the burning insulation had been less toxic, the crew would likely have been able to complete the diversion and land the aircraft before being overcome by the fumes and smoke.

[33] See discussion of cabin door at Section IV.C. above.