Manufacturer's perspective

Developing tools and techniques to support major investigations

Tutorial by
Albert Urdiroz / Accident Investigator

AIRBUS

Content

- Introduction
- AC data other than flight data recordings
- ACARS transmissions
- Engineering analyses
- Integration simulators
- Conclusion

Introduction

- Aircraft manufacturers have a number of tools and techniques available to support major investigations
- In line with modern aircraft design, airframe investigation tools continue to develop
- We would like in this tutorial to describe these developments and where they can benefit investigations
- However we would also like to explain where the limitations exist

Content

- Introduction
- AC data other than flight data recordings
- ACARS transmissions
- Engineering analyses
- Integration simulators
- Conclusion

NVM Non Volatile Memories

- DFDR & CVR are designed to support accident investigation
  - Data protected
  - Indicate what happened
  - After analysis, why it happened

- Some additional records are designed to support maintenance
  - Data not protected
  - Indicates what monitoring triggered
  - After analysis, how to fix the system

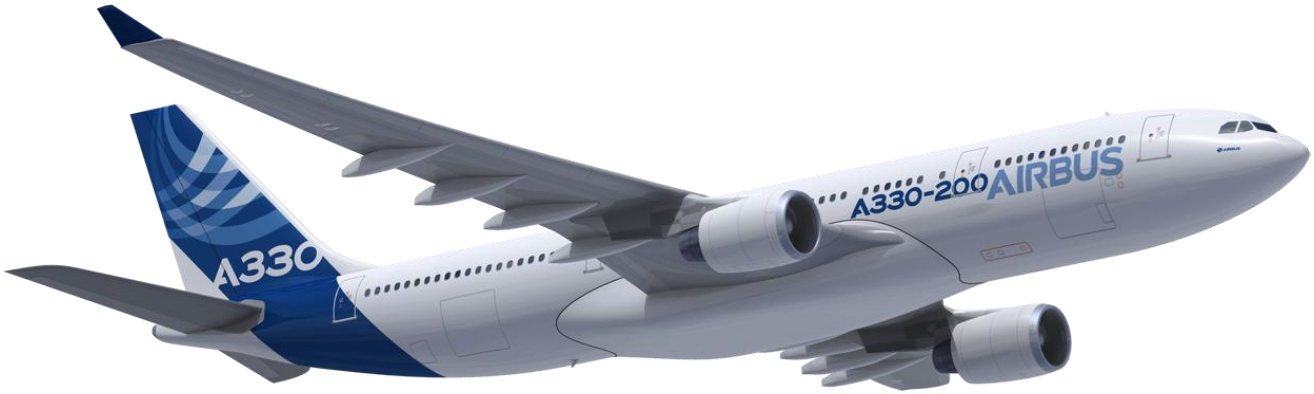
UTC	PH	ATA	WARNING		
1220	05	303100	ANTI ICE F/O TAT		
1358	06	270000	MAINTENANCE STATUS F/CTL		
1407	06	340000	ADR 2		
UTC	PH	ATA	FAULT MESSAGE	SOURCE	IDENT
1210	02	341234	ADIRU2 (1FP2)	ADR 2	EIS 2,AFS
1210	02	228212	MCDU3(3CA3)/ATSU1(1TX1)	ACARSMU	
1211	02	324234	NO BSCU 1 DATA (INTM)	CFDS	
1220	05	303134	NO PHC2 DATA	CFDS	
1358	06	279434	SEC2 OR BUS 2 FROM ADR2	EFCS 2	EFCS 1
1359	06	341234	AFS: ADIRU1/2/3 DISAGREE	AFS	
1359	06	279434	SEC3 OR BUS 2 FROM ADR3	EFCS 2	EFCS 1
1404	06	341234	AFS: ADIRU2	AFS	
1407	06	341117	ADM2 (19FP2)	ADR 2	

- Maintenance data may complement but not replace accident recorders

NVM onboard modern aircraft

Flight data analysis recorders
e.g. DAR, QAR, SAR

Computers BITE



Components
FAULT codes

Centralized Maintenance System
e.g. PFR Post Flight Report
LLR Last Legs Report

NVM onboard modern aircraft – BITE's

NVM onboard modern aircraft – A380 ANSU

- Aircraft Network Server Unit
  - 2 units for redundancy
  - Each unit stores
    - Aircraft Condition Monitoring System
    - Centralized Maintenance System
    - Data Loading & Configuration System
    - e-Logbook

NVM onboard modern aircraft – A380 ANSU

Centralized Maintenance System

Post Flight Reports history
- Last 64 legs stored

Fault messages history
- Flight Deck & Cabin Effects

System Test history

Data Loading & Configuration System

A/C configuration history

A/C software repository content

e-logbook

Pilot and maintenance inputs

Data transmitted to the ground

Aircraft Condition Monitoring System

Reports
- Contain “parameter digests” recorded or calculated according to pre-defined logics
- Typically transmitted per ACARS

SAR Files
- Time-continuous recording of parameters around pre-defined events
- High capacity (amount of parameters, rate)

Virtual QAR / DAR
- Copy of the QAR / DAR Frames

NVM onboard modern aircraft – A380 ANSU

CPT

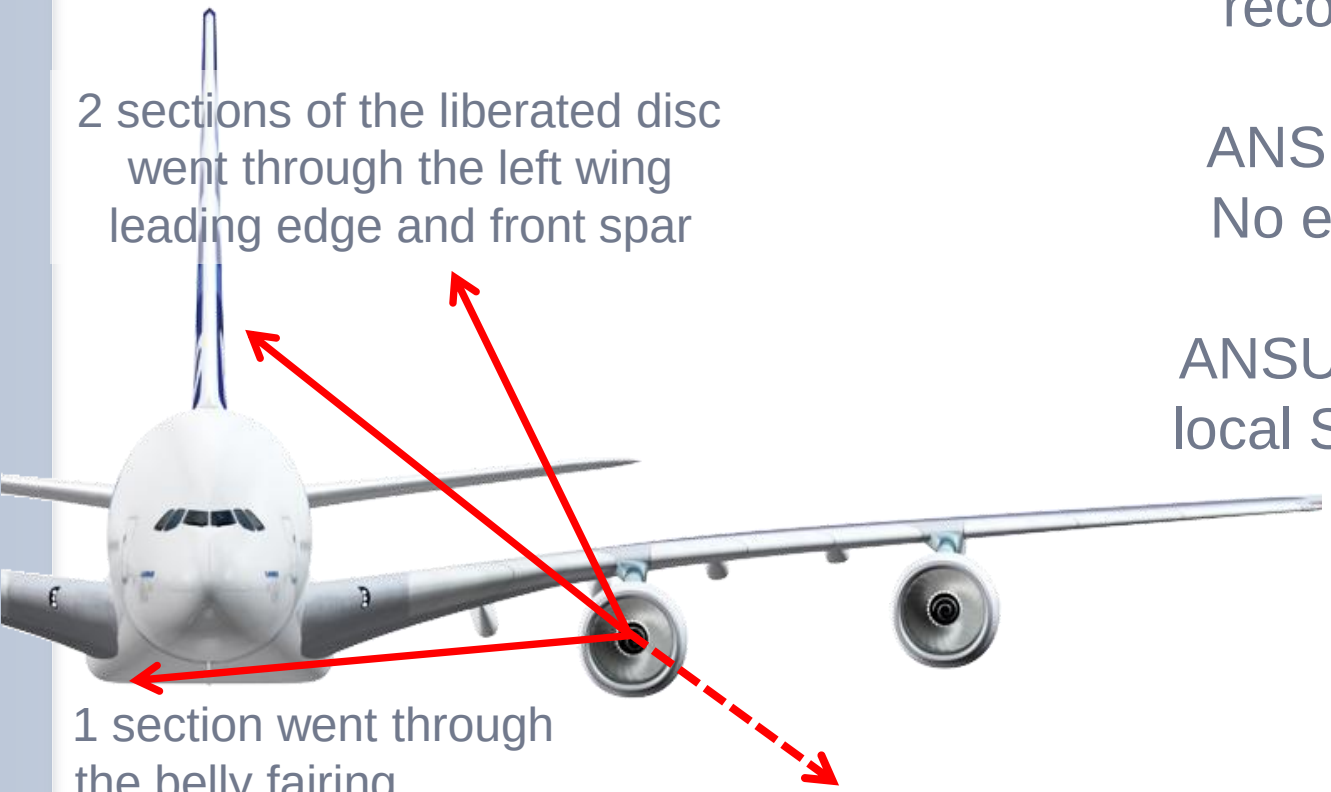
backup

F/O

NVM onboard modern aircraft – A380 ANSU

- Each ANSU stores about 10GB of data
- Interfaces allow smart recovery
  - The data you need
- In case the system cannot be powered, ANSU removal can be considered to perform export on ground
  - Hard disk image
- In order to ensure preserving evidences
  - Only at SAGEM shop facilities in France or Singapore
  - Never install an ANSU on another aircraft to recover data
- Hard disk image had to be recovered in Singapore

Case study – Flight QF32



2 sections of the liberated disc went through the left wing leading edge and front spar

1 section went through the belly fairing

1 additional section was found on ground

Not all failure conditions recorded in DFDR

⇓

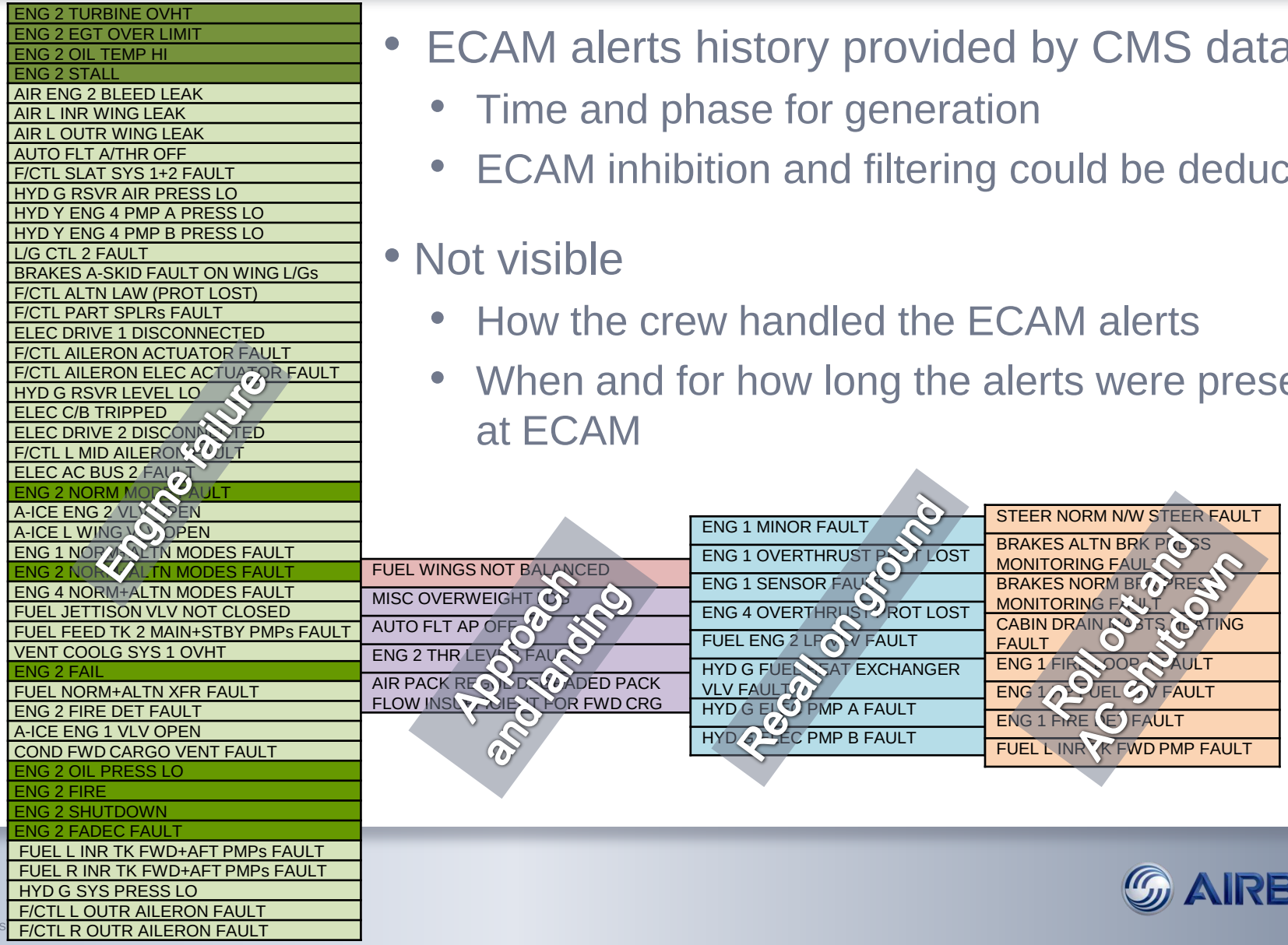
ANSU data needed
No electrical power

⇓

ANSU downloaded at local SAGEM facilities

Case study – QF32 ECAM review

- ECAM alerts history provided by CMS data
  - Time and phase for generation
  - ECAM inhibition and filtering could be deduced
- Not visible
  - How the crew handled the ECAM alerts
  - When and for how long the alerts were present at ECAM



Case study – QF32 ECAM review

CMS download

⇓

Data did not allow to recreate the exact ECAM sequence

Data allowed to better identify cockpit effects

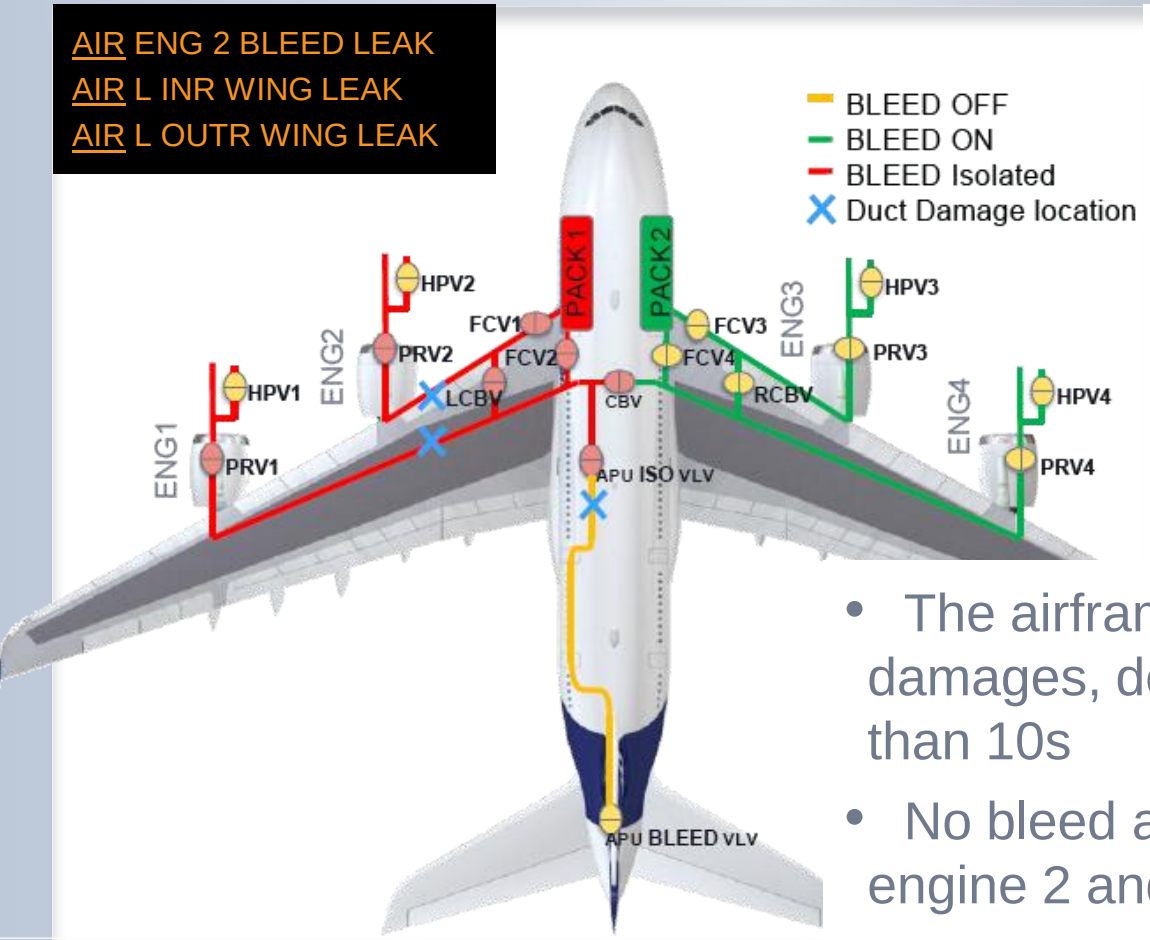
Data allowed to review the ECAM behavior

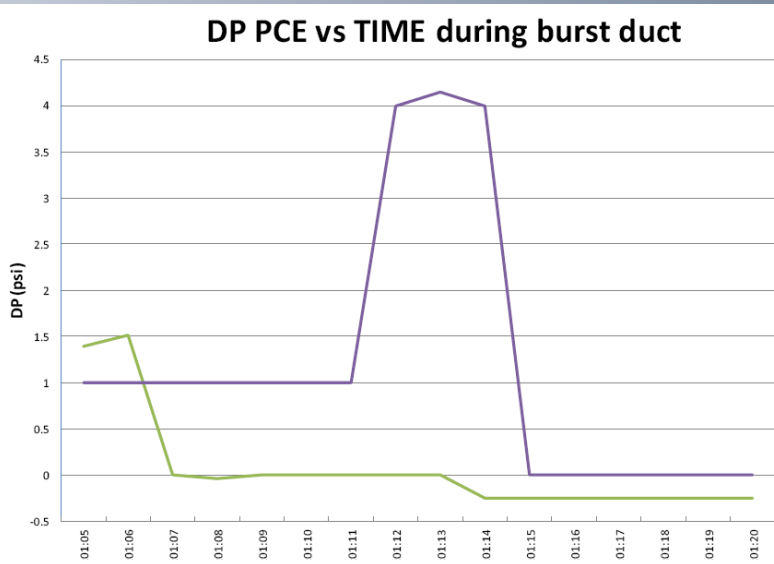
Data allowed to better understand the crew workload

ANSU provided valuable information in complement to accident recorders

Case study – QF32 systems review - Bleed

AIR ENG 2 BLEED LEAK
AIR L INR WING LEAK
AIR L OUTR WING LEAK





- The airframe experience 3 ducting damages, detected and isolated within less than 10s
- No bleed air leakage was experienced at engine 2 and APU bleed systems
- A leakage flow was experienced at engine 1 bleed system, for less than 4s

Case study – QF32 systems review - Wheels

	ACID	ACTYP	ENG	REP	CODE	FMT	CNT	DATE	UTC	FP
H01	.VH-OQA	A380-800	RR	208	2081	82	00308	04.NOV.10	03:49:05	12

	FROM TO	FLT	SW	AI-DB	DATABASE	MOD
H02		----------	S0385	S0385	AWC110909A	00.XXX.00

H03 REASON: Snapshot of brake temperatures for phase 12

BRAKE TEMPERATURE FOR WHEEL 1 to 16

BRTEMP.1	BRTEMP.2	BRTEMP.3	BRTEMP.4
31	32	350	530
BRTEMP.5	BRTEMP.6	BRTEMP.7	BRTEMP.8
40	37	534	523
BRTEMP.9	BRTEMP.10	BRTEMP.11	BRTEMP.12
831	1000	469	421
BRTEMP.13	BRTEMP.14	BRTEMP.15	BRTEMP.16
858	831	547	448

TAT : 28.9

Brake temperature report

- Snapshot generated upon last engine master lever switched off
- No tires burst during the landing roll
- The fuse plug melt and LH BLG tires deflated after the aircraft came to a stop

Case study – QF32 systems review

Aircraft Condition Monitoring System
data download
⇓

Data allowed to more accurately document systems response

Data allowed to review the systems statuses versus the airframe damage

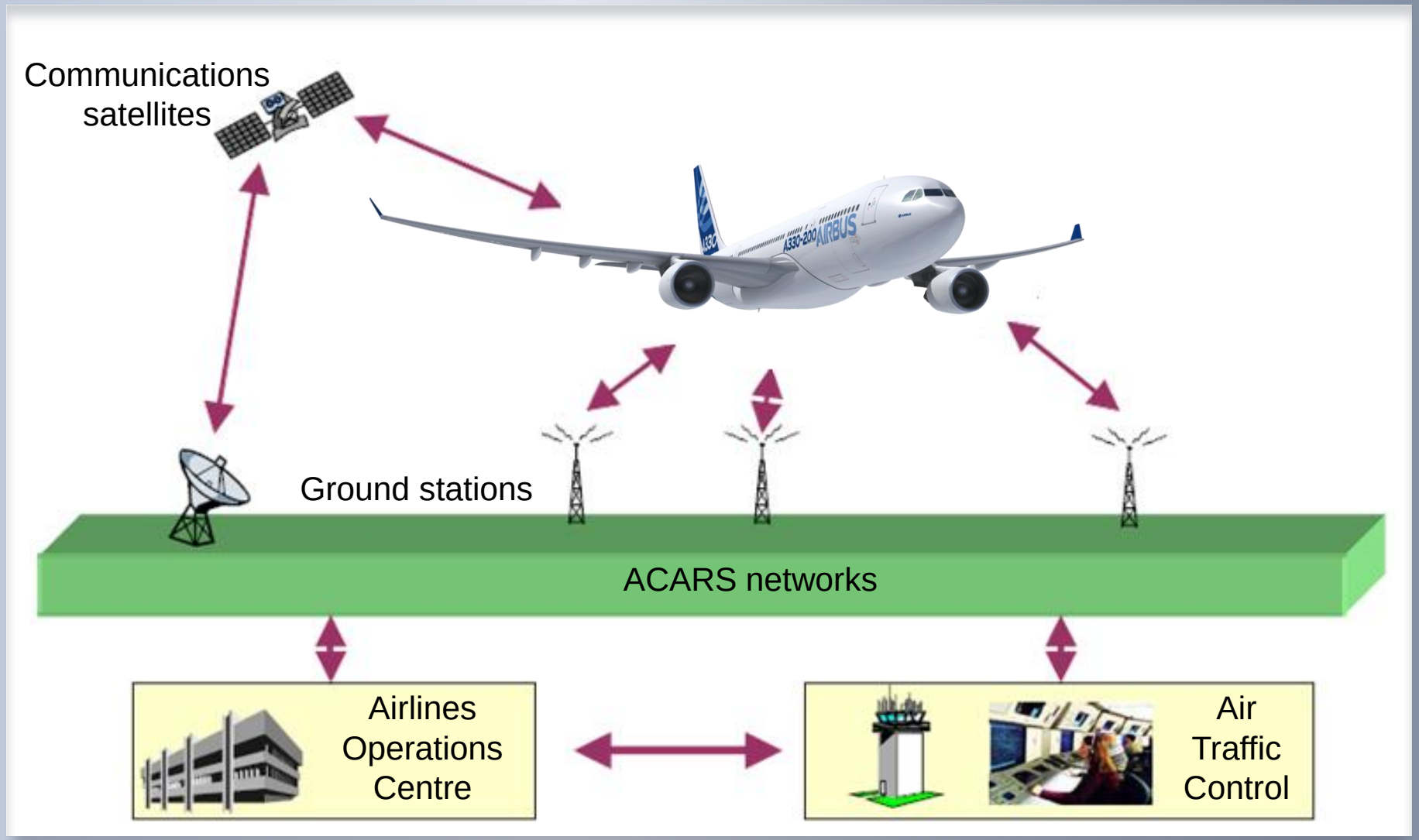
Data allowed to establish consistency with crew report

ANSU provided valuable information in complement to accident recorders

Content

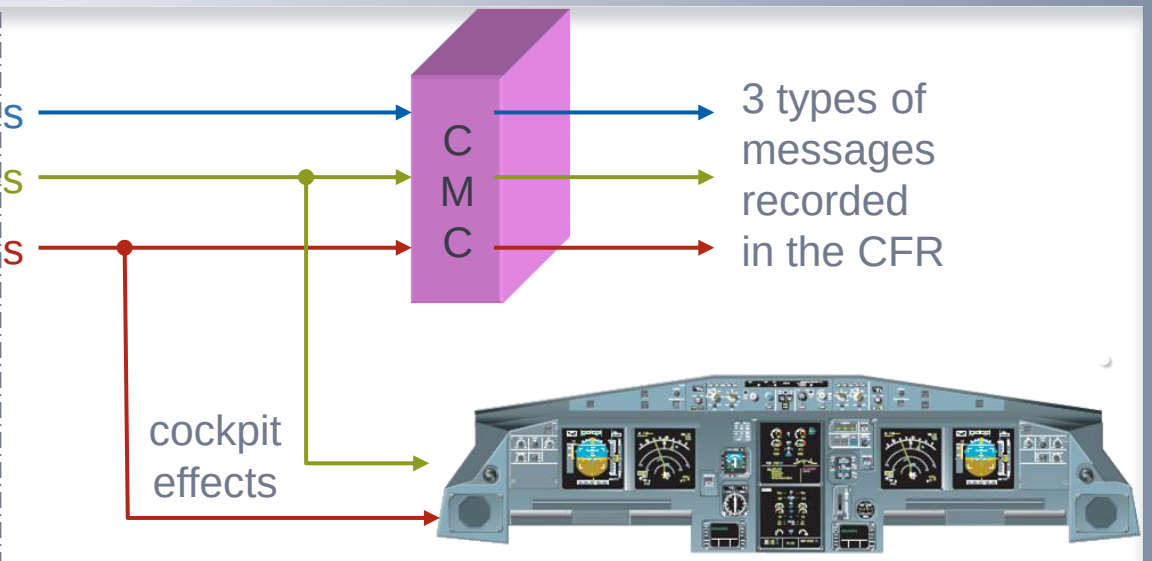
- Introduction
- AC data other than flight data recordings
- ACARS transmissions
- Engineering analyses
- Integration simulators
- Conclusion

ACARS transmissions



ACARS – Current Flight Report

Each aircraft system performs internal and peripheral monitoring



- CFR is the sum of cockpit effects and maintenance messages in real-time
  - Only maintenance related warnings
    - E.g. not stall warning, not overspeed
  - Not all flags and advisories
  - Date stamp is per minute

CMC: Central Maintenance Computer
ECAM: Electronic Centralized Aircraft Monitoring

ACARS – Current Flight Report

ATA _ _ _ _ _ _ _ _ cockpit effect _ _	TIME Flight Phase	

- ECAM warnings
  - 10ms acquisition rate
  - Warnings processed immediately and transmitted to ACARS
  - Order of ECAM warning messages corresponds to order of reception by the CMC as transmitted by the FWC
- Flags and advisories
  - About 3s confirmation for being processed and transmitted to ACARS

ACARS – Current Flight Report

	TIME Flight Phase	ATA _ _ _ _ _ _ Source _ _ _ _ _ Class 1 / 2 HARD / INTERMITTENT Ident _ _ _ _ , _ _ _ _ (6 max) _ _ _ _ _ _ _ _ Maintenance message _ _ _ _ _ _ _ _

- Maintenance messages
  - Acquired from the various BITE systems
  - 50ms to 250ms processing time
  - Upon occurrence
    - Opening a 1 minute correlation window
    - Redoing a complete scanning
- Transmission to ACARS within 1s after closure of the correlation window

Case study – Flight AF447 ACARS CFR

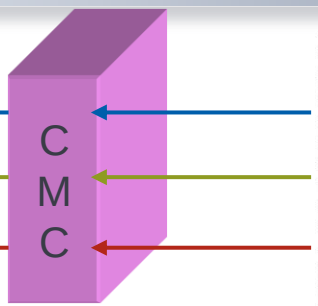
ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10	Maintenance messages Flags / Advisories ECAM Warnings			
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	PROBE PITOT 1+2/2+3/1+3 (9DA)	EFCS2	EFCS1, AFS	class 1
27		2:10	FCPC2(2CE2)/WRG:ADIRU1 BUS ADR1-2 TO FCPC2	*EFCS1	*EFCS2	class 2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	ISIS (22FN-10FC) SPEED OR MACH FUNCTION	ISIS		class 1
34		2:11	ADIRU2 (1FP2)	IR2	*EFCS1, IR1, IR3	class 1
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

Case study – Flight AF447 ACARS CFR

Maintenance messages

Flags / Advisories

ECAM Warnings



ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	PROBE PITOT 1+2/2+3/1+3 (SDA)	EFCS2	EFCS1, AFS	class 1
27		2:10	FCPC2(2CE2)WRG:ADIRU1 BUS ADR1+2 TO FCPC2	*EFCS1	*EFCS2	class 2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	ISIS (22FN-10FC) SPEED OR MACH FUNCTION	ISIS		class 1
34		2:11	ADIRU2 (1FP2)	IR2	*EFCS1, IR1, IR3	class 1
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

cockpit effects

Reverse engineering to investigate the initiating conditions

- Triggering logics
  - Threshold & confirmation time
- Processing time
  - From triggering to ACARS transmission
- Timing of occurrence
- Correlations between systems
- Priorities

Case study – Flight AF447 ACARS CFR

ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10	4 airspeed snapshots			
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	PROBE PITOT 1+2/2+3/1+3 (9DA)	EFCS2	EFCS1, AFS	class 1
27		2:10	FCPC2(2CE2)/WRG:ADIRU1 BUS ADR1-2 TO FCPC2	*EFCS1	*EFCS2	class 2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	ISIS (22FN-10FC) SPEED OR MACH FUNCTION	ISIS		class 1
34		2:11	ADIRU2 (1FP2)	IR2	*EFCS1, IR1, IR3	class 1
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

Case study – Flight AF447 ACARS CFR

ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	PROBE PITOT 1+2/2+3/1+3 (9DA)	EFCS2	EFCS1, AFS	class 1
27		2:10	FCPC2(2CE2)/WRG:ADIRU1 BUS ADR1-2 TO FCPC2	*EFCS1	*EFCS2	class 2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	ISIS (22FN-10FC) SPEED OR MACH FUNCTION	ISIS		class 1
34		2:11	ADIRU2 (1FP2)	IR2	*EFCS1, IR1, IR3	class 1
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

Sudden measured airspeed decrease on at least 2 of 3 systems
- Consistent with pitot icing

Case study – Flight AF447 ACARS CFR

ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	3 measured airspeeds at low value - Possibly pitot icing - Possibly the aircraft at low speed			
27		2:10				
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	ISIS (22FN-10FC) SPEED OR MACH FUNCTION	ISIS		class 1
34		2:11	ADIRU2 (1FP2)	IR2	*EFCS1, IR1, IR3	class 1
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

Case study – Flight AF447 ACARS CFR

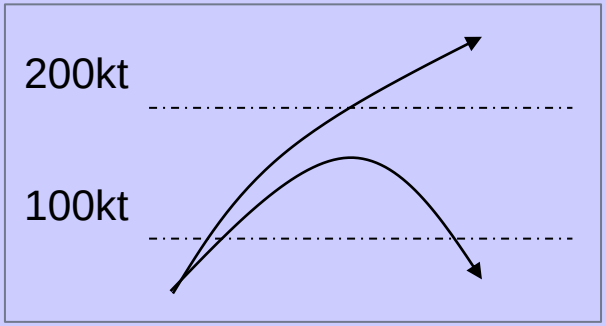
ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10				
27		2:10				
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	ISIS (22FN-10FC) SPEED OR MACH FUNCTION	ISIS		class 1
34		2:11	ADIRU2 (1FP2)	IR2	*EFCS1, IR1, IR3	class 1
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

3 measured airspeeds discrepant
- Possibly thawing
- Possibly airflow disturbance at air data sensors at high angle of attack

Case study – Flight AF447 ACARS CFR

ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10				1
27		2:10				2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11				1
34		2:11				1
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

Airspeed evolution ≈100kt



- Likely the real aircraft speed

Case study – Flight AF447 ACARS CFR

ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	PROBE PITOT 1+2/2+3/1+3 (9DA)	EFCS2	EFCS1, AFS	class 1
27		2:10	FCPC2(2CE2)/WRG:ADIRU1 BUS ADR1-2 TO FCPC2	*EFCS1	*EFCS2	class 2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	ISIS (22FN-10FC) SPEED OR MACH FUNCTION	ISIS		class 1
34		2:11				
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

Flight controls computers set OFF or reset

Case study – Flight AF447 ACARS CFR

ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	PROBE PITOT 1+2/2+3/1+3 (9DA)	EFCS2	EFCS1, AFS	class 1
27		2:10	FCPC2(2CE2)/WRG:ADIRU1 BUS ADR1-2 TO FCPC2	*EFCS1	*EFCS2	class 2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11				
34		2:11				
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13				
21	ADVISORY CABIN VERTICAL SPEED	2:14				

Cabin vertical rate higher than 1800ft/min

- If positive → Cabin leakage
- If negative → High rate of descent

Case study – Flight AF447 ACARS CFR

ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	PROBE PITOT 1+2/2+3/1+3 (9DA)	EFCS2	EFCS1, AFS	class 1
27		2:10	FCPC2(2CE2)/WRG:ADIRU1 BUS ADR1-2 TO FCPC2	*EFCS1	*EFCS2	class 2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	ISIS (22FN-10FC) SPEED OR MACH FUNCTION	ISIS		class 1
34		2:11	ADIRU2 (1FP2)	IR2	*EFCS1, IR1, IR3	class 1
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

Case study – Flight AF447 ACARS CFR

- With AF447 ACARS CFR we could confirm
  - 4 airspeed snapshots but
    - The measured airspeed, not necessarily the aircraft airspeed
    - Snapshots, but no time history
    - No connections established between events
    - No indication on crew response to ECAM messages
  - 2 F/CTL computers OFF, possibly reset
    - Sole crew action recorded
  - High cabin rate, either positive or negative

34		FCS1, IR1, IR3	class 1
27	F/CTL PRIM 1 FAU		
27	F/CTL SEC 1 FAUL		
34	MAINTENANCE ST		
22			class 1
21	ADVISORY CABIN		

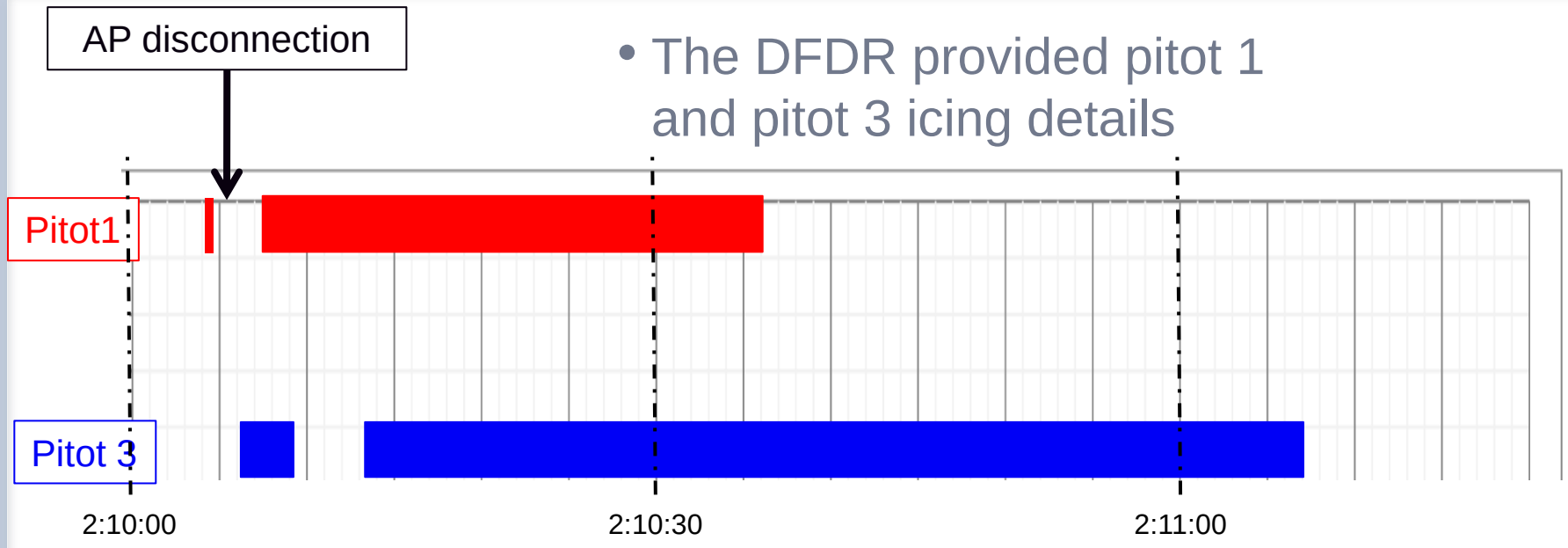
⇒ Incomplete picture

⇒ Not the accident sequence

⇒ Not the accident scenario

AF447 accident recorders recovery - DFDR

Case study – Flight AF447 DFDR



- The DFDR provided pitot 1 and pitot 3 icing details

CAS 1&3 recorded

Pitot 1 icing

Pitot 3 icing

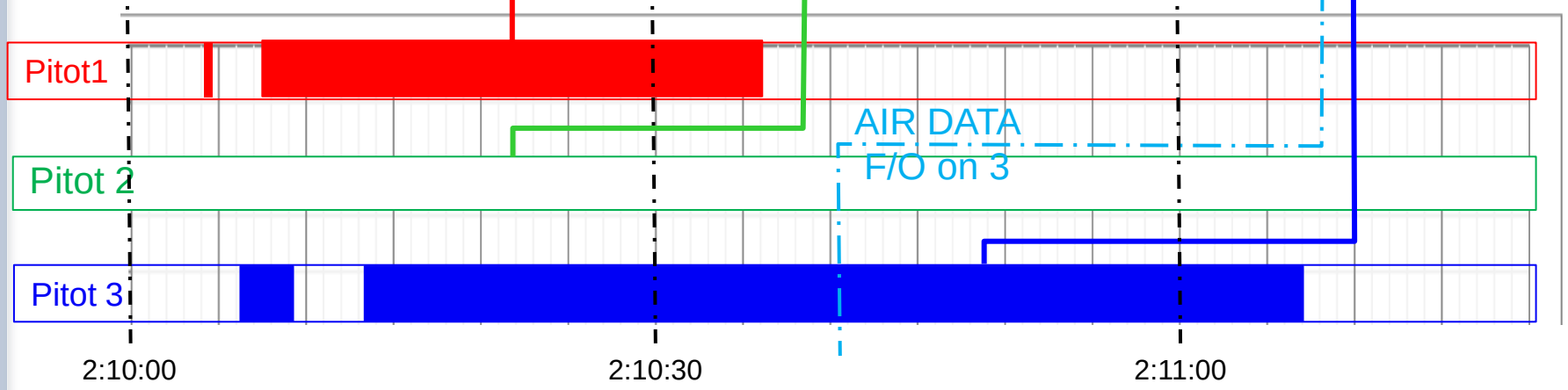
No icing

- System 2 airspeed not recorded

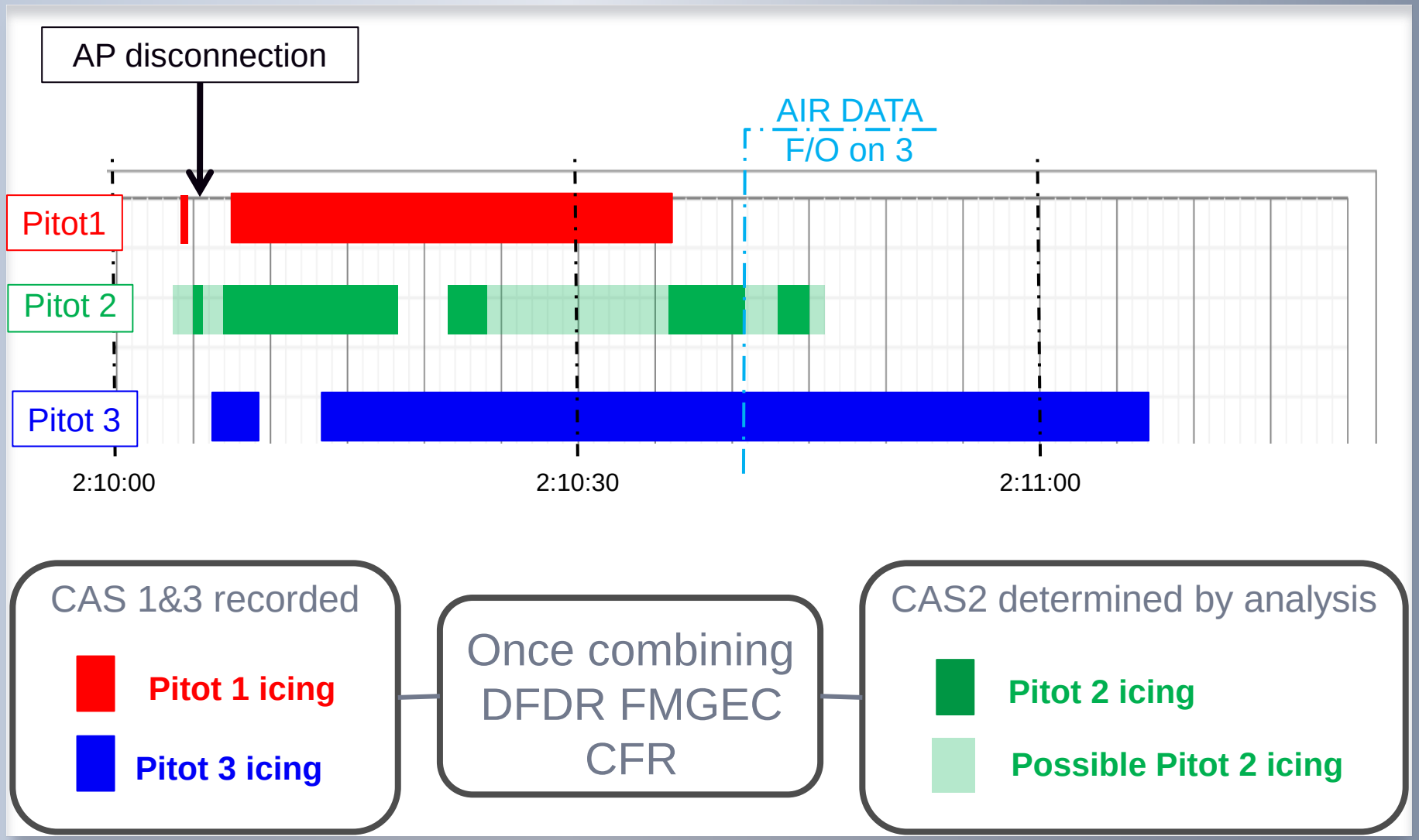
  ⇒ System review versus DFDR, FMGEC BITE, and previous ACARS analysis

Case study - Flight AF447 airspeed displays

- One of the objectives was to determine the airspeed at F/O display



Case study – AF447 Combined data review



Case study – AF447 Combined data review

ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	PROBE PITOT 1+2/2+3/1+3 (9DA)	EFCS2	EFCS1, AFS	class 1
27		2:10	FCPC2(2CE2)/WRG:ADIRU1 BUS	*EFCS1	*EFCS2	class 2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	MACH FUNCTION			
34		2:11				
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13				
21	ADVISORY CABIN VERTICAL SPEED	2:14				

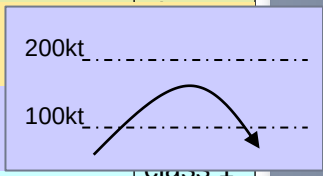
1st airspeed event:
- 3 pitots icing
- Not the same icing profile

2nd airspeed event: Stall, low speed

3rd airspeed event: Stall, airflow disturbed

Manual F/CTL computers reset

4th airspeed event: Stall



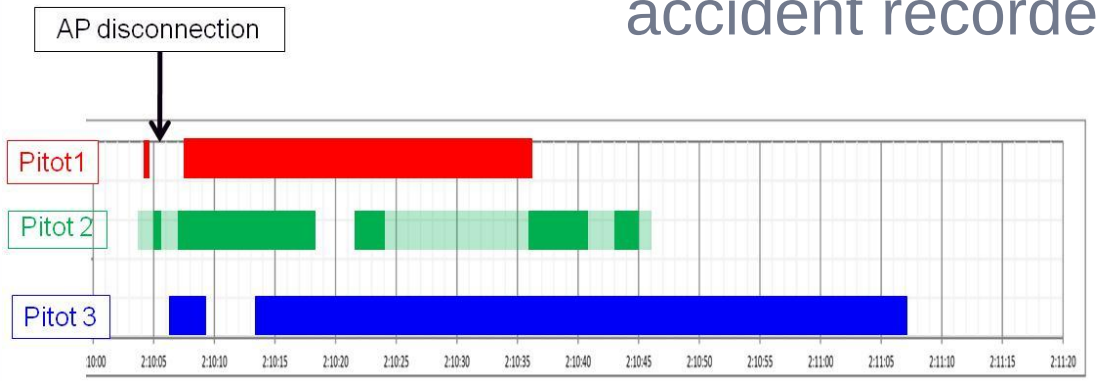
Cabin rate: Stall, high rate of descent

Case study – AF447 Combined data review

ATA	Cockpit Effect	Time	Fault Message	Source	Identifier	Class
22	AUTO FLT AP OFF	2:10				
22	AUTO FLT REAC W/S DET FAULT	2:10				
27	F/CTL ALTN LAW	2:10				
22	FLAG ON CAPT PFD SPD LIMIT	2:10				
22	FLAG ON F/O PFD SPD LIMIT	2:10				
22	AUTO FLT A/THR OFF	2:10				
34	NAV TCAS FAULT	2:10				
22	FLAG ON CAPT PFD FD	2:10				
22	FLAG ON F/O PFD FD	2:10				
27	F/CTL RUD TRV LIM FAULT	2:10				
27	MAINTENANCE STATUS EFCS2	2:10				
27	MAINTENANCE STATUS EFCS1	2:10				
34		2:10	PROBE PITOT 1+2/2+3/1+3 (9DA)	EFCS2	EFCS1, AFS	class 1
27		2:10	FCPC2(2CE2)/WRG:ADIRU1 BUS ADR1-2 TO FCPC2	*EFCS1	*EFCS2	class 2
34	FLAG ON CAPT PFD FPV	2:11				
34	FLAG ON F/O PFD FPV	2:11				
34	NAV ADR DISAGREE	2:12				
34		2:11	ISIS (22FN-10FC) SPEED OR MACH FUNCTION	ISIS		class 1
34		2:11	ADIRU2 (1FP2)	IR2	*EFCS1, IR1, IR3	class 1
27	F/CTL PRIM 1 FAULT	2:13				
27	F/CTL SEC 1 FAULT	2:13				
34	MAINTENANCE STATUS ADR 2	2:14				
22		2:13	FMGEC1(1CA1)	AFS		class 1
21	ADVISORY CABIN VERTICAL SPEED	2:14				

- One Airbus investigator leading the ACARS analysis for 6 months
- Support from experts for each involved system

Recovery of accident recorders



- Equivalent effort

Case study – AF447 Combined data review

- ACARS provided a snapshot of triggered system faults during the event
- ACARS data did not provide an accident scenario
  - Not a complete time history but snapshots as monitoring triggered
  - No flight parameters
  - No configuration warnings
  - No information on crew actions, except F/CTL computers reset
- Once combined with accident recorders, ACARS data provided additional understanding on the event

Content

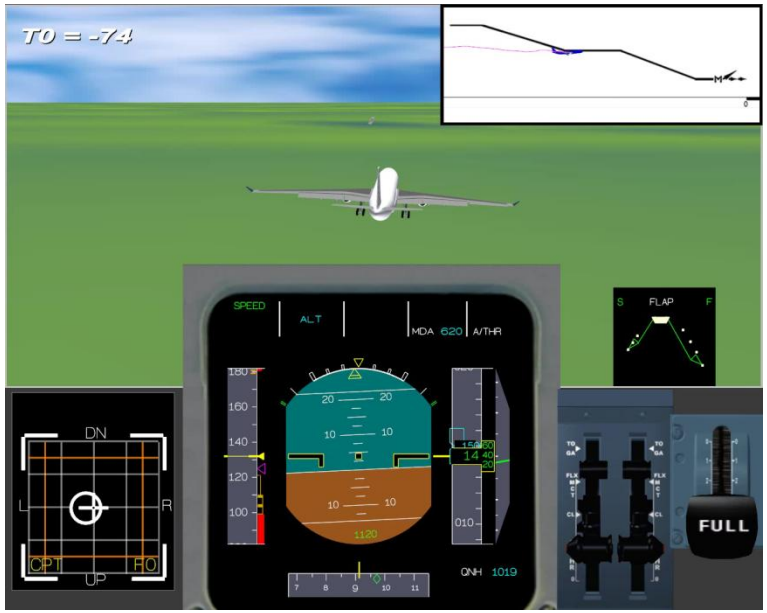
- Introduction
- AC data other than flight data recordings
- ACARS transmissions
- Engineering analyses
- Integration simulators
- Conclusion

Examples of engineering analyses

- Systems
  - Reconfigurations
  - Cockpit alerts
  - Displays
- Performance
  - In flight
  - At take-off and landing
- Handling qualities
  - Response to inputs
  - Response to environment
- Structure
  - Loads
  - Aeroelastics
- With the design details and the aircraft model, the manufacturer is best placed
  - To review the aircraft response as recorded
  - To investigate alternate scenarios
- The model is certified – It has been calibrated with flight tests

Examples of engineering analyses

- High acceleration go-around
  - Review AC response to crew inputs
  - Review audio alerts and warnings sequence
  - Recompute Primary Flight Display indications

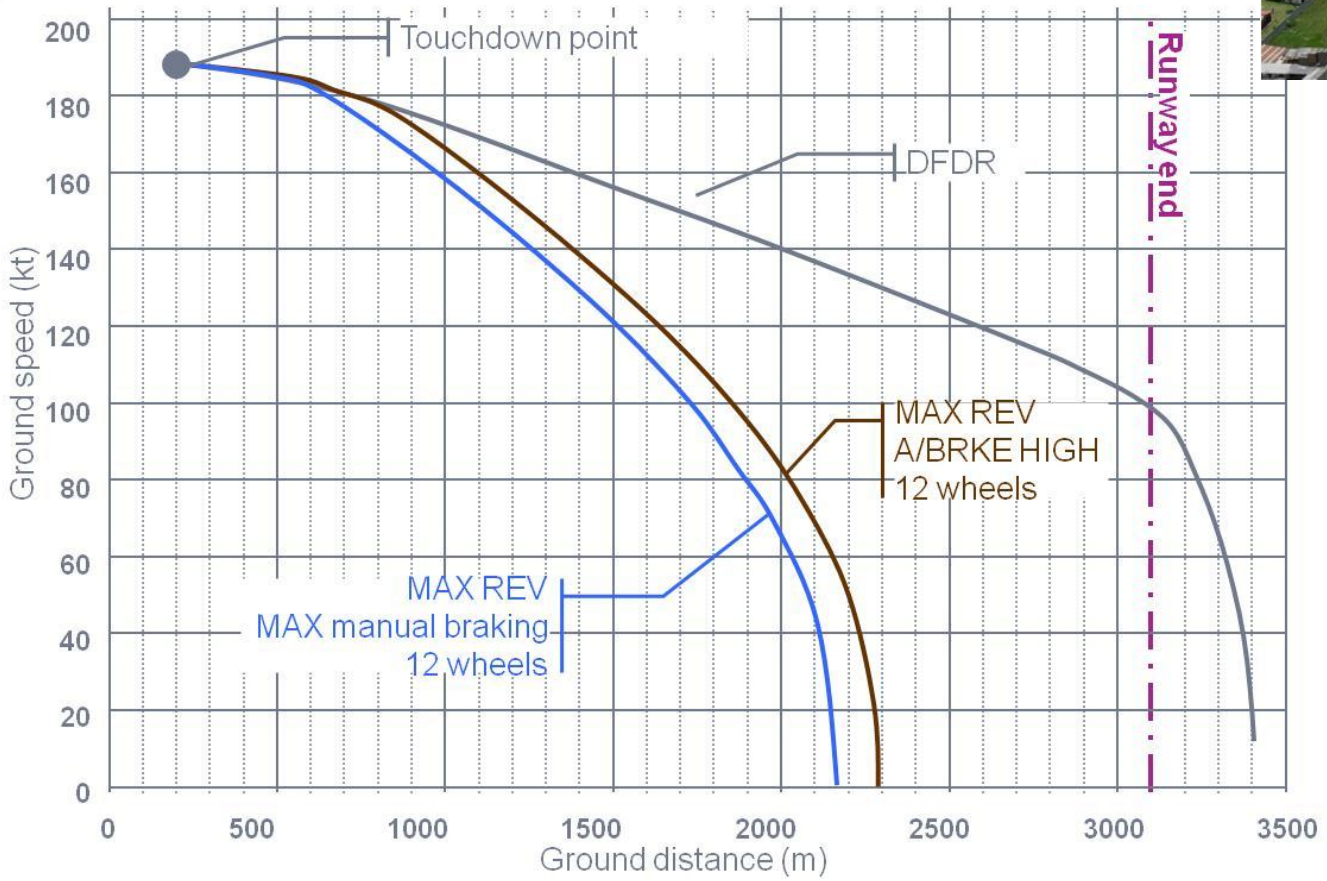


Examples of engineering analyses

- Wake vortex
  - Review AC response to crew inputs
  - Compare with natural aircraft stability
    - Alternate scenario no crew inputs

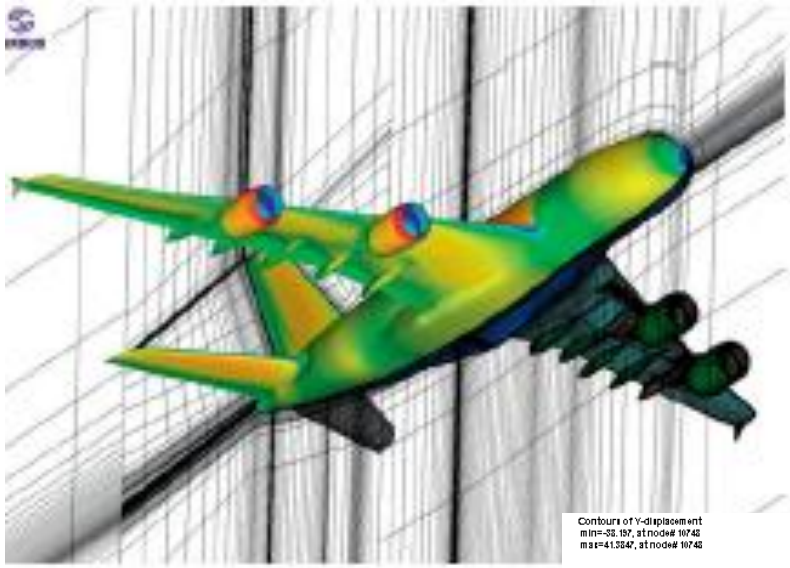
Examples of engineering analyses

- Runway overrun
  - Review landing performance scenarios

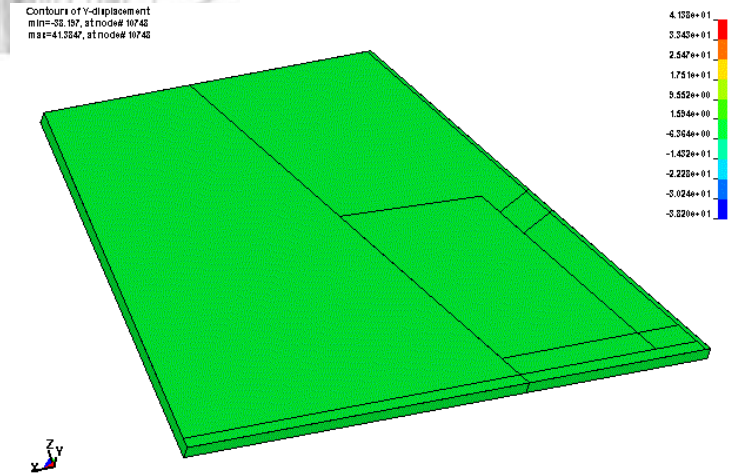


Examples of engineering analyses

- Structure
  - Aeroelastics



- Simulation of damage propagation



Content

- Introduction
- AC data other than flight data recordings
- ACARS transmissions
- Engineering analyses
- Integration simulators
- Conclusion

Integrations simulators – The iron bird

- Allows investigating complex scenarios that cannot be simulated with FFS
- Allows accurately reproducing some failure modes down to the components

AC systems either simulated or real

Integration simulators pro's

- Simulators can be configured with all systems relevant to the accident aircraft
- The terrain and FMS database can be loaded
- Combination of real cockpit, simulation units and iron bird offers a large panoply of tests configurations
  - Introduce complex failure modes
  - Consider numerous alternate scenarios
- Simulators have high-performance recording of parameters
  - Test acquisition units and DFDR
- There are seats for observers
- Fixed-Base simulator
  - No biased perceptions

Case studies

- US1549
  - Limitations in representing the aircraft and the environment
- High acceleration go-around
  - Accurate environment and aircraft representativity
  - Limitations in perceptions
- QF32
  - Complex failure modes

Case study – Flight US1549

- Simulator sessions were considered for investigation and training but limitations were faced
  - Environment
    - No simulator can recreate accurate visual references
  - Aircraft response
    - The aircraft model is certified and validated against flight data
    - No aircraft was flown in this configuration
      - Alpha max
      - CONF 2
      - Gear UP
      - All engines shutdown
      - Ground effect

Case study – High acceleration go-around

- Terrain database
- FMS database
- Exact systems configuration
  - Flight controls, auto-flight, terrain avoidance warning, powerplant…
  - Same PN as on accident aircraft
  - No failure condition introduced
- No spatial illusion

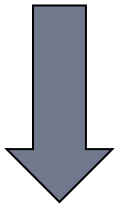
→ Fixed base simulator

} Event investigated on integration simulator not connected to iron bird

- Note: 2nd session done on a FFS
  - No added value as for the sequence of events and the AC response
  - Less environment and aircraft representativity
  - Motion = perceptions biased

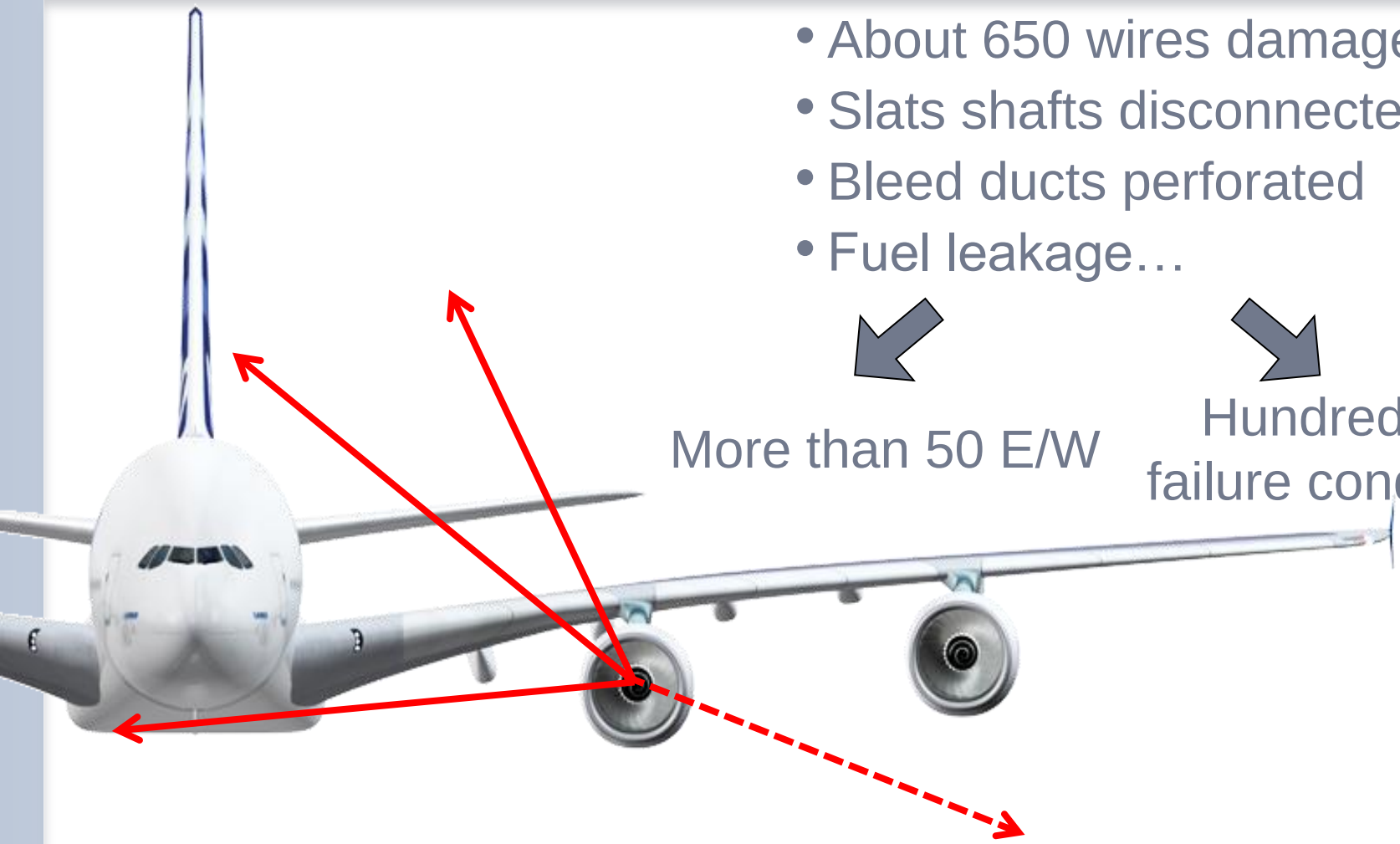
Case study - The QF32 brain teaser

- Investigation board request
  - Assess handling qualities
  - Review ECAM sequence



How can we replicate the damage?

The QF32 brain teaser



- About 650 wires damage
- Slats shafts disconnected
- Bleed ducts perforated
- Fuel leakage…

More than 50 E/W

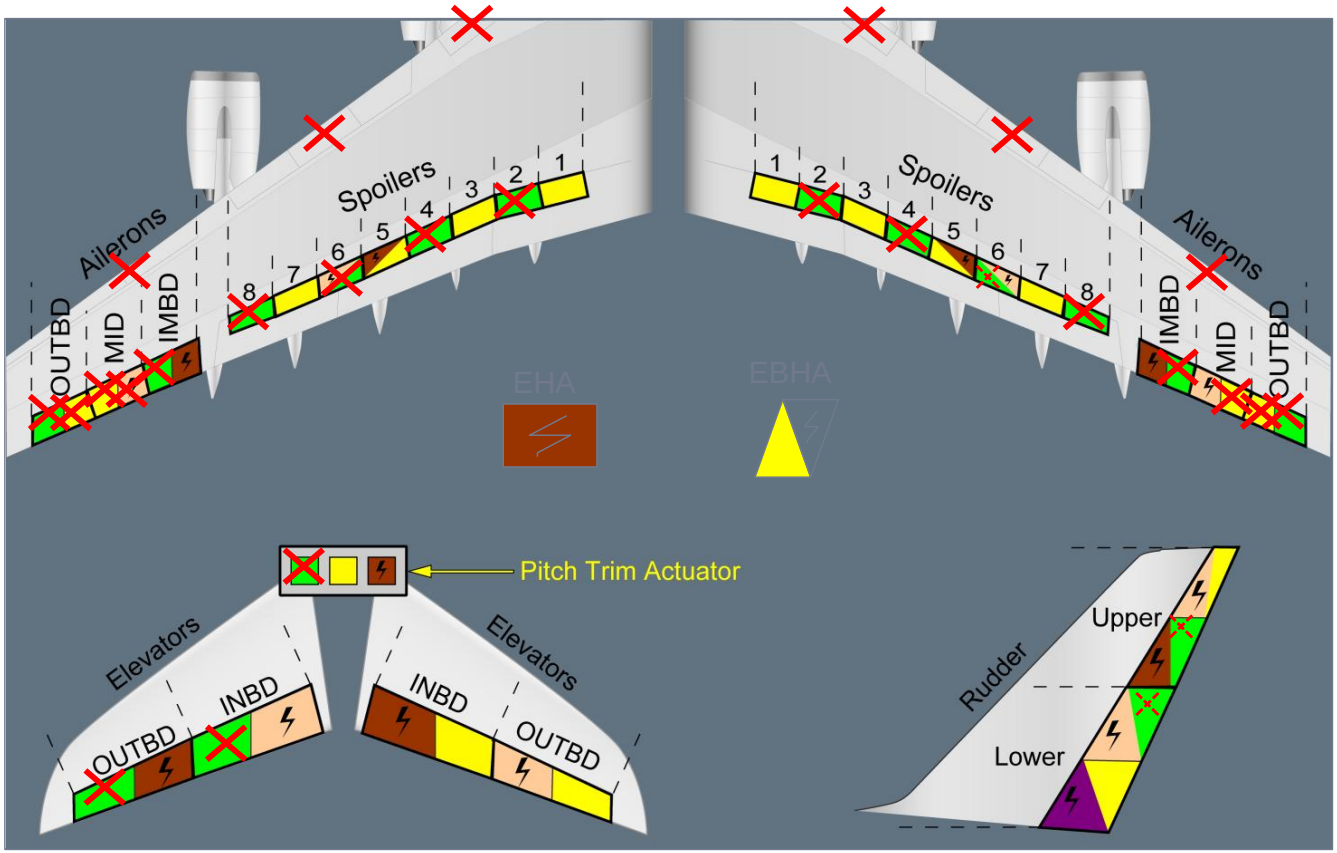
Hundreds of failure conditions

QF32 simulator test

- Integration simulator
- A380 cockpit, i.e. real controls and displays
- Not connected to iron bird
- Simulated systems but controlled with real computers, standard as installed during flight QF32
- Visual
- Session recorded with Flight Test Installation & DFDR

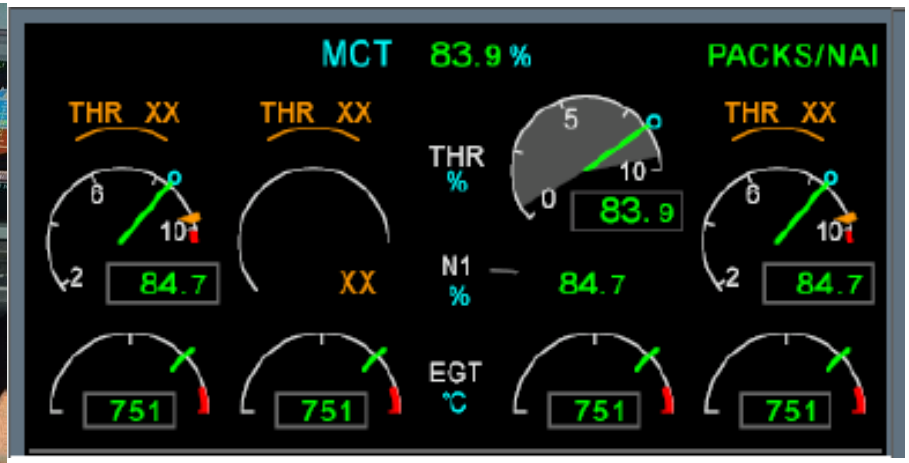
QF32 simulator test – HYD & F/CTL

- Green system depressed manually
- Simulator representative of QF32 actuation systems
- Alternate Law



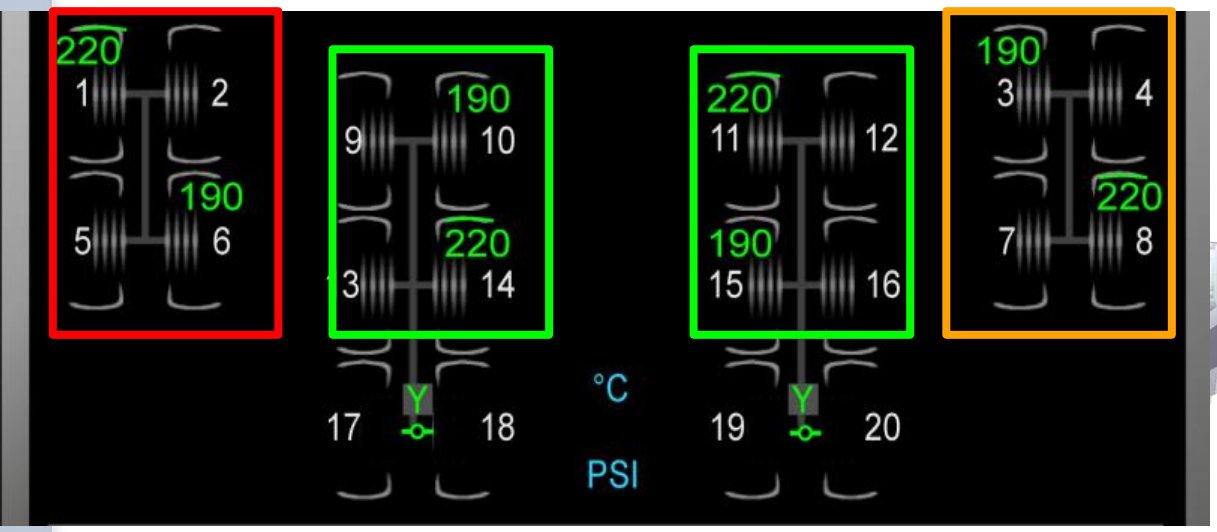
QF32 simulator test – ELEC & ENG

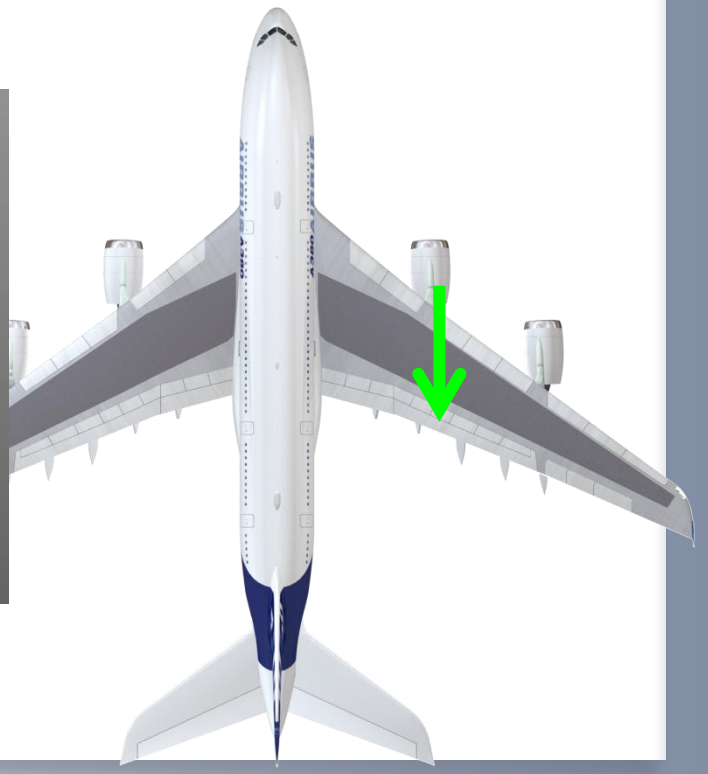
- AC bus2 disabled
- ENG2 manual shut down
- ATHR disconnection
- ENG 1,3&4 in unrated mode
- Representative ENG control and display



QF32 simulator test – Deceleration means

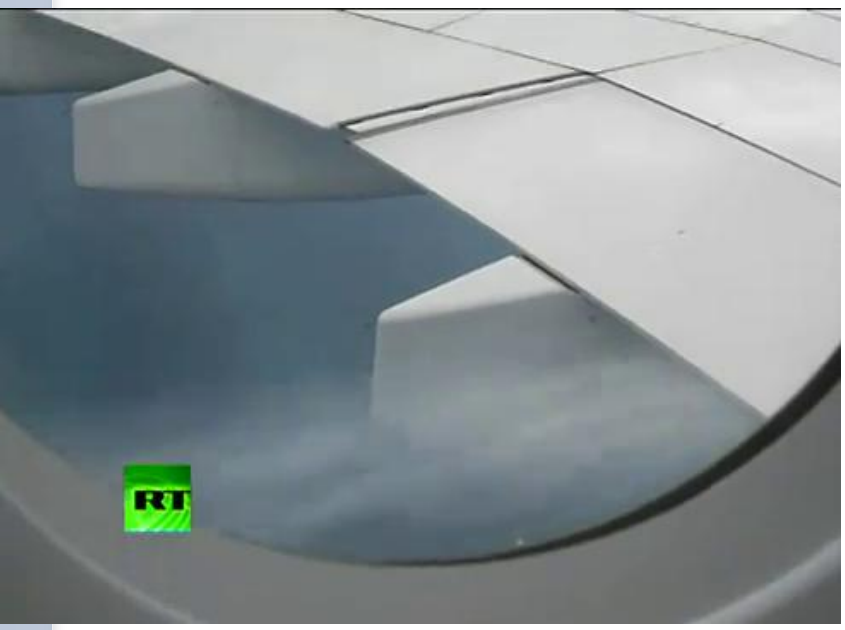
- Normal mode to BLG
- Alternate without antiskid 1000psi limitation at RH WLG
- No pressure at LH WLG
- REV3 only



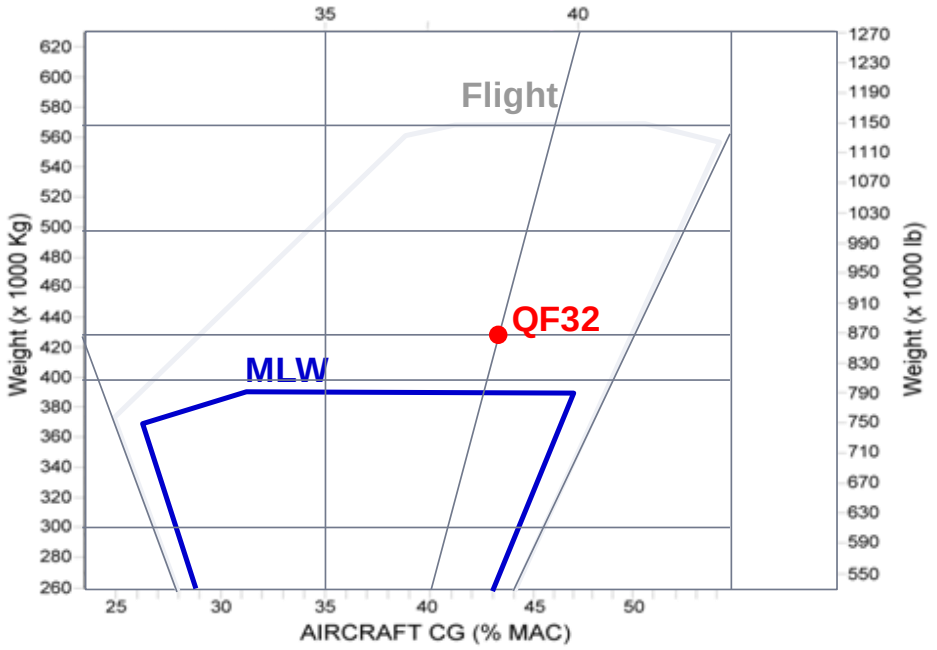


QF32 simulator test – Fuel distribution and CG

Outer tank	Feed tank1	Mid tank	Inner tank	Feed tank2	Feed tank3	Inner tank	Mid tank	Feed tank4	Outer tank
5.5	5.5	0	4.5	10	10	4.2	0	13	0



Landing figures



QF32 simulator test – Fuel distribution and CG

- Predefined fuel distribution scenarios
- Replay QF32

- Then up to extreme non-operational imbalance cases

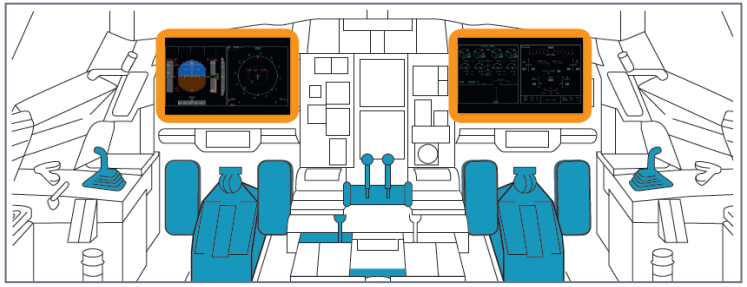
QF32 simulator test

- Integration simulator not connected to iron bird was the best option
- A demanding project
  - 5 months preparation
  - 2 test engineers full time dedicated to the project
  - F/CTL HYD ELEC FUEL BRK HQ engineers
  - QFA, French DGAC & Airbus pilots
- Achievements supporting HQ & HF investigations
  - Right level of representativeness to meet the investigation requirements
  - Handling qualities demonstrated
  - Crew workload partially demonstrated
    - Much higher in the real case

Research for future simulators

- Inject flight data recordings

- Use real aircraft as iron birds



Content

- Introduction
- AC data other than flight data recordings
- ACARS transmission
- Engineering analyses
- Integration simulators
- Conclusion

Conclusion

- Modern aircraft host various information that can complement DFDR and CVR
- High-Tech tools can support accident investigations
- These are opportunities
  - To investigate the accident scenario
  - To review alternate ones
- Enhanced investigation capabilities do not supersede expertise
- Enhanced investigation capabilities push the limitations back
  - But not everything is possible
- Get the best of them with the support from manufacturers