AO-2008-070, In-flight upset
154 km west of Learmonth, WA
7 October 2008, VH-QPA
Airbus A330-303

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Overview

- Occurrence sequence of events
- On-site phase
- Cabin safety
- Systems
- Investigation lessons

Based on ATSB *Interim Factual Report* (6 March 2009) available at
www.atsb.gov.au
Sequence – prior to anomalies

- 0132 UTC: QF72 left Singapore (to Perth)
  - 3 flight crew, 9 cabin crew, 303 passengers
- 0201: established FL370
  - weather clear, no turbulence
- Flight deck:
  - 0433: Capt returned from break
  - 0439: FO left for break
- Cabin:
  - meal service completed, carts in galley
  - 4 cabin crew in crew rest area
Sequence – initial anomalies

• 0440.28:
  – ADIRU 1 data spikes started
  – AP1 disconnected (Capt took manual control)
  – ECAM messages, master caution chimes, stall / overspeed warnings, fluctuations on Capt’s primary flight display

• Crew evaluating situation
  – 0441.12: AP2 attempted, disengaged
  – asked cabin crew to send FO back to flight deck

Sequence – first upset

• 0442.27: pitch nose-down
  – max pitch angle 8.4 degrees, g loading -0.80
  – many injuries in cabin

• Capt promptly applied back pressure
  – initially no response

• Descended 650 ft before return to FL370

• SO put seatbelt light on, made PA

• Crew commenced ECAM actions
  – NAV IR1 fault – switch to Capt on 3
  – PRIM 3 fault – OFF then ON
Sequence – second upset

- 0445.08: pitch down
  - max pitch angle 3.5 degrees, g loading 0.20
- Capt promptly applied back pressure
  - initially no response
- Descended 400 ft before return to FL370
- Reviewing ECAM
- Captain made PA
- 0447.39: FO returned
Sequence – post-upsets

- ECAM messages scrolling and could not action, frequent warnings and cautions
- Decided to land ASAP
  - unsure whether would reoccur
  - aware had some injuries
  - 0449.06: PAN call
- Received advice of serious injuries
  - 0454.26: MAYDAY
- Frequent communications with ATC, cabin, maintenance watch
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On-site phase

• Cabin inspection (impact damage)
• Aircraft inspection (no damage)
• Cargo / loading (no problems)
• Recorded data
  – preliminary FDR, QAR, CVR analysis
  – post flight report (PFR), maintenance data
  – (indicated ADIRU 1 problem)
• Functional testing
  – ADIRU 1 removed
  – (no problems found with other systems)

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Injury information

- Obtained from operator, interviews, survey, WA Dept of health
- WA Dept of health
  - 53 attended hospital, 12 of these ‘admitted’
- Serious injury:
  - ATSB definition: admitted to hospital
  - ICAO Annex 13: different definition, same result (though not all the same people)
- Due to serious injuries, was an ‘accident’

Passenger survey

- Difficulties with names, contact details
- Initial batch sent out 28 Oct 2008
- Questions about events, seatbelts, injuries, PEDs
- 95 responses (+ 6 children) and 29 interviews / email (+11 children)
  - in total information from 47%
- Nothing unusual prior to upset
Injury information

<table>
<thead>
<tr>
<th></th>
<th>Crew</th>
<th>Passengers</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Serious</td>
<td>1</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Minor</td>
<td>8</td>
<td>95</td>
<td>103</td>
</tr>
<tr>
<td>None</td>
<td>3</td>
<td>197</td>
<td>200</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>303</td>
<td>315</td>
</tr>
</tbody>
</table>

- All injuries at time of first in-flight upset
- Severity of injuries varied considerably

Passenger injuries by location

<table>
<thead>
<tr>
<th></th>
<th>Front</th>
<th>Centre</th>
<th>Rear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passengers</td>
<td>33</td>
<td>150</td>
<td>120</td>
</tr>
<tr>
<td>Total injuries</td>
<td>7</td>
<td>55 (37%)</td>
<td>44 (37%)</td>
</tr>
<tr>
<td>Attended hospital</td>
<td>-</td>
<td>32 (21%)</td>
<td>19 (16%)</td>
</tr>
<tr>
<td>Serious injury</td>
<td>-</td>
<td>7 (5%)</td>
<td>4 (3%)</td>
</tr>
<tr>
<td>Damage above seat</td>
<td>~10%</td>
<td>~20%</td>
<td></td>
</tr>
</tbody>
</table>
### Passenger injury details

<table>
<thead>
<tr>
<th></th>
<th>Seatbelts on</th>
<th>Seatbelts off</th>
<th>Standing</th>
<th>Toilet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total responses</td>
<td>82</td>
<td>61</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>Injured</td>
<td>35%</td>
<td>91%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Attended hospital</td>
<td>13%</td>
<td>38%</td>
<td>67%</td>
<td>100%</td>
</tr>
<tr>
<td>Serious injury</td>
<td>2%</td>
<td>5%</td>
<td>22%</td>
<td>50%</td>
</tr>
<tr>
<td>Common injuries</td>
<td>Strain, sprain of neck, back</td>
<td>Head, neck due ceiling impact; bruising to back, legs landing on seats, floor</td>
<td>Multiple (including spinal)</td>
<td>Multiple (including spinal)</td>
</tr>
</tbody>
</table>

**Seatbelt inspections**

- 4 passengers said had seatbelt fastened, but were not restrained
- Inspected sample of 51 seatbelts
  - including for those attended hospital and unsure whether seatbelt on or not
- No problems with condition of belts examined
- Potential design problem of lift-latch mechanism
Cabin safety summary

• Key findings:
  – most injuries to people standing, or seated without seatbelts fastened
  – seatbelts have potential for inadvertent release (never been noted before)

• Ongoing investigation:
  – passenger survey analysis
  – further examination of inadvertent release
  – review of industry seatbelt requirements

• Safety action to date:
  – seatbelt reminders
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Systems: key findings

- ADIRU 1 provided erroneous data (spikes) on many parameters to other aircraft systems
  - other 2 ADIRUs functioning correctly
- Spikes in angle of attack (AOA) data were not filtered by flight control computers (PRIMs)
  - computers subsequently commanded pitch-down movements
Air data inertial reference unit

Air data inertial reference unit (ADIRU)

- Air data part (ADR)
  - barometric altitude, speed, Mach, angle of attack (AOA), temperature
- Inertial reference part (IR)
  - attitude, flight path vector, track, heading, accelerations, angular rates, ground speed, vertical speed, aircraft position
AOA inputs to ADIRUs and PRIMs

- AOA sensor 1
- AOA sensor 2
- AOA sensor 3

ADIRU 1 → PRIM 1
ADIRU 2 → PRIM 2
ADIRU 3 → PRIM 3

Left AOA Vane (AOA1)
Right AOA Vanes (AOA2 and AOA3)
FDR Data (whole flight)

The two pitch-down events occurred during this time period. Refer to Plots 2 & 3.

FDR Data (both pitch downs)
ADIRU testing

- ADIRUs 1, 2, 3 sent to Northrop Grumman
- Test plan and protocols developed
- Initial testing (November 2008) attended by all parties:
  - ATSB, Qantas
  - NTSB, NG, FAA
  - BEA, Airbus
ADIRU testing

- ADIRUs 1, 2, 3
  - Physical inspection
  - Manufacturer test program (MTP)
  - OFP test (software verification)
  - BITE (test) data download

- ADIRU 1:
  - Ground integrity test
  - Bus tests
  - Internal visual inspection
  - Environmental tests (vibration, temp, EMI)
  - Level III (component) testing

ADIRU test results

- BITE data:
  - ADIRU 2 and 3 BITE data showed anomalies with ADIRU 1
  - ADIRU 1 had no BITE data from relevant time, several routine messages not stored

- No testing to date on ADIRU 1 has reproduced any faults related to ADIRU behaviour on accident flight

- Summary: even though ADIRU producing spikes, do not yet know why
PRIM data processing (general)

• Variety of redundancy and error-checking mechanisms to prevent erroneous ADIRU data affecting flight controls

• 3 different values of same parameter, each from different sensor and processed by different ADIRU

PRIM data processing (general)

• Parameter monitoring:
  – voting process – if any value differed from median by more than threshold for period of time, relevant part of ADIRU ignored

• Calculation of flight control commands:
  – median value used by PRIMs to calculate flight control commands
PRIM data processing (AOA)

- Parameter monitoring:
  - voting process – if any value differed from median by more than threshold for more than 1 second, relevant ADR ignored

- Calculation of flight control commands:
  - average value used (AOA1 + AOA2 / 2)
  - average value passed through rate limiter
  - if difference between AOA1 or AOA2 and median > threshold, PRIMs memorised last valid average for 1.2 seconds (then used current average)

PRIM data processing (AOA)

- AOA processing algorithms prevent most types of erroneous AOA inputs influencing flight controls

- However, problem if:
  - 2 or more high amplitude spikes
  - first spike < 1 second duration
  - second spike present 1.2 seconds after detection of first spike

- At least 42 AOA spikes on accident flight
Flight envelope mechanisms

- In normal law, computers prevent exceedance of predefined flight envelope
- High AOA protection (alpha prot):
  - if AOA too high, PRIMs command nose-down elevator command
  - only available in normal law
- Anti pitch-up compensation:
  - available when Mach > 0.65 and aircraft in clean configuration
  - maximum authority was 6 degrees

First upset was close to worst possible scenario:
- 4 degrees alpha prot, 6 degrees anti pitch-up
- AOA processing algorithm using just two sensors only on A330 and A340
  - different algorithms used on other Airbus aircraft
Related events

- ADIRU failures occur but rare (mean time between failure of 17,500 hours)
- Extremely rare for ADIRU failures to have an effect on aircraft flight controls
  - Boeing 777 August 2005, 240 km NW Perth (different ADIRU manufacturer and type)
  - no previous case reported involving Airbus aircraft
- Two other cases where ADIRUs exhibited similar anomalous behaviour

12 September 2006, VH-QPA

- QF68, Hong Kong – Perth
  - same aircraft, same ADIRU
- Tech log
  - ADR 1 fault and numerous ECAM messages
- Pilot report (after accident)
  - night, smooth conditions
  - numerous ECAMs, constantly changing
  - weak and intermittent ADR1 fault light, turned ADR1 off
- Maintenance action as per manual
  - ADIRU re-alignment, system test - nil faults
27 December 2008, VH-QPG

- QF71, Perth - Singapore
  - different aircraft, different ADIRU
- Sequence:
  - 0749.55: takeoff
  - 0814.01: FL360
  - 0828.55: IR1 fault indication
  - 0828.56: AP1 disconnect
  - multiple, scrolling ECAM messages
  - IR1 and ADR switched off (as per new procedure), though IR still provided erroneous data to systems
Search for other events

- 3 known events had similar PFR messages
- Airbus searched AIRMAN database for similar PFRs
  - covered most of world A330/340 fleet using same model ADIRUs (248 of 397 aircraft)
  - only one similar PFR: VH-EBC, 7 Feb 2008 (Sydney to Saigon) (not confirmed whether this flight had similar event)
- Summary: only 3 known events, same operator, same general area

Harold E Holt VLF transmitter

- Information from defence:
  - transmitting at time of all 3 events (transmits most of the time)
  - no equipment malfunctions, no changes in nature of transmissions
  - in operation since 1967 (similar transmitters in several other countries)
- Field strengths at event locations well below levels of ADIRU certification tests
- ADIRU tests examined VLF (no problem)
Systems – ongoing activities

- ADIRU problem:
  - ADIRU testing
  - theoretical analysis of ADIRU failures
  - configuration comparisons
  - review of technical records
  - aircraft testing
- AOA processing algorithm limitation
  - review of PRIM software development cycle

Systems – safety action

- Airbus
  - Operational Engineering Bulletin (OEB) (operational procedures in response to such events)
  - PRIM software modifications
- Qantas
  - FSO incorporating OEB
  - simulator training
  - Q&A sessions for pilots, memo
- EASA / CASA
  - ADs based on OEBs
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Investigation lessons (1)

• Team composition:
  – go with numbers
  – IIC not involved in data collection
• On-site communications:
  – regular team meetings, briefings
  – access to email
• Difficult decisions:
  – take time, keep asking questions, give explanations
• OH&S: beware of benign sites
Investigation lessons (2)

- Passenger contact details and injury information
- External communications:
  - face-to-face > conference calls > emails (until relationship established)
  - provide regular updates
  - understand different organisations’ approach to investigations (and how protecting information)

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