Australian Government
Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT
Aviation Occurrence Report – 200503722
Final

In-flight upset event
240 km north-west of Perth, WA
Boeing Company 777-200, 9M-MRG
1 August 2005

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Figure 2 courtesy of the Boeing Company.

Abstract

At approximately 1703 Western Standard Time, on 1 August 2005, a Boeing Company 777-200 aircraft, (B777) registered 9M-MRG, was being operated on a scheduled international passenger service from Perth to Kuala Lumpur, Malaysia. The crew reported that, during climb out, they observed a LOW AIRSPEED advisory on the aircraft's Engine Indication and Crew Alerting System (EICAS), when climbing through flight level (FL) 380. At the same time, the aircraft's slip/skid indication deflected to the full right position on the Primary Flight Display (PFD). The PFD airspeed display then indicated that the aircraft was approaching the overspeed limit and the stall speed limit simultaneously. The aircraft pitched up and climbed to approximately FL410 and the indicated airspeed decreased from 270 kts to 158 kts. The stall warning and stick shaker devices also activated. The aircraft returned to Perth where an uneventful landing was completed.

The aircraft's flight data recorder (FDR), cockpit voice recorder and the air data inertial reference unit (ADIRU) were removed for examination. The FDR data indicated that, at the time of the occurrence, unusual acceleration values were recorded in all three planes of movement. The acceleration values were provided by the aircraft's ADIRU to the aircraft's primary flight computer, autopilot and other aircraft systems during manual and automatic flight.

Subsequent examination of the ADIRU revealed that one of several accelerometers had failed at the time of the occurrence, and that another accelerometer had failed in June 2001.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Transport and Regional Services. ATSB investigations are independent of regulatory, operator or other external bodies.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the Transport Safety Investigation Act 2003 and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

ABBREVIATIONS

AD	Airworthiness Directive
ADIRU	Air Data Inertial Reference Unit
ADM	Air Data Module
AIMS	Airplane Information Management System
AGL	above ground level
AOA	angle of attack
ARINC	Aeronautical Radio, Incorporated
A/T	autothrottle
ATC	air traffic control
ATSB	Australian Transport Safety Bureau
EICAS	Engine Indication and Crew Alerting System
FAA	US Federal Aviation Administration
FCA	Fault Containment Areas
FCM	Fault Containment Modules
FDI	Fault Detection and Isolation
FDR	flight data recorder
FL	flight level
LNAV	lateral navigation
MCP	Mode Control Panel
MM	maintenance message
MVS	mid-value select
NTSB	US National Transportation Safety Board
OPS	operational program software
PFC	Primary Flight Computer
PFD	Primary Flight Display
QRH	quick reference handbook
RTCA	Radio Technical Commission for Aeronautics
SAARU	Secondary Attitude Air Data Reference Unit
TAT	total air temperature
US	United States of America
VNAV	vertical navigation

FACTUAL INFORMATION

History of the flight

At approximately 1703 Western Standard Time[1], on 1 August 2005, a Boeing Company 777-200 aircraft (B777), registered 9M-MRG, was being operated on a scheduled international passenger service from Perth, Australia to Kuala Lumpur, Malaysia. The flight crew reported that they observed a LOW AIRSPEED advisory on the aircraft's Engine Indication and Crew Alerting System (EICAS), when climbing through flight level (FL) 380. They also reported that, at the same time, the aircraft's slip/skid indication[2] deflected to the full right position on the Primary Flight Display (PFD)[3]. The PFD speed tape[4] then indicated that the aircraft was approaching the overspeed limit and the stall speed limit[5] simultaneously. The aircraft nose then pitched up, with the aircraft climbing to approximately FL410. The indicated airspeed then decreased from 270 to 158 kts, and the stall warning and stick shaker devices activated.

The pilot in command reported that he then disconnected the autopilot and lowered the nose of the aircraft. The aircraft autothrottle then commanded an increase in thrust, which the pilot in command countered by manually moving the thrust levers to the idle position. The aircraft nose pitched up again and the aircraft climbed 2,000 ft. The flight crew notified air traffic control (ATC) that they could not maintain altitude and requested a descent and radar assistance for a return to Perth. The crew were able to verify the actual aircraft groundspeed and altitude of the aircraft with ATC.

The pilot in command later reported that the PFD indications appeared normal when descending through FL200. He then reportedly selected the LEFT[6] autopilot 'ON', but the aircraft banked to the right and the nose pitched down, so the autopilot was disengaged. A similar result occurred when the RIGHT autopilot was selected, so the pilot in command left the autopilot disengaged and manually flew the aircraft. The pilot in command reported that, with the autopilot disengaged, there were no further control difficulties experienced.

The pilot in command reported that he attempted to disconnect the autothrottle by pressing the thrust lever autothrottle disconnect switches and pushing the autothrottle engage switch. The autothrottle arm switches had remained in the 'ARMED' position during the occurrence.

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1 The 24-hour clock is used in this report to describe the local time of day, Western Standard Time (WST), as particular events occurred. Western Standard Time was Coordinated Universal Time (UTC)+ 8 hours.

2 The slip/skid indication would indicate an aircraft out of trim condition in the yaw axis.

3 Electronic cockpit instrument which displays information to the pilot concerning flight of the aircraft in the vertical plane.

4 The speed tape was a visual indicator on the side of the PFD to display airspeed in an easy to reference method.

5 The aircraft overspeed limit was the maximum permitted operating speed and the stall speed was the speed at which stalling angle of attack was reached.

6 There were two positions for activation of the autopilot, LEFT and RIGHT.

The crew were given radar vectors by ATC to position for an instrument landing system approach onto runway 03 at Perth. When the aircraft was at an altitude of 3,000 ft above ground level (AGL), and the crew was preparing for the approach, the PFD again annunciated a low indicated airspeed condition. The autothrottle system responded to the low indicated airspeed condition by commanding an increase in thrust of the engines.

At the time of the landing, the wind at Perth was 25 kts gusting to 30 kts from the north-west, with moderate turbulence below 3,000 ft AGL. During the approach, the aircraft's windshear alert warning system indicated a windshear condition, but the flight crew continued the approach and landed the aircraft without further incident. The flight crew later reported that the aircraft's autobrake system was selected to AUTOBRAKE 3 before landing, but that after landing the autobrakes were not able to be cancelled by using the brake pedals. The AUTOBRAKE switch was then selected to OFF and normal operation resumed.

Recorded information

The aircraft's flight data recorder (FDR), cockpit voice recorder and the air data inertial reference unit (ADIRU) were removed for examination and analysis. The FDR data indicated that, at the time of the occurrence, unusual acceleration values were recorded in all three planes of movement[7]. Further information on the data recovered from the flight recorders is contained in Appendix A.

Testing, disassembly and examination of the ADIRU

The aircraft ADIRU, which was installed with operational program software (OPS) version -07, was removed and sent to the component manufacturer for examination, under the supervision of the US National Transportation Safety Board (NTSB) on behalf of the Australian Transport Safety Bureau (ATSB). The testing and examination indicated that fault codes stored in the unit's non-volatile memory confirmed the presence of faults in two internal accelerometers[8] and one ring-laser gyroscope[9] (gyro). It was determined that the ADIRU's accelerometer number-6 failed at the time of the occurrence, and that accelerometer number-5 failed in June 2001, but was still capable of producing high acceleration values or voltages that were erroneous[10]. The component manufacturer reported that a search of all field history records showed that there were a total of four other occasions when two accelerometers had failed in other ADIRUs of the same type. None of these cases resulted in reported erroneous output, indicating that the accelerometer hardware failure modes in these cases had not produced similar high accelerometer value/voltage.

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7 Vertical, Lateral and Longitudinal.

8 An accelerometer is a device for measuring acceleration. It measures its own motion, in contrast to a device based on remote sensing. The accelerometer output is a voltage signal.

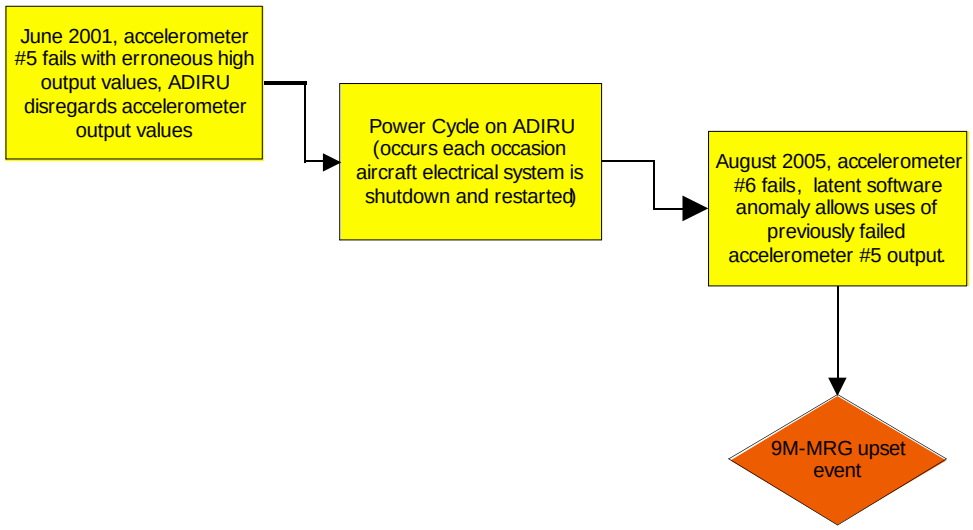
9 A device which measures rotation and rate of rotation, by sending laser light in both directions round closed circuit.

10 The failure mode of the number-5 accelerometer was unusual in that it failed to a high value/voltage. Most accelerometer failures were to a zero value/voltage output, indicating a steady state.

Further investigation revealed that the conditions necessary for the occurrence were (figure 1):

- an accelerometer failure producing high value/voltage output
- the ADIRU excluding that failed accelerometer from use in its acceleration computations
- power to the ADIRU cycled (system reset)
- a second accelerometer then failing and the latent software anomaly allowing the ADIRU to once more utilise the previously failed accelerometer information with its high output values in its computations, resulting in erroneous acceleration outputs into the flight control outputs but not the navigation (ground speed, velocity, position, etc.) outputs.

Figure 1: Component event flow chart

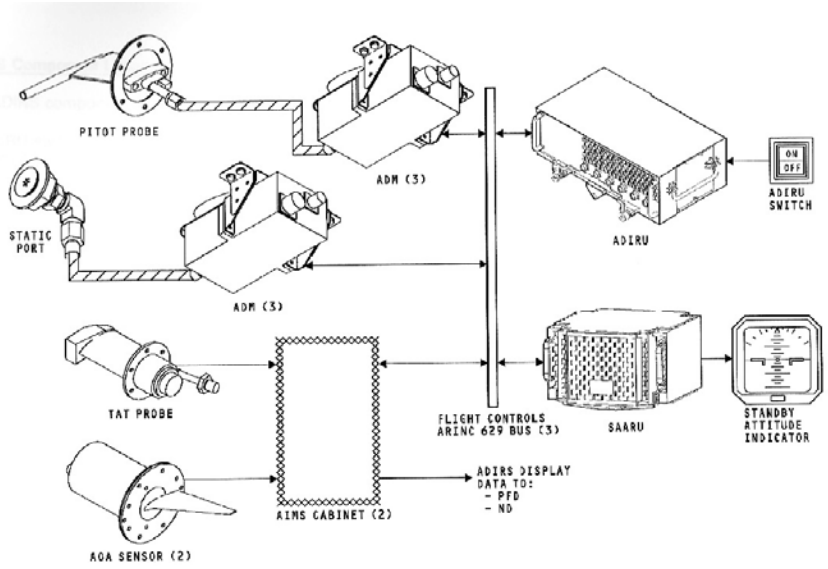


Air data inertial reference unit system operation

The function of the ADIRU was to provide air data and inertial reference data to several systems on the aircraft, including the primary flight control system, the autopilot flight director system and the flight management system. Components within the air data inertial reference system included (figure 2):

- the ADIRU
- the secondary attitude air data reference unit (SAARU)
- the air data modules (ADM)
- the pitot probes
- the static ports
- the total air temperature (TAT) probe
- the angle of attack (AOA) sensors
- standby attitude indicator.

Figure 2: Air data inertial reference system



Source: The Boeing Company

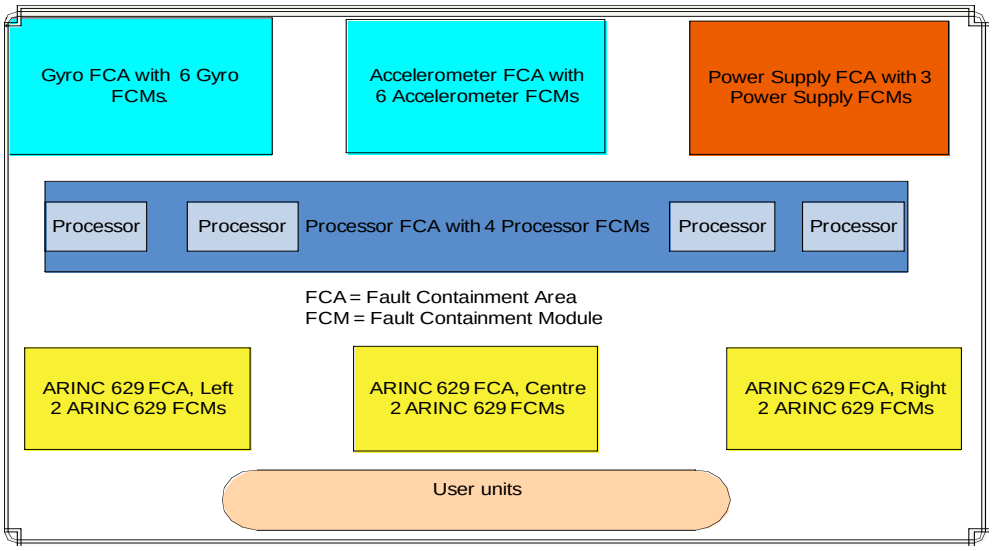
The ADM received air pressure from the pitot probes or static ports. The ADM then converted that air pressure into Aeronautical Radio, Incorporated (ARINC) 629[11] data. The ADM then sent that data to the ADIRU and SAARU. The 'airplane information management system' (AIMS) cabinets received TAT and AOA analog inputs, converted that data to digital and sent it to the ADIRU and SAARU.

The ADIRU utilised inputs of pitot and static pressure, TAT and AOA to calculate and supply air data information to the user systems. The ADIRU incorporated six ring-laser gyros and six accelerometers to calculate the inertial reference and navigation data for other aircraft systems. The ADIRU was programmed using the operational program software (OPS), which could be manually loaded into the unit.

The ADIRU in the B777 aircraft was a fault tolerant, system redundant unit. The ADIRU had internal system redundancy and automatically made allowances for internal component faults to ensure the unit's overall functionality. It contained seven fault containment areas (FCA) with each containing fault containment modules (FCM). Each module was physically and electrically separated from the other modules (figure 3).

11 A multiplexed bus used for sharing data using Integrated Modular Avionics distributed architecture.

Figure 3: ADIRU diagram



The ADIRU could have an unserviceable item in any of the FCAs and the aircraft was still considered serviceable. That feature allowed operators to defer maintenance until the number of serviceable FCMs in any single area was less than that specified by the component manufacturer, and provided operators with lower maintenance costs and less disruption to aircraft scheduling.

Data from the accelerometers and gyros was sent to the processor FCA which produced navigation and flight control inputs. The processor FCA performed redundancy management on the gyro and accelerometer data by using fault detection and isolation software. The data was then checked by the software before it was sent to the ARINC 629 units for distribution to the aircraft user units. That design feature was to ensure that only data from serviceable sensors would be used in the ADIRU outputs.

System redundancy

Acceleration values were provided by the ADIRU and were used by the aircraft's primary flight computer during manual and automatic flight modes. The primary flight computer software compared the information from the ADIRU with the information from the secondary attitude air data reference unit (SAARU). During the occurrence, that comparison function in the primary flight computer reduced the severity of the initial pitching motion of the aircraft.[12]

The SAARU provided an independent back-up source of attitude, heading and air data. The SAARU used the same inputs as the ADIRU to also calculate and supply air data to user systems. It utilised four fibre-optic gyros and four accelerometers to calculate and supply inertial reference data to user systems in a similar method to the ADIRU. It also supplied attitude data to the standby attitude indicator.

12 The primary flight computer included a mid-value select (MVS) on some parameters and compared the SAARU acceleration values to those being generated by the ADIRU which effectively limited or smoothed the output values before they were used by the primary flight computer.

System fault advisories

Any internal fault in the ADIRU generated a fault or maintenance message (MM) that was then recorded into the on-board maintenance computer. These recorded maintenance messages could be accessed and reviewed by maintenance personnel using the maintenance access terminal while the aircraft was on the ground, to identify any system anomalies. In some cases, an anomaly in the ADIRU could also result in a status message advisory to the flight crew on the engine indication and crew alerting system (EICAS) display. There was no requirement to remove the ADIRU from the aircraft and replace it with a serviceable unit until three days after a status message on the EICAS was displayed.

When the upset event occurred, the aircraft EICAS reportedly displayed an ADIRU status message, indicating a fault with the ADIRU, but the flight crew was not provided with information that detailed the nature of the fault.

Following the occurrence, maintenance personnel reported that, on power-up of the system, the EICAS displayed a status message 'ADIRU' and that the turn and slip indicator cursor on both the pilot and copilot displays was in the full left position. A review of the maintenance access terminal indicated a MM 34-20010 and 34-20000 (ADIRU internal failure) were recorded.

Information gathered during laboratory examination of the ADIRU following the occurrence indicated that:

- 13 June 2001, the number-5 accelerometer failed resulting in a MM 34-20010 being recorded
- 16 November 2004 processor number 2 failed, but that fault would not have resulted in any status message or additional MM beyond the MM 34-20010 recorded earlier
- 30 May 2005, the number-1 gyro failed, but that fault would not have resulted in any status message or additional MM beyond the MM 34-20010 recorded earlier
- 1 August 2005, the number-6 accelerometer failed, approximately 1 second prior to the upset event as noted by the flight crew, and resulted in an EICAS status message 'ADIRU' along with MM 34-20010 and 34-20000[13].

Component history and previous maintenance

The operator's maintenance documentation on the aircraft indicated that the following maintenance action related to the ADIRU had been completed:

- 15 May 1998, the ADIRU, serial number 98010197, was installed on the aircraft
- 18 June 1998, MM 34-20010 (ADIRU internal failure) recorded on the on-board maintenance computer[14].

---

13 The transition from MM 34-20010 to 34-20000 occurs to denote that a status message was generated.

14 The ADIRU operationally checked satisfactorily.

- 12 January 1999, during pre-departure checks, an ADIRU status message was displayed along with MM 34-20060 (ADIRU operational program configuration does not agree with aircraft type)[15]
- 13 October 2000, the unit was removed and replaced with a temporary replacement unit serial number 98070228, while the OPS in unit serial number 98010197 was upgraded
- 21 November 2000, ADIRU serial number 98070228 was replaced with upgraded unit serial number 98010197, because of an existing MM 34-20010 (ADIRU internal failure)
- 20 January 2003, OPS version -06 was loaded into the ADIRU
- 4 January 2005, OPS version -07 was loaded into the ADIRU
- 19 January 2005, MM 22-12000 (LNAV or VNAV data invalid[16]) was logged on the maintenance access terminal. The system was reset and operationally checked with no faults found.

The documentation also indicated that from 31 May 2005 until the time of the occurrence, a MM 34-20010 (ADIRU internal failure) was being logged on the on-board maintenance computer.

Dispatch deviation guides

Aircraft manufacturers develop dispatch deviation guides to assist maintenance engineers in assessing the permissible non-operational equipment allowed for the conduct of safe flight of the aircraft. The guide for the B777 listed the following condition under the reference to an EICAS status message related to the ADIRU:

> ADIRU is faulted below normal certification requirements. The next ADIRU failure can cause it to shut down.

Regarding the management of ADIRU maintenance and status messages, the aircraft manufacturer advised:

> Regarding management of maintenance messages for the ADIRU, Boeing recommends that operators utilize Honeywell Technical Newsletter (TNL) M23-3344-005, originally released on 4 Apr 2003. The TNL provides a method of determining risk of incurring an ADIRU Status message from the time of initial display of a maintenance message (such as MM 34-20010). Boeing's experience shows that 777 operators' tolerance to incurring an ADIRU Status message varies.

15 The ADIRU circuit breaker was recycled and an alignment operational check indicated no faults.

16 Navigational data invalid.

Regarding the requirements to remove the ADIRU when maintenance or status messages are noted, the aircraft manufacturer advised:

> Some operators remove the ADIRU immediately when the MM is first observed, or within a short time period thereafter. Some operators elect to wait until the ADIRU Status message is displayed. Others utilize the TNL, combined with their own risk criteria, to establish an optimum time to allow the ADIRU to continue to operate with a MM before removing the ADIRU prior to the Status message appearing. Boeing notes that there is no requirement to remove the ADIRU until such time as the ADIRU Status message appears and that there is 3 day MMEL [Master Minimum Equipment List] relief provided at that point. The previous statement means that the ADIRU can be dispatched with MM 34-20010 present until such time that the operator deems it prudent to remove the ADIRU to avoid a schedule interruption due to occurrence of the ADIRU Status message. The decision to remove the ADIRU based on the presence of MM 34-20010 only is made by the operators on an economic basis, not a safety basis.

Regarding continued operation of the aircraft with MM 34-20010 displayed, it further advised:

> Maintenance Message (MM) 34-20010 is a latched fault and indicates an internal failure in the ADIRU that does NOT result in a status message. The MM indicates the first failure within a fault containment module (FCM), for example a gyro or processor failure, in the ADIRU. The second failure within a FCM will result in an ADIRU Status Message and MM 34-20000.
>
> The ADIRU on the 777 airplane is a fault tolerant unit. Therefore, operating with MM 34-20010 only means that an "extra" FCM (used for deferred maintenance) has been lost. ADIRU's with MM 34-20010 have sufficient resources to meet the performance requirements of the ADIRU. Also, when the ADIRU Status message is displayed, although redundancy has been lost the ADIRU continues to output its voted solutions for Air Data and Inertial parameters. There is 777 MMEL dispatch relief to operate with an ADIRU Status message for 3 days.

Component software evolution

The ADIRU OPS versions up to and including version -07 contained a latent software error in the algorithm to manage the sensor set used for computing flight control outputs which, after the unit went through a power cycle, did not recognise that accelerometer number-5 was unserviceable. The status of the failed unit was recorded in the on-board maintenance computer memory, but that memory was not checked by the ADIRU software during the start-up initialisation sequence. The software error had not been detected during the original certification of the ADIRU and was present in all versions of the software. The effect of the error was suppressed by other software functions in OPS version -03. When the OPS version -04 was released in December 1998, the software functions that suppressed the error were further revised to improve shop repair capability, re-exposing the undiscovered latent problem.

The variations to OPS version -04 and subsequent versions included changes to the Fault Detection and Isolation (FDI) software which monitored the serviceability of various ADIRU components. The changes allowed the FDI software to detect any transient unserviceability of hardware and reinstate it if no further unserviceability

was detected. The FDI software allowed the erroneous output values from accelerometer number-5 that had failed in 2001, to be used by the primary flight computer and other aircraft systems when accelerometer number-6 failed, just prior to the in-flight upset.[17].

The effect of the software error was partially offset by the inclusion of mid-value select (MVS) within the primary flight computer. The MVS function was included in the primary flight computer to moderate the effect of anomalous outputs from the ADIRU. Analysis and testing during initial development indicated that these theorized outputs could not occur, and the MVS function was deemed no longer necessary. However, a decision was made by the aircraft manufacturer to retain the MVS function in the PFC.

Engine autothrottle operation

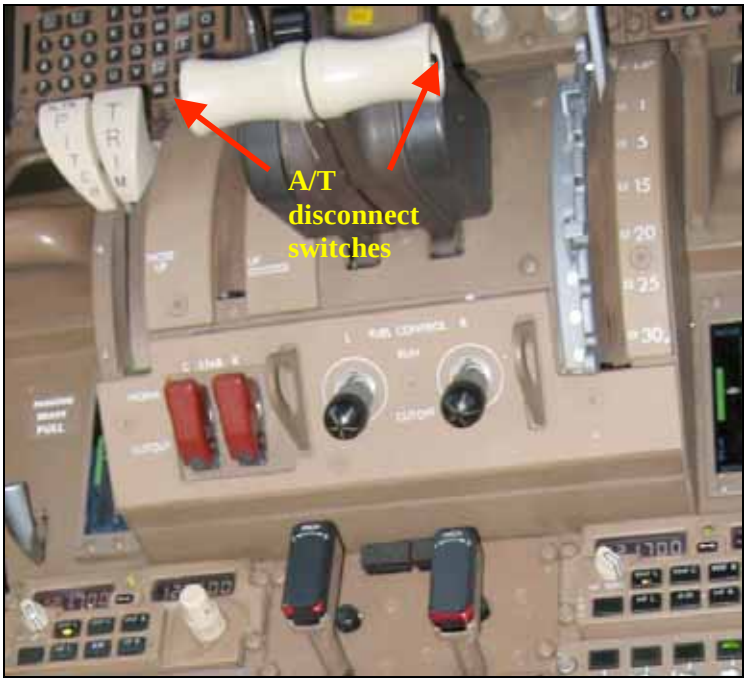
The aircraft mode control panel (MCP) had three distinct switches which operated the engine autothrottle (A/T). The autothrottle arm switches were located on the MCP and consisted of two toggle switches that armed the selected autothrottle for mode engagement. The autothrottle engage switch was a push-button type switch that was used to engage an autothrottle mode for various aircraft pitch modes, or if no pitch mode was selected, in the speed mode. The autothrottle could be disconnected at the MCP by moving the relevant autothrottle arm switch to OFF (figure 4).

Figure 4: MCP autothrottle arm and engage switches

17 Even though the second fault resulted in proper annunciation of a status message, the ADIRU flight control FDI algorithm which excluded accelerometer number -6 from the flight control outputs at the moment it failed, erroneously allowed accelerometer number -5 back into the computation of the flight control outputs.

In addition, the autothrottle could be disconnected by pushing either of the autothrottle disconnect push-button type switches on the engine thrust levers located on the pilots centre console (figure 5).

Figure 5: Engine thrust lever autothrottle disconnect switches



Pushing the disconnect switches would cause the following to occur:

- disconnection of the autothrottle (both LEFT and RIGHT)
- illumination of the master caution lights
- display of the engine indication and crew alerting system (EICAS) message AUTOTHROTTLE DISC.

If the disconnect switch was pushed a second time, the master caution lights and the EICAS message were reset, and the autothrottle remained armed. With the autothrottle armed it would automatically activate if the autopilot was not engaged and the airspeed was less than a flight management computer calculated value for 1 second, or the thrust was below that required for the mode of flight at the time.

B777 checklists

The aircraft manufacturer provided checklists for UNRELIABLE AIRSPEED in the quick reference handbooks (QRH) of its other aircraft types. Those procedures contained references to various indications that were available to the flight crew as evidence of unreliable airspeed. Examples of those indications included:

- speed or altitude information not consistent with pitch attitude and thrust setting
- airspeed/Mach failure flags
- blank or fluctuating airspeed displays
- variation between pilot in command and copilot airspeed displays

- amber line through one or more primary flight display or Attitude Direction Indicator flight mode annunciations
- overspeed indications
- simultaneous overspeed and stall warnings.

The aircraft ADIRU was designed with system redundancy to prevent those malfunctions from occurring, so no checklist such as UNRELIABLE AIRSPEED was provided for B777 flight crews. With only one erroneous input, the system was designed to automatically stop accepting that input and divert to another input source for information. That event would not require any action by the flight crew, and was intended to minimise the number of checklist items that a crew would need to action. With multiple erroneous sources of information or internal failures in the ADIRU, the EICAS message NAV AIR DATA SYS would be displayed. That would direct the crew to the appropriate checklist and the unreliable airspeed table. The nature of the accelerometer failure in this occurrence meant that the NAV AIR DATA SYS message was not displayed on the EICAS during the occurrence.

The B777 QRH Section 10 *Flight Instruments*[18], displayed non-normal items. The checklists within the section related to messages displayed on the EICAS, and only consisted of condition statements. Those statements briefly described the condition which resulted in the respective EICAS messages, and did not contain procedural steps for the flight crew to action.

The AIRSPEED LOW status message, which was displayed on the EICAS at the start of the occurrence, was referred to in Section 15, *Warning Systems*, of the QRH, but required no crew response or action, as it was a condition statement.

The QRH preamble on non-normal checklist operation stated:

> While every attempt is made to provide needed non-normal checklists, it is not possible to develop checklists for all conceivable situations, especially those involving multiple failures. In some unrelated multiple failure situations, the flight crew may combine elements of more than one checklist or exercise judgement to determine the safest course of action. The captain must assess the situation and use good judgement to determine the safest course of action.

The only non-normal checklist available to the crew was the UPSET RECOVERY procedure which was specified in the non-normal manoeuvres section of the QRH.

Software certification standards

In 1980, the Radio Technical Commission for Aeronautics, now RTCA Incorporated, established a special committee to develop and document software practices that would support the development of airborne systems and equipment which were reliant on software for their operation. Parallel studies were also conducted in Europe by the predecessor to the European Organisation for Civil Aviation Equipment. The two organisations established a combined working group to develop a common set of guidelines. The result was RTCA document, DO-178, *Software Considerations in Airborne Systems and Equipment Certification* and the identical European document, ED-12. The current versions of the two documents

18 Version 13 December 2004.

are DO-178B and ED-12B, which reflect advances in technology and software development.

The purpose of the document was to provide guidelines for the production of software for aircraft systems to ensure that the software can comply with certifying authorities airworthiness standards, but it was not a compliance document. It was incorporated into compliance documentation of the US Federal Aviation Administration (FAA)[19].

The B777 ADIRU OPS was designed and developed in accordance with DO-178A but was consistent with the changes that were being incorporated into DO-178B[20]. During certification, the aircraft manufacturer and ADIRU manufacturer conducted validation and verification tests of the ADIRU systems. All features of the ADIRU navigation OPS were checked, but none of the tests duplicated exactly the elements of the occurrence; an accelerometer failure resulting in high value output, followed by a power cycle, followed by a second large-magnitude accelerometer failure, while maintaining the large value on the first accelerometer.

Flight control automation and reliance by flight crews

According to a magazine article published in 1999 by the aircraft manufacturer[21], flight deck automation and flight control technology, coupled with excellent systems reliability and redundancy, allowed flight crews to easily control their aircraft from takeoff to landing regardless of outside visibility. However, if an anomaly occurs, the complex systems that automate, control and display information in modern flight decks can produce erroneous or insufficient information. When faced with the resulting uncertainties, flight crews must determine what information is reliable and what information should not be used in order to make the proper decisions.

The article further stated that, unfortunately, safety data shows that not all flight crews have satisfactorily handled situations caused by erroneous flight instrument information. From October 1988 to 1999, more that 300 accidents and incidents had been reported as a result of erroneous flight deck information, including problems with pitot-static probes and air data computers. Several fatal accidents that involved erroneous flight instruments information and six occurrences resulting from lost or erratic air data occurred in 1996 alone. Investigations of those occurrences indicated that, with proper preparation, the flight crews involved probably could have prevented them.

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19 In January of 1993, Advisory Circular (AC) 20-115B, "RTCA, Inc., Document RTCA/DO-178B," was released by the U.S. Federal Aviation Administration (FAA), and it permitted the use of RTCA/DO-178B by Technical Standards Orders authorization, Type Certificate, or Supplemental Type Certificate applicants as a means, but not the only means, to secure FAA approval of digital computer software. Prior to this AC, the FAA allowed the use of RTCA/DO-178A plus Issue Papers to secure approval of digital computer software.

20 Referred to as DO-178A+.

21 *Erroneous Flight Instruments*, Boeing Company 'Aero' Magazine No. 8, Seattle, Washington, USA, October 1999.

The most notable of those accidents were:

- 6 February 1996, a Boeing Company 757-21K aircraft crashed after takeoff from Puerto Plata, Dominican Republic with 189 fatalities. The investigation uncovered that erroneous airspeed indications were being supplied to the flight crew as a result of a blocked pitot tube[22]
- 2 October 1996, a Boeing Company 757-23A aircraft crashed into the ocean about 30 miles off the coast of Lima, Peru with 70 fatalities. The investigation uncovered that erroneous airspeed and altitude indications were being supplied to the flight crew as a result of blocked static ports.

The article also stated that:

> Three valuable lessons emerged from the investigation of these events. First, the effects of flight instrument anomalies appear during or immediately after takeoff. Second, flight crews must overcome the startle factor associated with rare anomalous events and immediately begin to implement specific corrective procedures and techniques. Finally, flight crews should acquire enough system knowledge to be able to determine the difference between valid and faulty display information.

The article also pointed out that erroneous flight information such as the many and varied symptoms of pitot static anomalies can confuse an unprepared flight crew. Because of the confusion caused by multiple and sometimes conflicting alerts and warnings, the flight crew may not recognize an air data error and may fail to respond appropriately.

22 On large aircraft such as the B777 and B757, the pitot tubes and static ports supply information to the air data inertial reference system concerning airspeed and altitude.

ANALYSIS

ADIRU design and checklist items

The B777 aircraft was designed to achieve a level of serviceability and system redundancy that would allow operators to reduce maintenance costs. The air data inertial reference unit (ADIRU), with its fault-tolerant design and advances in software capability, was a significant part of that design philosophy. The built-in redundancy was designed to allow for deferred maintenance on the ADIRU and to reduce the flight crew actions required in responding to any fault within the unit. An internal failure would not be apparent to the flight crew during normal operations, other than through an Engine Indication and Crew Alerting System (EICAS) status message. The B777 Quick Reference Handbook (QRH) did not, and could not, include '…checklists for all conceivable situations…'. Therefore, the aircraft manufacturer did not include an AIRSPEED UNRELIABLE checklist in the B777 QRH.

When the upset event occurred and the primary flight display indicated an underspeed, then an overspeed condition, as well as the slip/skid indicator showing full right deflection, the crew experienced a situation that had previously been considered not possible. The primary flight display pitch and roll indications, and the standby instrument indications were not affected by the failure of the accelerometer within the ADIRU, but the crew were not sure which indications were correct.

ADIRU operational program software

The certification of the ADIRU operational program software (OPS) was dependent on it being tested against the requirements specified in the initial design. The conditions involved in this event were not identified in the testing requirements, so were not tested.

The mitigating effects of the mid-value select and secondary attitude and air-data reference unit on the primary flight computer response to the erroneous accelerometer outputs was not an intended function, but did prevent a more severe upset event from occurring.

Flight crew actions

During the occurrence, the autothrottle system remained active or armed, even though the pilot in command attempted to disconnect it by pressing the thrust lever disconnect switch and pushing the autothrottle engage switch. The reason it remained active was because the flight crew did not deselect the autothrottle arm switches from the ARMED position to the OFF position. As a consequence, the autothrottle activated and automatically advanced the thrust levers when it sensed a low-speed condition as a result of erroneous data being provided by the ADIRU.

Maintenance actions

Although the aircraft on board maintenance computer was continually logging a maintenance message indicating an internal anomaly in the ADIRU, there was no status message generated by the system. Therefore, no maintenance action was required to replace the ADIRU, and the replacement or repair of the unit was at the discretion of the operator. A status message would have required maintenance action to replace or repair the ADIRU within 3 days of the message, but the software hierarchy, based on internal system redundancy, did not consider the degraded condition of the ADIRU sufficient to generate the status message. A status message was generated by the ADIRU when the second accelerometer failure occurred just prior to the event.

Summary

This occurrence highlights the reliance of modern transport aircraft on computer software and hardware for successful operation. The ADIRU operational program software had been tested and certified to the standard required at the time of certification. However, that testing was limited to the original specification and requirements of the component. The increased use of automation to manage internal hardware failures was designed to reduce the workload of the flight crew, by reducing the number of checklists that required actioning in the event of a non-normal situation. When the hardware failure occurred, combined with the software anomaly, the crew were faced with an unexpected situation that had not been foreseen. Subsequently, the crew had not been trained to respond to a specific situation of this type and had no checklist to action for ‘airspeed unreliable’.

FINDINGS

Contributing safety factors

– An anomaly existed in the component software hierarchy that allowed inputs from a known faulty accelerometer to be processed by the air data inertial reference unit (ADIRU) and used by the primary flight computer, autopilot and other aircraft systems.

Other safety factors

– The software anomaly was not detected in the original testing and certification of the ADIRU.

– The aircraft documentation did not provide the flight crew with specific information and action items to assess and respond to the aircraft upset event.

SAFETY ACTION

As a result of this occurrence, the following safety action was taken.

US Federal Aviation Administration

On 29 August 2005, the US Federal Aviation Administration (FAA) issued Emergency Airworthiness Directive (AD) AD 2005-18-51 which required all B777 operators to install operational program software (OPS) part number 3470-HNC-100-03 (version -03) in the air data inertial reference unit (ADIRU) in accordance with the accomplishment instructions of Boeing Alert Service Bulletin 777-34A0137 dated 26 August 2005. In addition, the *Limitations* section of the Airplane Flight Manual was to be amended by inserting Boeing operations manual bulletins CS3-3093 and CS3-3155 dated 26 August 2005.

Component manufacturer

The component manufacturer developed a new version of the ADIRU OPS, part number 347B-HNC-100-08 (version -08) to remove the latent software failure reported with earlier OPS versions following version -03. Testing of OPS version-08 included failing multiple internal hardware items, then cycling power to the ADIRU. Proper function of the Fault Detection and Isolation software was verified by checking all outputs, data words and the effect on ADIRU operations after failures were introduced.

In addition, the component manufacturer, along with the aircraft manufacturer, conducted a review of the OPS hierarchy using 'state of the art' analysis criteria and additional analytical tools to determine the OPS susceptibility to other events of this type.[23] The analysis did not identify any potential problem areas.

Aircraft Manufacturer

On 9 August 2005, the aircraft manufacturer issued a Multi Operators Message, to all B777 operators that recommended that they do not despatch an aircraft with an inoperative secondary attitude air data reference unit (SAARU), which was previously permitted under the conditions of the Master Minimum Equipment List.

On 19 August 2005, the aircraft manufacturer issued Fleet Team Digest Article 777-FTD-34-05002, to further inform B777 operators of the upset event.

On 26 August 2005, the aircraft manufacturer issued Service Bulletin 777-34A0137 which directed operators to install OPS version -03 to prevent erroneous accelerations that affect the primary flight computer control laws during normal and automatic flight. That service bulletin was mandated by FAA Emergency AD 2005-18-51.

On 22 November 2005, the aircraft manufacturer issued Service Bulletin 777-34A0138 which directed operators to install OPS version -08 and was an alternative method of compliance with Emergency AD 2005-18-51.

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23 Using *Software Considerations in Airborne Systems and Equipment Certification* RTCA/DO-178B.

Additionally, the aircraft manufacturer informed the Australian Transport Safety Bureau (ATSB) that the following aircraft operations manuals were revised:

- 11 October 2006, the B777 Flight Crew Training Manual was revised to include information regarding UPSET RECOVERY procedures
- 11 October 2006, the B777 Flight Crew Training Manual was revised to include information regarding disconnecting the Primary Flight Computers.
- 11 December 2006, the B777 Quick Reference Handbook was revised to include the addition of an AIRSPEED UNRELIABLE checklist, that reinforces the use of pitch and thrust
- 11 December 2006, the B777 Flight Crew Operations Manual was revised to include an improved description and standardised wording of the disarmed versus the disconnected state of the autothrottle system.

Aircraft operator

On 29 August 2005, the aircraft operator issued a technical and development department circular to its B777 flight crew advising them to check the ADIRU for any accelerometer faults prior to despatch. If an accelerometer was failed, then the flight crew were to ensure that the SAARU was serviceable, and that the autopilot was not engaged below 500 ft above ground level.

Effective 3 March 2006, the aircraft operator included several exercises on jet upset recovery and airspeed unreliable scenarios in recurrent B777 simulator training.

Effective 3 March 2006, the aircraft operator complied with Flight Crew Operations Manual bulletins issued by the aircraft manufacturer on all fleet aircraft and had installed OPS version -08 in accordance with B777 Service Bulletin 777-34A0138.

APPENDIX A: TECHNICAL ANALYSIS REPORT

ATSB TECHNICAL ANALYSIS REPORT

Analysis of Flight Recorders
Aviation Occurrence 200503722
130 NM North-west of Perth, WA
Boeing 777-200, 9M-MRG
1 August 2005

SUMMARY

The aircraft was fitted with a Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR). The operator provided the ATSB with both flight recorders which were downloaded by ATSB Technical Analysis staff to assist in the analysis of this incident.

Approximately 18 minutes after takeoff, as the aircraft climbed through 36,500 ft, Flight Level (FL) 365, a pitch upset event commenced in response to erroneous vertical, lateral and longitudinal acceleration data provided by the Air Data Inertial Reference Unit (ADIRU) to the aircraft. The data was not flagged to the aircraft as invalid. Erroneous acceleration values were recorded for the remainder of the flight.

The autopilot was manually disconnected and nose down column was applied by the crew. The aircraft pitched to 18 degrees nose up and climbed to approximately FL410 with a rate of climb up to 10,560 feet per minute (fpm). The airspeed decreased from 270 kts to 158 kts. The autopilot (A/P) overspeed and stall protection activated simultaneously and the autopilot flight director system (AFDS) pitch mode failed prior to A/P disconnection. The stick shakers activated near the top of the climb.

The aircraft subsequently descended 4,000 ft before momentary re-engagement of the autopilot by the flight crew resulted in another nose-up pitch (13 degrees) and climb of 2,000 ft. The maximum rate of climb during this excursion was 4,400 fpm. The response of the aircraft reported by the flight crew was confirmed from the FDR data.

Other non-acceleration related outputs sourced from the ADIRU remained valid for the flight. The upset was a result of erroneous acceleration data transmitted by the ADIRU combined with effects of A/P disconnection/ reconnection and automatic autothrottle (A/T) mode activation with the A/T armed during the event and for the remainder of the flight.

The flight crew conducted a descent and return to Perth from FL380 without the autopilot engaged. During the approach, the aircraft's windshear alert warning system indicated a windshear condition, but the crew continued and landed the aircraft on Perth runway 03. The flight time was 46 minutes. The CVR was of limited value in this analysis because the upset event had been overwritten by subsequent ground operations.

FACTUAL INFORMATION

Introduction

On 1 August 2005 at approximately 1703 Western Standard Time, a Boeing 777-200 aircraft, registered 9M-MRG, was being operated on a scheduled passenger service from Perth to Kuala Lumpur, Malaysia. The crew reported that they observed a low airspeed warning on the aircraft's engine indicating and crew alerting system (EICAS) while climbing through 38,000 ft, Flight Level (FL) 380. At the same time, the aircraft's slip/skid indication deflected to the full right position on the Primary Flight Display (PFD). The PFD speed tape then indicated that the aircraft was approaching the overspeed limit and the stall speed simultaneously. The aircraft reportedly pitched up and climbed to approximately FL 410 and the indicated airspeed decreased from 270 kts to 158 kts. The stall warning and stick shaker devices reportedly also activated.

The ATSB requested the flight data recorder (FDR) and cockpit voice recorder (CVR) from the operator to assist in their investigation. The operator advised that a Quick Access Recorder (QAR) was not fitted to the aircraft. The recorders were provided to ATSB investigation staff in Perth and transported to Canberra on the 1 August 2006. ATSB Technical Analysis staff in Canberra performed the download and analysis of the recorded flight data.

Flight recorder data recovery procedures

The FDR fitted to 9M-MRG at the time of the incident, was a Sundstrand solid-state memory flight data recorder, part number 980-4700-003, serial number 0609. The FDR was received at the ATSB Technical Analysis laboratory on 2 August 2005.

An image of the recorded flight data was made using the AlliedSignal Handheld Download Unit (HHDLU) on 2 August 2005. Examination and analysis of the FDR data was carried out using Flightscape Insight™ software. The recorded flight data from the incident flight was provided to the aircraft manufacturer on the 3 August 2005.

The FDR was found to contain 26.1 hours of recorded flight data which included the incident flight and five previous flights. The FDR was returned to the operator on 8 August 2005.

Tables, plots and an animation of relevant recorded engineering parameters were prepared to assist in analysis of the incident using Flightscape Insight™ software and the aircraft manufacturer's signal details document.

CVR data recovery procedures

The CVR fitted to 9M-MRG at the time of the incident was an AlliedSignal solid state memory cockpit voice recorder, part number 980-6022-001, serial number 0587.

An image and decompression of the CVR memory was made using the AlliedSignal Playback and Test System (PATS) software on 2-4 August 2005.

The CVR was found to contain approximately 121 minutes of audio data. The recording, however, contained only the last five minutes prior to touchdown of the incident flight. The remaining time comprised of audio recorded while on the ground in Perth following the incident. The CVR was returned to the operator on 8 August 2005.

Examination of the CVR recording was carried out using Sony Soundforge™ software.

Flight data parameters

Plots and tabular listings of the parameters considered relevant to this incident were prepared.

Table 1: Key engineering parameters examined

Parameter name: **(sense)**	**Units:**	**Sampling interval (secs):**
Western Standard Time (WST)	hh:mm:ss	4
Barometric pressure altitude (1013.25)	feet	1
Computed airspeed	knots	1
Groundspeed	knots	1
Mach number	units	2
Vertical speed (+ve sense up)	fpm	1
Displayed heading	degrees	1
Drift angle (+ve sense drift right)	degrees	4
Pitch attitude (+ve sense nose up)	degrees	0.25
Roll attitude (+ve sense right wing down)	degrees	0.5
Indicated Angle of Attack (+ve sense nose up)	degrees	1
Vertical acceleration (+ve sense up) (Nz)	g	0.125
Lateral acceleration (+ve sense right) (Ny)	g	0.25
Longitudinal acceleration (+ve sense fwd) (Nx)	g	0.25
Wind direction	degs	4
Wind speed	kts	4
Latitude	degs	4
Longitude	degs	4
Engine Pressure Ratio (L & R engine)	units	1
Throttle rate command (L & R engine) (+ve sense towards greater thrust)	(degs per sec)	1
Thrust lever angle ((L & R engine)	degrees	1

Table 2: Key discrete parameters examined

Parameter name	Units	Sampling interval (secs):
A/P engaged	No A/P engaged/ any A/P engaged	1
A/P disconnect normal	Warning inactive/ warning active	1
A/P caution	Not caution / caution	1
Captain/ F/O A/P engage request switch pressed	A/P request engage not active/ A/P request engage active	1
A/P overspeed protect active	A/P overspeed protection not active/ A/P overspeed protection-active \	1
A/P stall protect active	A/P stall protection not active/ A/P stall protection active	1
AFDS pitch/ roll engaged modes	Various modes	1
A/P F/D pitch/ roll mode fail	Pitch mode not failed/ Pitch mode failed	1
A/P caution (from EICAS)	Message not active/ message active	1
A/P disconnect normal/ manual (from EICAS)	Message not active/ message active	1
L/R autothrottle (A/T) arm switch selected to arm	A/T switch not selected to arm/ A/T switch selected to arm	1
A/T engaged modes	None, Speed, Idle, Test, Hold, Thrust, Thrust Reference modes	1
A/T manual or automatic disconnect (from EICAS)	Message not active/ message active	1
Master warning light on (Captain/ FO)	Master warning light not illuminated/ Master warning light illuminated	1
Stick shaker (L/ R)	Stick shaker not activated/ Stick shaker activated	1
Overspeed warning	No warning/ warning	1
Ground proximity windshear warning	Not GPWS windshear warn/ GPWS windshear warn	1
ADIRU/ SAARU data invalid	Message not active/ message active	2
ADIRU Inertial Reference Data invalid	Message not active/ message active	2
3-axis accelerometer data is suspect	Acceleration data is not suspect (OK)/ Acceleration data is suspect (not OK)	2

Greenwich Mean Time (GMT) was recorded on the FDR. The local time of day Western Standard Time (WST) was used in this analysis and was calculated from GMT+ 8 hours.

Parameters that are sourced from the Air Data Inertial Reference System (ADIRS) included:

- pressure altitude
- computed airspeed
- mach number
- wind speed
- wind direction
- vertical speed
- pitch attitude
- roll attitude
- heading
- temperature
- drift angle
- accelerations.

Groundspeed, latitude and longitude can also be sourced from the ADIRU.

FDR recorded acceleration values

The B777 does not have accelerometers located at the aircraft centre-of-gravity (c.g). The ADIRU, located in the electronics bay, contains accelerometers that calculate the c.g accelerations within a range of ±8g for all accelerations which are then transmitted to the AIMS Digital Flight Data Acquisition Function (DFDAF) card. The DFDAF retransmits the vertical acceleration at ±8g but the longitudinal and lateral accelerations are truncated to a range of ±2g and resolution of 0.002. The longitudinal and lateral acceleration range and resolution recorded on the FDR comply with the standards in ICAO Annex 6 (i.e. ±1g and ±1.5% of max range).

Autothrottle(A/T) and Autopilot (A/P) interactions

The A/T system moves the thrust levers to provide speed or thrust control depending on the A/T mode engaged. The A/T must first be armed prior to engagement. The A/T can be used with or without the A/P engaged. On A/T engagement with the A/P engaged, the A/T mode engaged is dependent on the selected AFDS pitch mode. If no pitch mode is selected, the A/T engages in the speed (SPD) mode.

With the A/T armed, the A/T automatically activates if there is no A/P active and the airspeed is less than a flight management computer (FMC) calculated value or thrust is below the reference thrust.

The thrust levers can be manually positioned without disengaging the A/T. After manual positioning, the A/T system repositions the thrust levers to comply with the engaged mode unless the A/T mode is HOLD.

Sequence of events

A sequence of events was developed from the FDR and CVR readout and is shown in Table 3. Greenwich Mean Time (GMT) was recorded on the FDR, but was converted to Australian Western Standard Time in this sequence of events.

Table 3: Sequence of events

Time (WST)	Event
16:44:22	9M-MRG takes off from runway 03 Perth Airport at computed airspeed of 166 kts and groundspeed of 153 kts. A/T arm switch selected and remained at this position for entire flight.
17:02:46	9M-MRG climbed through 36,000 ft at a vertical speed of 1,392 fpm, computed airspeed of 275 kts and groundspeed of 419 kts. Aircraft pitch attitude steady at +3.9º. All recorded accelerations are at reasonable values - vertical acceleration ≈+1g, lateral acceleration ≈ 0g, longitudinal acceleration ≈ +0.06g. A/P engaged in VNAV/ LNAV mode. A/T engaged in thrust reference mode with EPRs = 1.5.
17:03:11 Start of In-flight upset	9M-MRG climbing through 36,571 ft at vertical speed of 1,392 fpm, computed airspeed of 271 kts groundspeed of 418 kts. A/P engaged in VNAV/ LNAV mode. A/T engaged with TLAs = 65º, EPRs = 1.5. All accelerations change abruptly within a fraction of a second. Vertical acceleration decreases to -2.3g (i.e. down) within ½ s. Lateral acceleration decreases to -1.01g (i.e. left) within ½ s. Longitudinal acceleration increases to +1.2g (i.e. forward) within ½ s.[24]
17:03:12 – 17:03:29	9M-MRG pitches nose-up to +17.6º and climbs through 38,590 ft at a vertical speed increasing to 10,560 fpm. A/P overspeed and stall protection activate together and the AFDS pitch mode goes to FAIL resulting in A/T changing to speed mode. The A/P disengages and the thrust levers retard slightly before returning to original 65º position. A/P disconnect is again pressed and thrust levers retarded to 45º. All accelerations maintain their excessive values. Airspeed reduces through 241 kts.
17:03:30 – 17:03:54	9M-MRG continues climbing at a decreasing vertical speed reaching a maximum pressure altitude of 41,480 ft at a computed airspeed (CAS) of 171 kts. Indicated angle of attack (AoA) increased to 10.5º. Stick shaker activates at 17:03:52.
17:03:55 – 17:03:59	9M-MRG pitch attitude increased to 12.8º with angle of attack (AoA) at 10.5º and CAS of 160 kts. Aircraft altitude is 41,400 ft. The stick shaker activates
17:04:00 – 17:04:04	A minimum CAS of 158.5 kts occurs while aircraft nose lowers to a pitch attitude of 2.1º. Stick shaker continues. Thrust levers retarded from 43º to 38º with A/P disconnect activated. Aircraft begins descending from FL413.
17:04:09 – 17:04:16	9M-MRG at FL409. Stick shaker activates at airspeed of 163 kts. A/T disconnected.

24 When the ADIRU was tested at the manufacturer the vertical acceleration output ≈ -3.3g (-2.3g cg referenced), lateral acceleration output ≈-1g and longitudinal acceleration output ≈ +3.1g.

Time (WST)	Event
17:04:17 – 17:04:58	Aircraft pitches nose down (to -7.4º) with rate of descent reaching 7,824 fpm before rate of descent (RoD) and pitch attitude decreases. During descent, stick shaker activates a number of times prior to A/P re-engaged at 17:04:39 in VNAV/ LNAV mode resulting in immediate activation of A/P overspeed and stall protection and pitch mode failure. A/P disconnected five seconds later. Descent continues to 36,974 ft and CAS increases to 240 kts.
17:04:59	9M-MRG commences climb from FL370.
17:05:34	A/T re-engaged in speed mode at FL378.
17:05:37 – 17:05:41	9M-MRG at FL380. First officer (F/O) engages A/P in vertical speed and track hold mode. Pitch mode fails and stall protection active. Pitch mode is changed to flight level change mode.
17:05:42	A/T mode changed to thrust mode.
17:05:45	Pitch attitude reaches 12.7º (AOA 6.3º) at FL384.
17:05:47	Vertical speed reaches 4.400 fpm and A/P disconnected at FL386.
17:06:10	Vertical speed reduces to zero at FL390.
17:06:14	A/T changed to speed mode.
17:06:17 – 17:06:18	9M-MRG at FL390. Stick shaker activates at airspeed of 203 kts.
17:06:19	Aircraft commences descent to FL380 stick shaker activates during descent.
17:11:56	9M-MRG commences descent from FL380.
17:23:04 – 17:23:06	9M-MRG at FL200. right A/P engaged in vertical speed and heading attitude hold mode. Aircraft pitches nose up and the pitch mode fails and stall protection activated. A/P disconnected.
17:24:20 – 17:24:31	9M-MRG at FL197. left A/P engaged in flight level change and heading hold mode. Aircraft pitches nose down and banks to the right. A/P disconnected.
17:24:51 – 17:24:58	A/P re-engaged in vertical speed heading hold modes with immediate pitch mode failure.
17:24:59 – 17:25:03	9M-MRG at FL167. A/P pitch mode changed to flight level change mode and pitch mode failure ceases. A/P disconnected at 17:25:04.
17:34:32	Altitude 2,742 ft. A/T disconnected.
17:34:45	Altitude 2,585 ft. A/T re-engaged in speed mode.
17:36:47 - 17:36:50	9M-MRG descending through altitude of 1,427 ft on final approach. Windshear warning from the GPWS activates.
17:38:30	9M-MRG touches down on Perth runway 03 at computed airspeed of 143 kts (groundspeed 141 kts).

Graphical and animated representation of flight data

Various representations of key parameters were prepared from the 9M-MRG downloaded flight data to assist in the analysis.

Graphical representation of relevant recorded data

General parameters over a 60-minute period containing the entire incident flight are displayed, see figure 6. Other relevant parameters are displayed over a 5-minute period incorporating the upset event, see figures 7-10.

Animated representation of relevant recorded data

An animation of the incident was prepared using Insight Animation™ software and is part of this report. A file containing the animation in Insight View™ format (.isv) is available for download from the ATSB website. This file requires the installation of an Insight Viewer that can be downloaded from www.flightscape.com/products/view.php at no charge. A still screen capture of the animation is shown at figure 11.

ANALYSIS

Recorder analysis

The recorded flight data was utilised to accurately determine the sequence of events leading up to and subsequent to the in-flight upset event. The oldest recorded audio data was during the final approach approximately 5 minutes prior to touchdown. This was 30 minutes after the start of the incident so detailed analysis of the audio information was not required.

The upset event commenced as a response to erroneous vertical, lateral and longitudinal data provided by the ADIRU to the aircraft as it passed through FL365. The data was not flagged as invalid. Altitude, airspeed, mach number, wind speed, wind direction, vertical speed, pitch attitude, roll attitude, heading, temperature, drift angle and air data sourced from the ADIRU appeared to remain valid. The groundspeed, latitude and longitude outputs from the ADIRU were also not affected despite these parameters being derived from acceleration data. This indicated that valid acceleration data was available within the ADIRU and that a problem during the output processing of the accelerations within the ADIRU had occurred.

The erroneous acceleration values were recorded for the remainder of the flight. The response of the aircraft reported by the crew was confirmed in the FDR data. This was a direct result of erroneous acceleration data transmitted by the ADIRU combined with effects of A/P disconnection/ reconnection and automatic A/T mode activation with the A/T armed during and subsequent to the event.

FDR recorded acceleration values

The digital flight data acquisition function (DFDAF) card retransmits the longitudinal and lateral accelerations truncated to a range of ±2g and resolution of 0.002g. The ADIRU manufacturer advised that the failed output of the ADIRU in longitudinal acceleration when tested was 2g higher than the FDR recorded value (approximately +3.1g compared with FDR value of +1.1g). The aircraft manufacturer advised that the aircraft response in the upset matched that expected from a longitudinal acceleration of the higher value. The recorded lateral and vertical accelerations matched those measured during tests on the failed ADIRU by the manufacturer.

CVR analysis

The oldest recorded audio was found to be approximately 5 minutes prior to the incident flight touchdown. The remainder of the audio was recorded during ground activities in Perth following the incident. This indicated that electrical power to the CVR was not isolated following the incident flight and consequently the most useful recorded audio information was overwritten. The CVR recording was able to confirm activation of the windshear warning during approach but otherwise was not able to be utilised in the analysis of this incident.

FINDINGS

Contributing factors

- Erroneous acceleration values sourced from the Air Data Inertial Reference Unit (ADIRU) and flagged as valid to the aircraft precipated an in-flight upset as the aircraft climbed through FL365.
- The engine autothrottle remained armed for the entire incident flight. The autothrottle was manually disconnected during the event but re-engaged automatically in response to autopilot mode failures and disconnections. This resulted in thrust lever movements that complicated the upset.

Other key findings

- The autothrottle and autothrottle were engaged during the climb prior to the upset.
- Approximately 18 minutes after take-off as the aircraft climbed through FL365 accelerations abruptly changed from reasonable values to excessive values within ½ sec. The vertical acceleration decreased to -2.3g, longitudinal acceleration increased to +1.2g (recorded – actually +2.2g) and lateral acceleration decreased to -1.01g.
- Erroneous acceleration values from the ADIRU were recorded for the remainder of the flight. The acceleration data was recorded as being flagged to the aircraft as valid.
- The recording range for longitudinal and lateral accelerations recorded by the FDR (±2g) was smaller than the output range of the ADIRU (±8g). The ICAO standard is ±1g.
- Other outputs sourced from the ADIRU such as altitude, airspeed, mach number, wind speed, wind direction, vertical speed, pitch attitude, roll attitude, heading, temperature, and drift angle remained valid for the flight.
- During the approach at an altitude of 1,427 ft, the aircraft's windshear alert warning system indicated a windshear condition, the crew continued the approach and landed the aircraft on Perth runway 03.

REFERENCES

- Boeing Document D247W018-8, Revision B, 16 May 2003 - 777 Flight Data Recording System, Signal Details Document – 1997 rule – 128WPS data rate
- Boeing Document D632W001-MAS, 11 December 2000 – 777 Flight Crew Operations Manual.
- ICAO – Annex 6 to the Convention on International Civil Aviation– Part 1 International Commercial Air Transport – Aeroplanes, Attachment D. Flight Recorders, 8th Edition July 2001.

Figure 6: General parameters over sixty-minute period

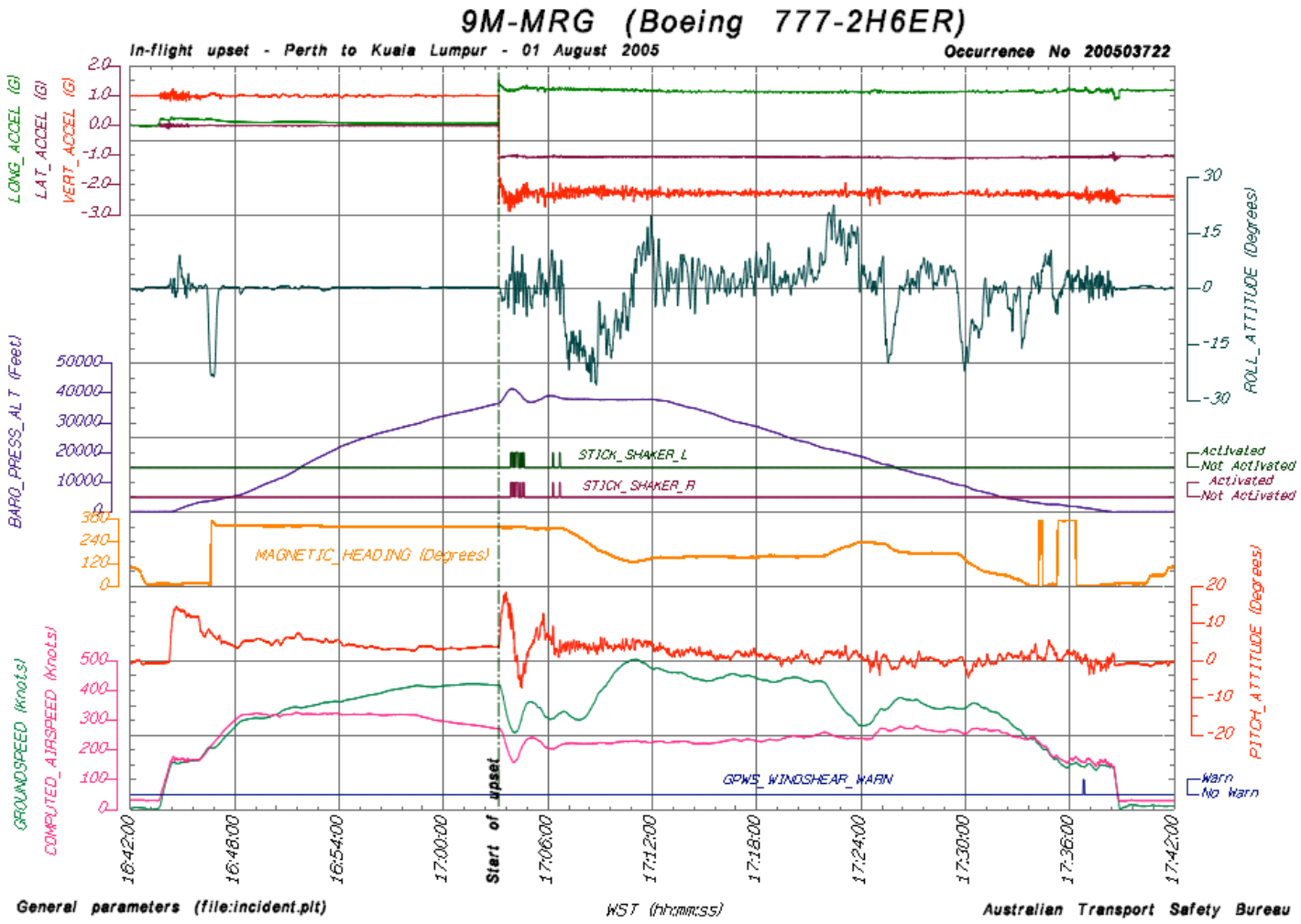

Figure 7: Relevant parameters displayed over a five-minute period

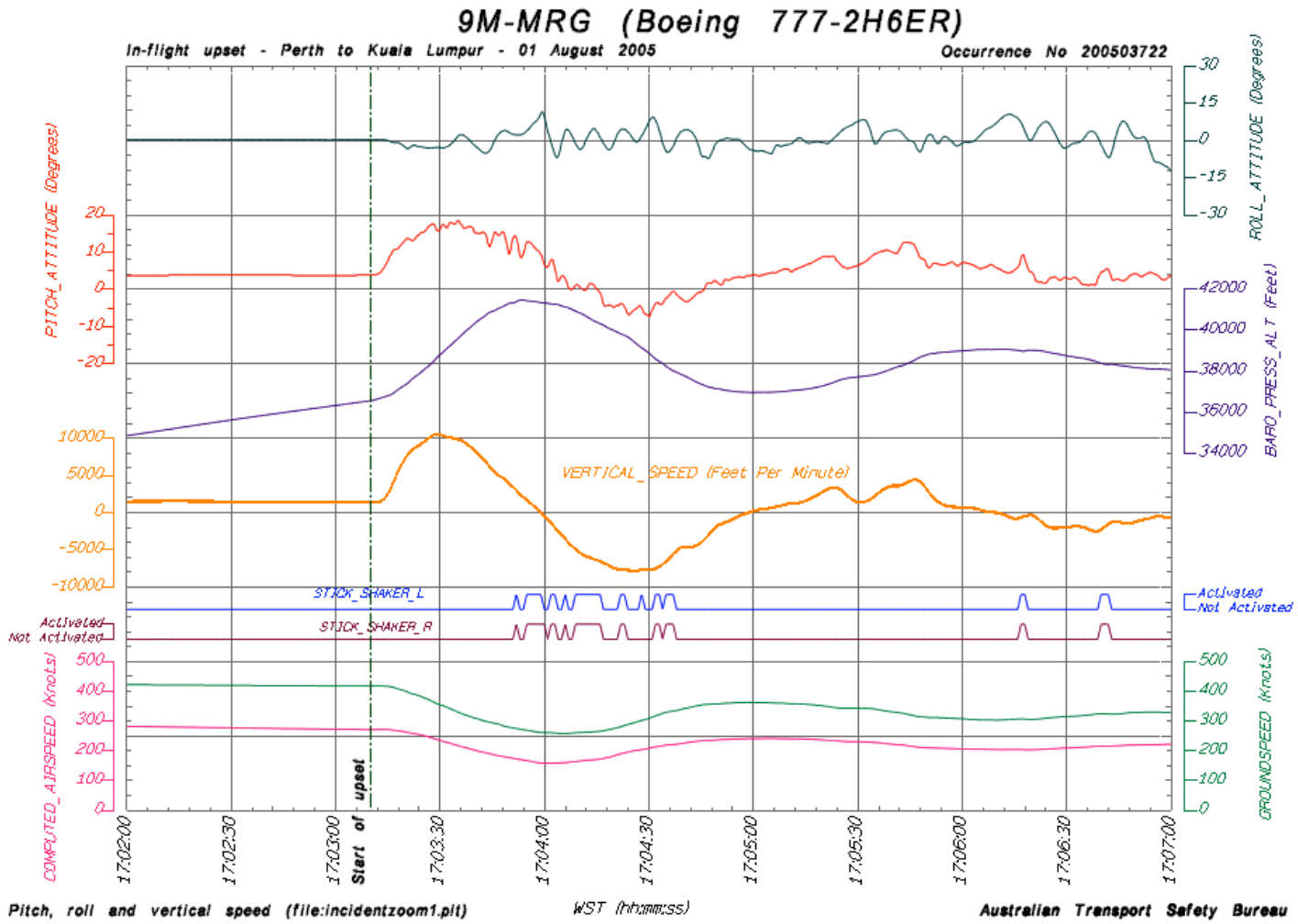

Figure 8: Relevant parameters displayed over a five-minute period

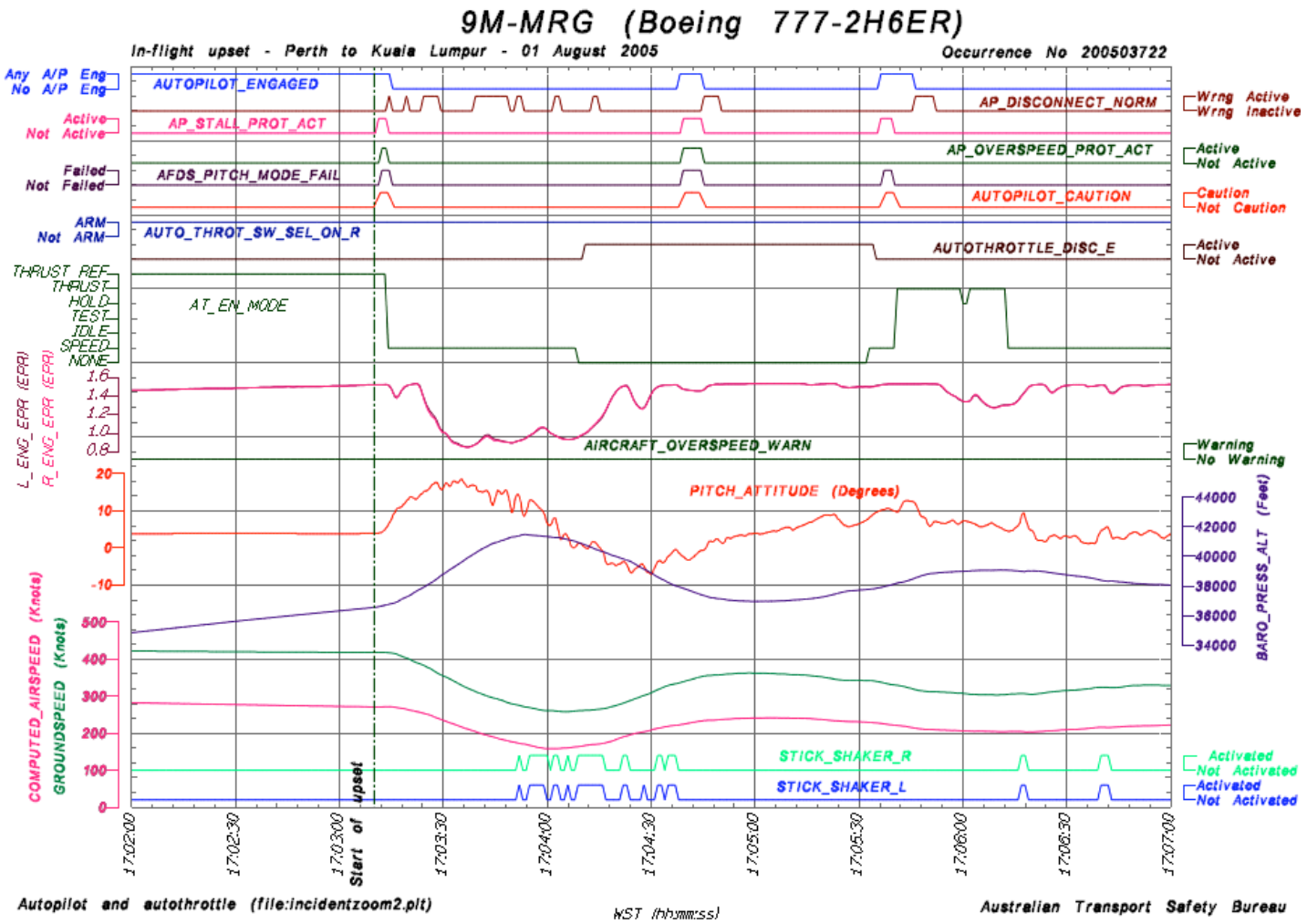

Figure 9: Relevant parameters displayed over a five-minute period

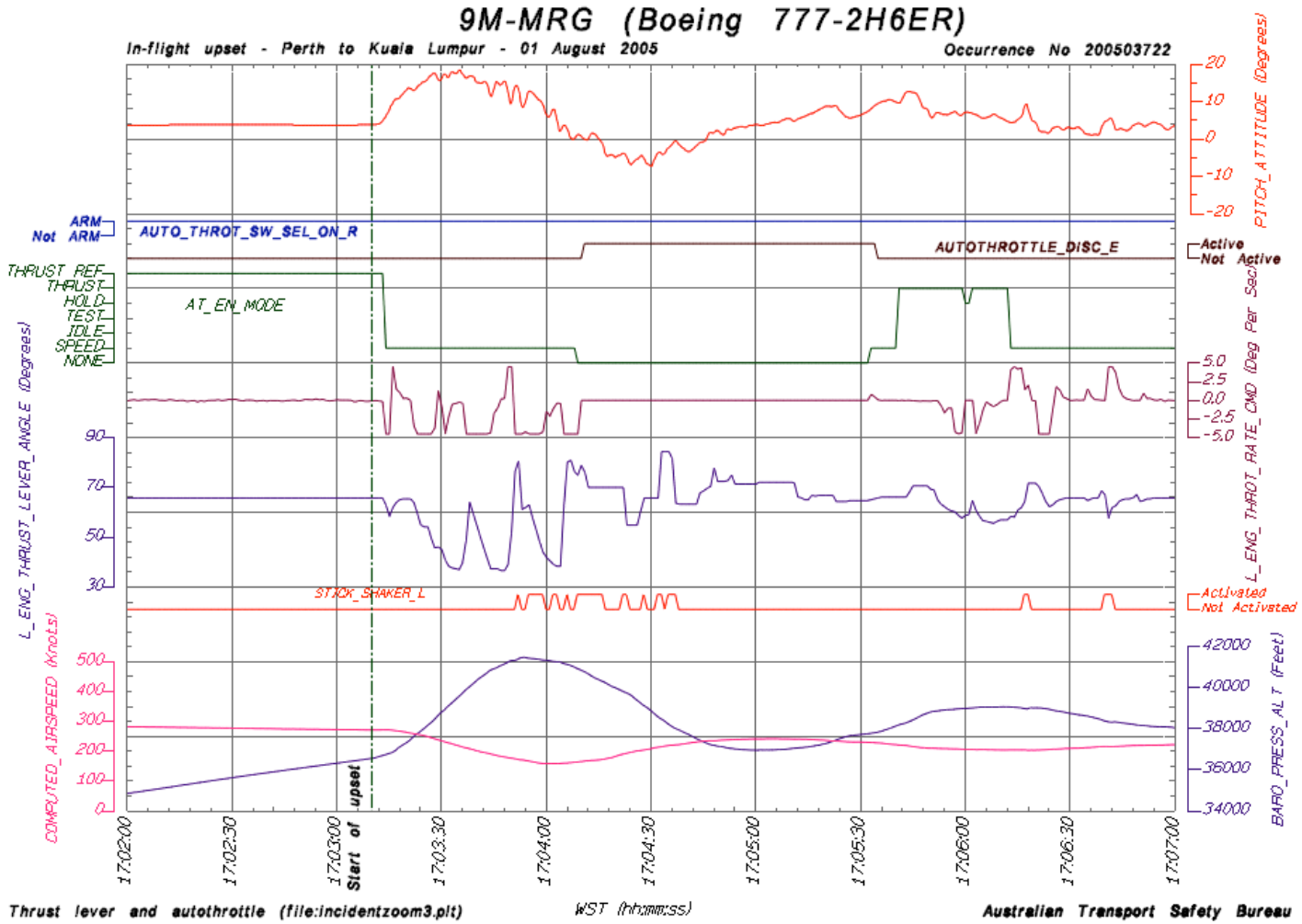

Figure 10: Relevant parameters displayed over a five-minute period

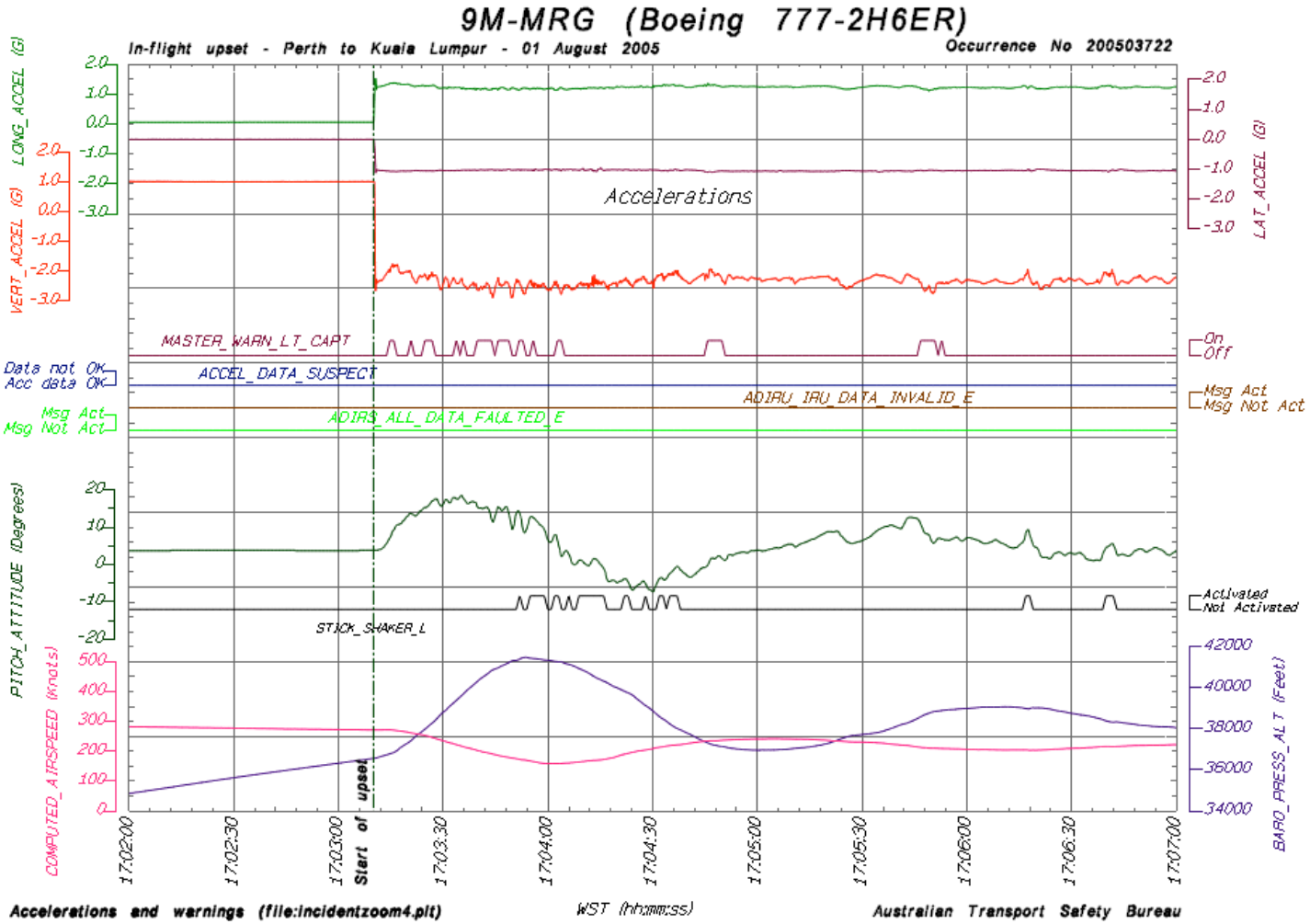

Figure 11: Screen capture of 9M-MRG animation