Boeing 747-419, Air New Zealand ZK-NBU, failure of inertial reference units 300 nm north-east of auckland, 12 March 1997

Micro-summary: **A failure of a brake control system unit due to water contamination takes out the inertial reference unit data bus.**

Event Date: **1997-03-12 at 0032 NZDT**

Investigative Body: **Transport Accident Investigation Commission (TAIC), New Zealand**

Investigative Body's Web Site: **http://www.taic.org.nz/**

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Report 97-005

Boeing 747-419

ZK-NBU

failure of inertial reference units

300 nm north-east of Auckland

12 March 1997

Abstract

On Wednesday 12 March 1997, at 0032 hours, Boeing 747-419 ZK-NBU was enroute from Auckland to Los Angeles as Flight NZ18. The Captain's electronic primary flight display no longer displayed flight reference information and appeared blank. An internal failure within the brake system control unit, due to water ingress, in turn caused a fault with the inertial reference unit data bus supplying information to the Captain's display. An alternate inertial reference unit was selected and it failed to supply the required information. The selection of a third inertial reference unit resolved the problem and the Captain regained his display. The two affected systems were turned off and the aircraft returned to Auckland without further incident. Safety issues discussed include the adequacy of the Quick Reference Handbook and the vulnerability of an inertial reference unit to an external fault. Safety recommendations were made on both these safety issues.

Transport Accident Investigation Commission

Aviation Incident Report 97-005

Aircraft type, serial number and registration:	Boeing 747-419, 25605, ZK-NBU
Number and type of engines:	Four Rolls-Royce RB211-524G
Year of manufacture:	1992
Date and time:	12 March 1997, 0032 hours[1]
Location:	300 nm north-east of Auckland Latitude: 34° 30' S Longitude: 179° 25' E
Type of flight:	Scheduled air transport
Persons on board:	Crew: 19 Passengers: 420
Injuries:	Crew: nil Passengers: nil
Nature of damage:	Nil
Pilot-in-Command's Licence:	Airline Transport Pilot Licence (Aeroplane)
Pilot-in-Command's age:	57
Pilot-in-Command's total flying experience:	Over 20 000 hours 1663 hours on type
Investigator-in-Charge:	K A Mathews

[1] All times in this report are NZDT (UTC + 13 hours)

1. Factual Information

1.1 On Tuesday 11 March 1997 at 2340 hours B747-419 ZK-NBU began taxiing at Auckland International Aerodrome for departure to Los Angeles, as flight NZ18. On board were 3 pilots, 16 cabin crew and 420 passengers.

1.2 The flight had been scheduled to depart earlier that evening, but was delayed before dispatch due to a fault with the aircraft antiskid system requiring the brake system control unit (BSCU) to be replaced.

1.3 The aircraft departed normally and climbed to flight level 295. After departure however several messages appeared on the engine indication and crew alerting system (EICAS) screen. These included antiskid advisory and autobrakes system and brake limiter status messages. The advisory message was displayed only for a short period but the status messages remained. As the status messages were for information purposes, only requiring action prior to dispatch, and maintenance after the next landing, the Captain elected to continue with the flight. (See 1.22).

1.4 At about 0032 hours the Captain's electronic primary flight display (PFD) "went blank". The PFD was still "alive" but did not display attitude, heading and vertical speed information. Warning flags signalling the loss of information appeared on the PFD.

1.5 The pilots noticed numerous alert messages showing on the EICAS screen including, electronic interface unit (EIU) disagree, traffic alert and collision avoidance system (TCAS), and inertial reference system (IRS) left. A weather radar message appeared on the navigation display. The stick shaker activated. The right automatic pilot, engaged at the time, disconnected but was re-engaged satisfactorily. The automatic throttles disengaged.

1.6 The Captain re-selected the centre panel EIU source selector switch from automatic (AUTO) to centre (C) with no change to his display. The Captain followed the guidance in the Quick Reference Handbook (QRH) for the aircraft dealing with IRS alert messages and selected his IRS source selector switch from its normal left (L) position to C. An "IRS CENTRE" advisory message then appeared on the EICAS screen with no change to the PFD. The Captain selected IRS right (R). The PFD indications began to flicker on and off for some five minutes. The left and centre inertial reference units (IRU) were subsequently switched to ATT (attitude), with no change, then to OFF.

1.7 Following some further flickering of the Captain's PFD it finally stabilised and presented normal information.

1.8 The First Officer's flight displays were already selected to IRS R, in accordance with standard practice, and remained normal throughout the flight. No switch selections were made from his side.

1.9 The Captain decided to return to Auckland Aerodrome and dumped sufficient fuel to bring the aircraft down to its maximum authorised landing weight. During descent antiskid, brake limiter and body gear steering alert messages displayed on the EICAS screen. The Captain asked for the emergency services at Auckland Aerodrome to be placed on standby, as a precaution, since cross-wind conditions existed for the landing and the instrument landing system (ILS) was out of service. The aircraft landed safely at around 0230 hours.

1.10 Air New Zealand engineering services discovered a central maintenance computer (CMC) message 32282 (BSCU fail) displayed and replaced the BSCU. All three IRUs were aligned satisfactorily and the left IRU was replaced as a precaution. Following replacement of the BSCU the faults did not reoccur.

1.11 The fault was traced to water entering the BSCU. The BSCU was located in the aircraft in an avionics equipment bay, situated under the forward cargo container compartment. The "floor" structure in the cargo container compartment consists of transverse structural beams, leaving an open area under them. Supporting rails, for cargo containers loaded into the compartment, are laid longitudinally on the beams.

1.12 A moulded plastic (polycarbonate) dripshield, situated under the transverse beams, protects the BSCU from accumulated water dripping from the cargo containers. However, after replacement of the BSCU it was discovered that the dripshield was cracked. There was heavy rain at Auckland when cargo containers were loaded into the cargo compartment of ZK-NBU and during the departure of the aircraft.

1.13 It was determined that the water probably entered the BSCU via the cracked dripshield. The water ingress to the unit caused a BSCU internal failure of the Captain's IRS input to the antiskid cards within the BSCU. A BSCU voltage spike on IRU bus three is likely to have occurred causing an internal failure of IRU bus one (see 1.20), resulting in the failure of the Captain's PFD to present normal information. When the Captain selected the IRS to C and then R the centre and right IRUs were connected in turn to the same fault source. An "IRS RIGHT" message did not show on the EICAS screen.

1.14 Three ring-laser gyroscopic IRUs (left, centre, and right) make up the IRS in the B747-400 series aircraft. The purpose of the IRS is to provide aeroplane orientation and movement data necessary for control and navigation. Each IRU makes independent measurements of aeroplane attitude change rates and linear accelerations. The IRU calculates and provides attitude, heading, velocity, navigation and acceleration information.

1.15 The Captain's IRS source selector is normally selected to the left IRU and the First Officer's source selector is normally selected to the right IRU. In the event of an IRS alert message being displayed on the EICAS screen the QRH requires an operable IRU to be selected by moving the IRS source selector to either L, C or R. The IRS mode selector for the affected IRU should then be selected to ATT. If the IRS fault message is still displayed after 30 seconds the affected IRU should be turned OFF via the IRS mode selector.

1.16 The IRU attitude mode is a reversionary mode providing some in-flight recovery of inertial functions in the event of loss of alignment, temporary total power loss or certain equipment failures. Attitude mode can be selected in flight from any mode and only requires the aircraft to be flying reasonably straight for about 30 seconds. If attitude mode is selected from the navigation mode all built-in test equipment (BITE) faults should clear, and the system should begin alignment for attitude mode operation. The non-selected IRUs can be operated in attitude mode. In this mode the IRU provides valid attitude, heading, vertical speed, body accelerations and body rates. No navigation data is available.

1.17 The aircraft manufacturer advised that the attitude mode should function normally on an IRU faulted by an external fault voltage from the BSCU input, if an alternate IRU is selected before selecting attitude mode on the faulted IRU. This sequence should isolate the first IRU from the BSCU input. The Captain reported however, that he selected attitude mode on the left and centre IRUs after selecting the right IRU, with no change to the IRS messages.

1.18 Each IRU feeds three separate external Aeronautical Radio Incorporated (ARINC) 429 data buses (one, two and three) that are buffered from one another. Each bus independently supplies attitude data to various units. Dedicated systems, including attitude and flight director commands for the PFD, run off each bus. Normally the Captain's PFD is driven by the left EIU which receives input from the left IRU bus one. The First Officer's PFD is driven from the right EIU which receives input from the right IRU bus one. The centre IRU bus one is available to both the left and right EIUs.

1.19 If a data bus is faulty other units utilising the data bus will also be affected, resulting in multiple status or higher priority messages being displayed to the pilots.

1.20 It is a design requirement that the IRUs should not be faulted by any external failures such as a shorted or open circuited data bus, and one faulty data bus should not affect another. An IRU transmitter fault should not affect the performance of other transmitters in the same IRU. Testing of the BSCU removed from ZK-NBU has shown that BSCU BITE power (28v DC) shorted across the ARINC 429 receiver and back fed through the data bus into the IRU ARINC 429 transmitter. If an IRU is back fed with a voltage in excess of about 5 to 7.5 volts DC the IRU output transmitter wraparound BITE test can trip. This can result in the IRU transmitting fail warning data on all three output buses and displaying IRS alert messages on the EICAS screen.

1.21 The aircraft manufacturer said that although the IRU has three separately buffered ARINC output transmitters, the BITE fault response to an output transmitter wraparound test failure was inappropriate, as it was classified as a critical fault. A single transmitter fault could therefore result in output data on all three buses being invalidated.

1.22 Continuous annunciation of all the flight critical aircraft system faults is performed by the EICAS. Alerting messages are shown on the primary EICAS display unit with their degree of urgency indicated by colour and associated aural signals. Warning messages are red, caution and advisory messages are amber, and status messages are white. Warning messages indicate a system condition that requires immediate corrective or compensatory action by the crew. Caution messages indicate a system condition that requires immediate crew awareness and future compensatory crew action. Advisory messages indicate a system condition that requires crew awareness and possible future compensatory crew action. Status messages, displayed on the auxiliary (lower) EICAS display, indicate minimum equipment list related items requiring crew awareness prior to dispatch only.

1.23 The aircraft was equipped with independent standby flight instruments providing attitude, airspeed, altitude and heading information. A global positioning system (GPS), very high frequency omni-directional radio range (VOR), instrument landing system (ILS), distance measuring equipment (DME) and automatic direction-finding equipment (ADF) systems were fitted. These systems provided additional long-range and short-range navigation and approach guidance information and were independent from the IRUs. ILS localiser and glideslope deviation information was available on the standby attitude indicator as well as the navigation display.

1.24 Boeing Service Bulletin (SB) 747-25-3033 alerted operators to the potential for dripshields to crack and therefore allow accumulated water from cargo containers to leak onto the avionics equipment located directly below the dripshields. The SB stated the cracking resulted from service and maintenance personnel stepping on the dripshields despite the dripshields being clearly marked with NO STEP signs.

1.25 The SB was issued following repeated reports of damage to the existing polycarbonate dripshields. The SB recommended replacement of the dripshields with aluminium panels. No compliance time was specified.

1.26 The company's Engineering Services were aware of the SB but had afforded it a low priority for action due to its non-urgent nature. Forty-eight working hours are required to replace the dripshields

1.27 Following the incident Engineering Services changed the SB to a higher priority, requiring replacement of the dripshield as soon as practicable and not later than the next aircraft base maintenance check. A fleet inspection was carried out on all B747-400 aircraft and temporary repairs carried out as necessary to any cracked dripshields. Several dripshields were found cracked. The forward cargo compartment area in ZK-NBU was previously inspected on 15 February 1997. There was no record of the dripshield having been found cracked or repaired as a result of that inspection.

2. Analysis

2.1 The BSCU installed in ZK-NBU was affected by water ingress to the unit. A cracked polycarbonate dripshield over the BSCU allowed accumulated water from cargo containers, loaded into the cargo compartment above the BSCU, to drip onto the unit and leak into it.

2.2 The water in the BSCU caused an internal failure of the IRS input to the antiskid cards in the BSCU which in turn affected the left IRU data bus three. An inappropriate IRU BITE response to this fault resulted in fail warning data being transmitted on buses one, two and three. This caused the Captain's PFD to lose flight reference information and for warning flags to show. Other systems connected to the buses were also affected and several related navigation display and EICAS messages were displayed to the pilots.

2.3 The Captain followed the QRH procedures for IRS EICAS alert messages and selected a serviceable IRU by moving his IRS source selector switch to C. This action connected the centre IRU bus three to the same defective BSCU input line, causing the EICAS to indicate a failure of the centre IRU in a similar way to the left IRU, and an "IRS CENTRE" advisory message appeared on the EICAS screen.

2.4 The Captain then selected the right IRU by moving his IRS source selector switch to R. The EICAS did not annunciate a defect in the right IRU although potentially a fault could have been introduced causing the right system to be faulted in the same way as the left and centre IRUs. The Captain, by following the QRH, connected each of the three IRUs in turn to the same fault source. Why the right system and the First Officer's PFD were not affected is unclear. However, if enough water had drained away from the sensitive circuitry in the BSCU, it is likely the IRU input to the BSCU did not have enough conductivity to its voltage source to cause a failure internal to the IRU. Enough conductivity probably remained for a time to affect the ARINC 429 signal quality on the bus, resulting in the Captain's PFD flickering on and off for a few minutes.

2.5 After following the QRH procedures, if an IRS fault did not clear, the Captain was required to turn off the faulted system. Had an "IRS RIGHT" message also been displayed and the QRH followed, with a fault message not clearing, the pilots could have shut down all three IRUs. Although this was unlikely the potential existed for it to occur. Once the IRUs are turned off the aircraft must be stationary for re-alignment of the navigation function.

2.6 Although the manufacturer believed the IRUs should have functioned normally in attitude mode, following correct selection, the events reported by the Captain indicate the two affected IRUs did not operate in attitude mode after he followed the QRH sequence of actions.

2.7 The aircraft was equipped with standby flight instruments and a navigational system independent of the affected systems. Had all three IRUs been shut down the pilots had sufficient flight reference instruments to fly the aircraft safely using the backup systems.

3. Findings

3.1 A BSCU internal failure, a component external to the IRU, initiated a critical fault condition in the IRU selected by the Captain.

3.2 The IRU fault resulted in the Captain's PFD losing flight reference information.

3.3 The IRUs were vulnerable to an external fault.

3.4 The internal failure of the BSCU resulted from water ingress to the unit via a cracked dripshield.

3.5 The dripshield was susceptible to cracking.

3.6 The non-implementation of the SB recommending replacement of the dripshield led to the ingress of moisture into the BSCU.

3.7 As the SB was not a mandatory requirement the allocation of a low priority for action was appropriate for the status of the bulletin.

3.8 The existing QRH procedures (for an IRS alert message) allowed a pilot to continue to select alternate IRUs following an indicated failure of one unit, thereby enabling each IRU in turn to be connected (inadvertently) to the same fault source.

3.9 The procedures in the QRH created potential for the First Officer's PFD to lose flight reference information, and for all three IRUs to be turned off in flight if a fault message did not clear.

3.10 The aircraft was capable of being flown safely by using the standby flight instruments and additional navigational equipment on board.

4. Safety Recommendations

4.1 Following this investigation it was recommended to the Director, Air Safety Investigation, Boeing Commercial Airplane Group, that he:

4.1.1 Review the QRH for the B747-400 series regarding the procedure for IRU selection by the crew, after an EICAS IRS fault message is displayed, to determine if any change is necessary to ensure all three IRUs are not switched off unnecessarily, (038/97) and;

4.1.2 Carry out an investigation, and take any necessary action, to ensure the design requirement for an IRU not to be faulted by an external failure, such as a shorted or open circuited data bus, is met, (039/97).

4.2 The Director for Air Safety Investigation, Boeing Airplane Group, responded:

4.2.1 In regards to the Quick Reference Handbook (QRH), we have concluded that a revision to the QRH as requested in the subject report does not conform to the 747-400 flight deck procedures philosophy.

The basic philosophy is that EICAS messages are the primary cue for accomplishing a non-normal procedure. If a message is displayed, the flight crew refers to the associated non-normal procedure. Non-normal procedures generally address single failures. It is not possible to develop procedures for all situations particularly those involving multiple failures. Therefore, the IRS procedure has been written assuming a single failure. If a second failure occurs when selecting an operable IRU, the flight crew must use appropriate judgement to determine the best course of action. It is not possible to write the non-normal procedure which correctly addresses all possible multiple failure scenarios.

4.2.2 According to Boeing specifications, the IRU wraparound BITE test failure should not be a critical failure which causes the box to transmit data with FW (Fail Warning) SSMs (Sign Status Matrix) on all outputs and annunciate IRS failure in-flight on EICAS.

Accordingly, Boeing is currently working with the IRU supplier, Honeywell, to incorporate a software change to the ARINC output wraparound BITE test to change it from a critical to a non-critical fault and eliminate this type of discrepancy. In addition the IRU transmitter circuit designs are being reviewed to determine if sufficient transmitter to transmitter isolation exists to tolerate a worst case external bus fault voltage that could knock out one transmitter. We anticipate that corrective action for the IRU may be available during 1st quarter 1998.

18 August 1997

Hon. W P Jeffries
Chief Commissioner