FLIGHT SAFETY FOUNDATION

Accident Prevention

Vol. 55 No. 5 *For Everyone Concerned with the Safety of Flight* May 1998

Boeing 737 Postmaintenance Test Flight Encounters Uncommanded Roll-and-yaw Oscillations

Fluid leaking from the cabin onto the yaw-damper coupler in the electronic-and-equipment bay affected electronic signals transmitted to the yaw-damper actuator and caused a dutch-roll oscillation.

FSF Editorial Staff

On Oct. 22, 1995, a Boeing 737-236 Advanced was in straight-and-level flight at Flight Level (FL) 200 (20,000 feet), at an indicated airspeed of 290 knots when roll-and-yaw oscillations began. The flight crew disengaged the autopilot, autothrottles and yaw damper, but the uncommanded roll-and-yaw oscillations continued.

The crew declared an emergency and descended to 7,000 feet. The oscillations stopped when airspeed was reduced to about 250 knots. After a satisfactory check of the aircraft's low-speed handling characteristics, the crew returned to London (England) Gatwick Airport and landed without further incident.

The U.K. Air Accidents Investigation Branch (AAIB), in its final report on the incident, identified four causal factors:

- "Contamination of the connector on the yaw-damper coupler, in the electronic-and-equipment (E&E) bay, by an unidentified fluid had occurred at some time prior to the incident flight and compromised the function of [the yaw-damper coupler's] pin-to-pin insulation;
- "Sufficiently conductive contaminant paths between certain adjacent pins had affected the phase and magnitude of the signals transmitted to the yaw-damper actuator, thereby stimulating a forced dutch-roll mode of the aircraft;
- "The location of the E&E bay — beneath the cabin floor in the area of the aircraft doors, galleys and toilets — made it vulnerable to fluid ingress from a variety of sources; [and,]
- "The crew actions immediately following the onset of the dutch-roll oscillations did not result in the disengagement of the malfunctioning yaw-damper system."

The B-737, operated by British Airways, was built in 1980 and had accumulated 37,871 hours in service. The aircraft had undergone a "P6 check," a major inspection required every five years or 11,200 flight hours. The inspection included removal of the aircraft's galleys and toilets, disassembly of the E&E bay, and removal of the avionics equipment to facilitate corrosion checks and cleaning.

Boeing 737-236 Advanced

The Boeing 737 first flew in April 1967. The Advanced Model 737-200, introduced in 1971, has aerodynamic improvements, including modified wing-leading-edge slats, Krueger flaps and engine-nacelle fairings, as well as automatic brakes and a new antiskid system. Standard accommodation is for two flight crewmembers and 120 passengers. The aircraft has two Pratt & Whitney JT8D-15 turbofan engines rated at 15,500 pounds (6,975 kilograms) thrust each. Standard maximum ramp weight is 116,922 pounds (52,615 kilograms). Standard maximum landing weight is 103,822 pounds (46,720 kilograms). Maximum cruising speed at Flight Level 330 (33,000 feet) is 462 knots.♦

Source: *Jane's All the World's Aircraft*

"There were no indications of any abnormalities which may have indicated heavy fluid contamination," said the report. "Evidence of dried-blue-fluid (toilet-sanitizing-fluid) contamination was noted on the floor structure under the toilet, but … this was considered commonplace. AAIB examination of several similar aircraft … confirmed this."

After the structural inspection was completed, the E&E bay was reassembled and the avionics equipment was reinstalled and tested.

"This included a built-in-test-equipment (BITE) check on the yaw-damper coupler," said the report. "No malfunctions were found.

"The main-rudder PCU [power control unit] had been replaced by a unit modified to Boeing SB [service bulletin] 737-27-1185 (*Rudder PCU — Replacement of the Dual Servo Valve*), but in all other respects, the rudder/yaw-damper-system components were the same as those fitted prior to the P6 maintenance check."

Both pilots assigned to the postinspection test flight had airline transport pilot licenses and B-737 type-rating-examiner ratings issued by the U.K. Civil Aviation Authority (CAA). The captain also had a CAA-approved test-pilot rating. The captain had 8,290 hours of flight time, including 5,500 hours in type. The first officer had 8,600 hours of flight time, including 6,000 hours in type.

Aircraft takeoff weight was 87,502 pounds (39,376 kilograms); maximum authorized takeoff weight is 117,222 pounds (52,750 kilograms). The fuel load was 23,333 pounds (10,500 kilograms), with 4,444 pounds (2,000 kilograms) of fuel in the center fuel tank.

"Neither wing tank was full, with the right wing containing more fuel than the left because of earlier ground-running of the engines and the auxiliary power unit," said the report.

The aircraft took off from Runway 26L at London Gatwick Airport at 1553 hours local time. The captain used left-rudder trim and left-aileron trim to maintain wings-level flight during the initial climb.

"The crew assessed [the lateral-trim imbalance] to be due to the fuel imbalance," said the report. "The [fuel] crossfeed was opened, and fuel was used from the right wing tank until lateral balance was achieved."

The aircraft flew through a layer of clouds between 3,000 feet and 4,000 feet. The temperature was 10 degrees Celsius (50 degrees Fahrenheit).

"There was no cloud above this, and no icing was encountered," said the report. "At the time of the incident, it was daylight [with] clear air, no turbulence and … a good horizon above a general overcast."

The aircraft climbed in stages to FL 200. The first officer took control of the aircraft while the captain checked the speed-brake system. Both pilots then donned supplemental-oxygen masks to prepare for a test of the passenger-oxygen-mask automatic-deployment system. The test required the pressurization system to be reset to a cabin altitude of 14,000 feet.

The aircraft was on a heading of 270 degrees when an uncommanded left roll began at 1607. The flight-data recorder (FDR) showed that the aircraft initially rolled three degrees left-wing-down before the autopilot began to roll the aircraft back to a wings-level attitude.

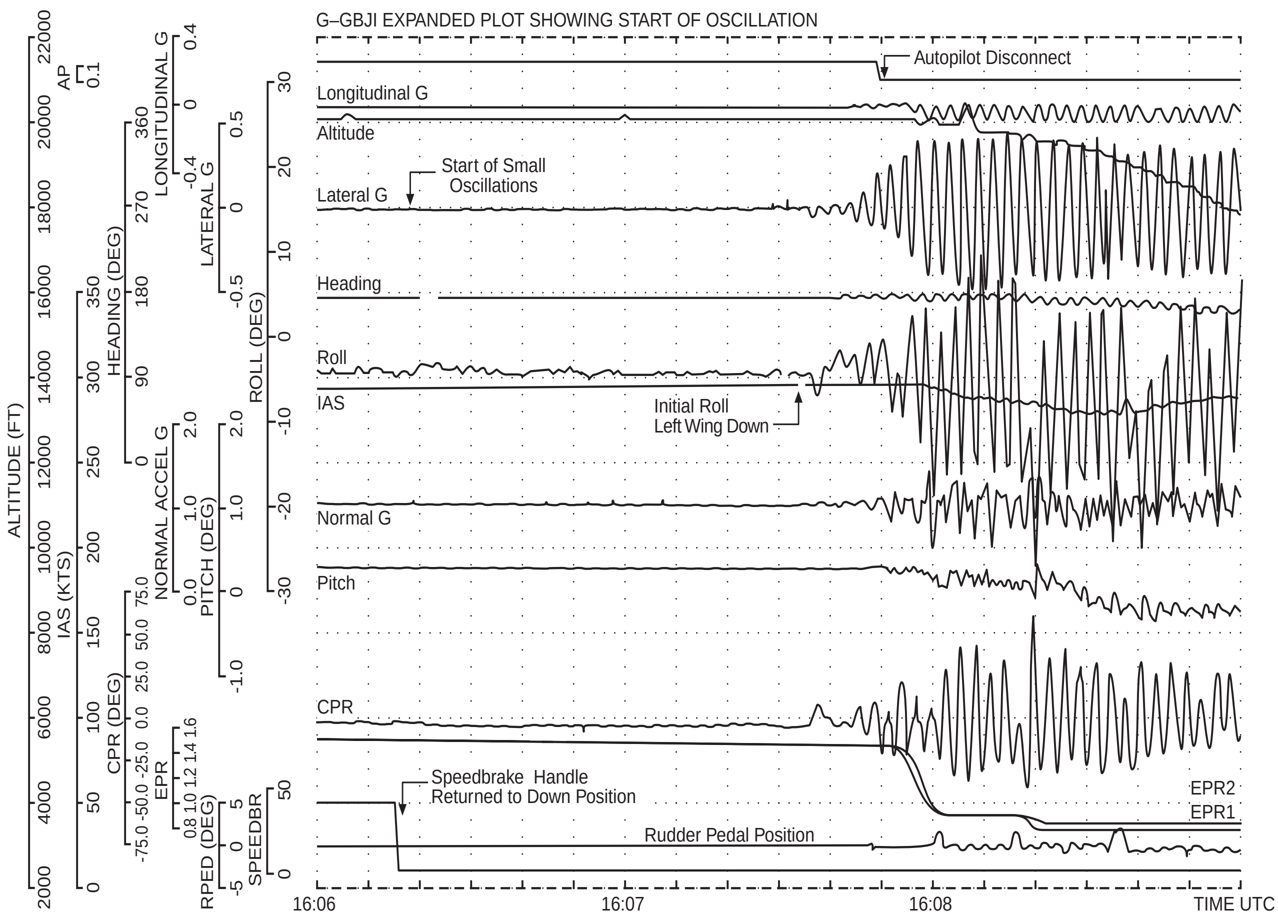
The report said that roll-and-yaw oscillations then began (Figure 1 and Figure 2, page 4). The oscillations became larger in amplitude for the next 15 seconds.

The captain told the first officer to turn off the autopilot and autothrottles. The roll-and-yaw oscillations continued after the autopilot and autothrottles were turned off. The first officer was unable to stop the oscillations with manual control-wheel inputs.

"The crew reported that the oscillations were similar to dutch roll, with a period of about two to three seconds," said the report. "The roll control felt normal to apply, with no signs of any mechanical reversion. There were no indications of any abnormalities associated with the hydraulic systems [which power the flight-control surfaces] throughout the flight. The characteristics of the oscillations did not appear to change when the autopilot was disengaged."

The captain then turned off the yaw damper because the yaw-damper indicator showed oscillation. Disconnection of the yaw damper was in accordance with Boeing Operational Bulletin GUI(C/K/L)-15, issued in August 1995, said the report.

Flight Data Recorder Plot Showing Start of Roll-and-yaw Oscillations, British Airways B-737, Oct. 22, 1995

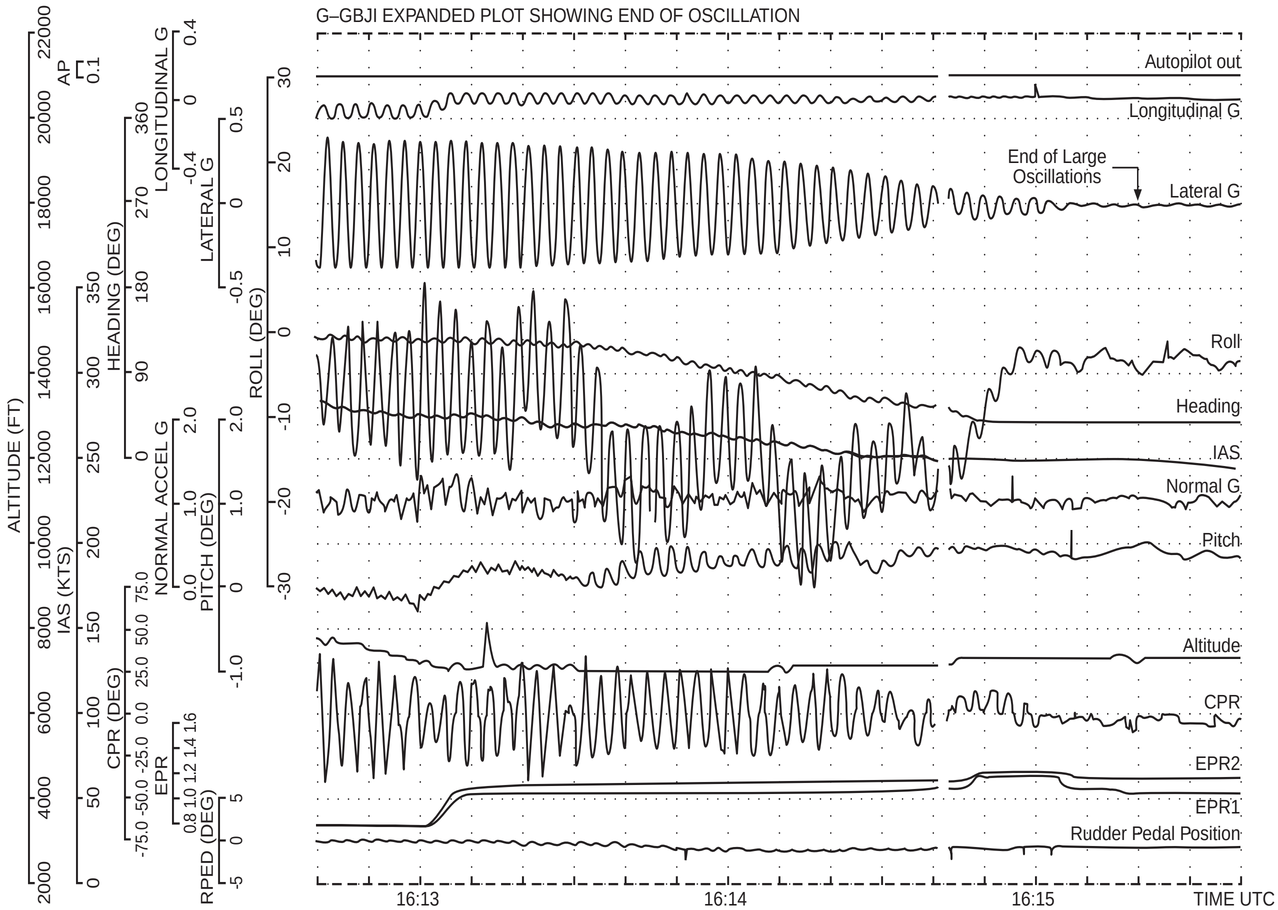


Note: G-GBJI = aircraft identification; EPR = engine pressure ratio; DEG = degrees; G = acceleration of gravity; UTC = universal time coordinated; SPEEDBR = speedbrake; IAS = indicated airspeed; FT = feet; RPED = rudder pedal; CPR = control position roll; KTS = knots

Source: U.K. Air Accidents Investigation Branch

Figure 1

Flight Data Recorder Plot Showing End of Roll-and-yaw Oscillations, British Airways B-737, Oct. 22, 1995



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Source: U.K. Air Accidents Investigation Branch

Figure 2

The bulletin said that there are three yaw-damper failure modes:

"First, the system can fail and not provide commands to deflect the rudder. … In a second failure mode, the yaw-damper system gives commands that appear as an oscillation or erratic motion in the yaw axis. The third failure mode occurs when the system commands a full yaw-damper input."

The incident aircraft experienced the second yaw-damper-failure mode described in the bulletin. The bulletin said that the procedure for this failure mode is to turn off the yaw damper.

The captain took control of the aircraft and began an immediate descent. The report said that the captain wanted to descend to an altitude at which the flight crew would not have to use supplemental oxygen.

The captain was not able to stop the roll-and-yaw oscillations with control-wheel inputs.

The crew made a MAYDAY declaration by radio at 1609. Air traffic control offered a radar vector to the nearest airport. The vector required a left turn to a heading of 170 degrees. The report said that the captain was reluctant to turn the aircraft because he believed that the aircraft's bank angle would become excessive during the turn.

"The crew had the impression that the bank angle would have continued to increase had opposite roll-control inputs not been applied," said the report. "Neither pilot could recall any movement of the rudder pedals, and no deliberate rudder-pedal inputs were made by the crew." [The yaw damper does not provide feedback to the rudder pedals.]

The crew maintained airspeed of 290 knots or higher during the descent. The captain turned over control of the aircraft to the first officer, to see if the first officer could stop the roll-and-yaw oscillations with control-wheel inputs. The first officer was unable to stop the roll-and-yaw oscillations.

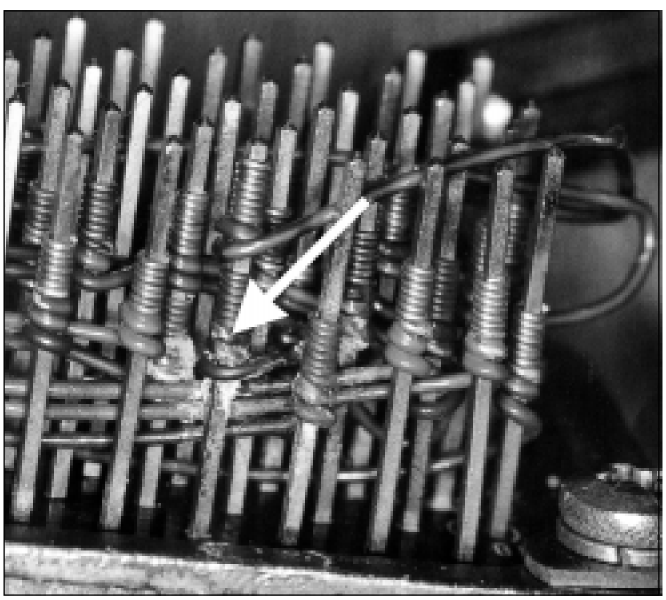
After leveling the aircraft at 7,000 feet, the pilots removed their oxygen masks. The captain took control of the aircraft.

"Some power was reapplied once the aircraft had leveled off, and the airspeed was allowed to decay towards 250 knots," said the report. "As the aircraft approached this speed, the oscillations began to decay rapidly and [then] stopped. The total duration of the roll/yaw event was about seven minutes."

The first officer went to the passenger cabin to inspect the aircraft's wings. He saw no abnormalities.

The flight crew then checked the aircraft's flying characteristics with the airspeed at 150 knots, the landing gear extended and the wing flaps extended 15 degrees. The aircraft handled well, and the crew maintained the aircraft configuration while returning to London Gatwick Airport. They changed the MAYDAY (distress) declaration to PAN (urgency).

The active runway at London Gatwick Airport was Runway 08R. Surface winds were from the south at five knots.



Contamination and corrosion deposits on yaw-damper coupler disrupted electronic signals sent to yaw-damper actuator. (Photo: U.K. Air Accidents Investigation Branch)

"The crew [decided] that the most appropriate checklist for landing [with 15 degrees of flap extension] was the one-engine-inoperative descent/approach/landing checklist," said the report.

"On checking the master caution [panel] in [compliance with] the landing checklist, the [captain] noted that the amber [flight-control-annunciator light] was illuminated. On checking, he saw that the yaw-damper-off amber light was illuminated, and he switched the system back on. However, on final approach, at about 3,000 feet, he felt that there may have been a small roll/yaw oscillation commencing. He therefore switched off the yaw damper and continued the approach for an uneventful landing at 1644 hours."

The aircraft was towed to a hangar. "It was agreed that the examination would commence by subjecting the aircraft to practically every check in the maintenance manual of the flying-control, autopilot and yaw-damper systems which could be achieved without breaking into any systems," said the report.

"The airframe was inspected visually. Nothing significant was found.

"The next stage involved a rigging check on all of the flying-control surfaces and cables which could be accessed without extensive removal of panels. Some discrepancies were found relative to the maintenance-manual requirements for both control-surface rigging and cable tensions, but there was nothing found which could have been responsible for the aircraft's aberrant behavior during the incident flight."

Function tests and BITE checks were performed on the flight controls, autopilot and yaw damper.

"Although the autopilot failed one of its parameter checks on the BITE test, analysis showed that this could have had no effect which would explain the aircraft's behavior," said the report. "None of the wiring checks performed at this stage revealed any abnormalities."

Structural checks of the vertical fin and rudder attachments then were performed in preparation for a test flight.

"These checks did not reveal any damage or excessive clearances in the attachment fittings or structure," said the report.

The aircraft was loaded to replicate the takeoff gross weight and center of gravity of the incident flight. The flight crew consisted of the captain of the incident flight and a Boeing test pilot. Several observers were aboard the aircraft for the test flight on Nov. 10, 1995.

The aircraft took off from Runway 08R at London Gatwick Airport and climbed to FL 200. The test flight was performed in the same area as the incident flight — between the Southampton VOR (very-high-frequency omnidirectional radio range) and Boscombe Down Airfield.

"The test pilot performed rudder doublets [i.e., applied pressure on one rudder pedal, then the other] in order to excite the dutch-roll mode, and the aircraft response was monitored," said the report. "The testing was unable to reproduce the forced lateral oscillations experienced during the incident flight. All of the tests indicated that the rudder [and] yaw-damper systems on the aircraft were operating correctly."

After the test flight, the yaw-damper coupler was removed and tested. No significant defects were found. The yaw-damper coupler then was disassembled to remove the rate gyro for testing.

"Contamination [and] corrosion deposits were found on the back of the multipin connector inside the [yaw-damper coupler]," said the report. "This took the form of bluish white, powdery deposits around some of the wire-wrapped connections to the back of the pins. Closer inspection also showed evidence of light grey deposits on the outside of the connector shell.

"These observations, which pointed toward moisture impingement on the outside of the connector and subsequent ingress into the unit, were reinforced when the lower cover plate for the unit was examined and signs of dried-fluid residue were seen on its inner face."

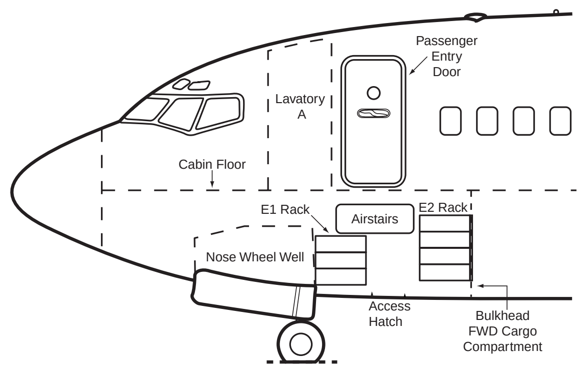
The moisture contamination created electrically conductive paths between pins on the yaw-damper-coupler connector. The contamination disrupted electronic signals sent from the yaw-damper coupler to the yaw-damper actuator and may have prevented the flight crew from turning off the yaw damper, said the report.

"Experiments demonstrated that it might be possible to generate stray current paths capable of sustaining engagement of the yaw-damper system when selected to OFF, but only in the presence of a high resistance in the engage-switch earth [ground] path. Although the evidence was tenuous, the possibility that such a resistance was present during the incident flight cannot be discounted."

The AAIB did not determine conclusively how moisture entered the E&E bay and contaminated the yaw-damper-coupler connector.

The E&E bay is in the forward section of the aircraft, between the nose-wheel well and the forward cargo compartment (Figure 3). The bay is below the passenger-door vestibule, the galley and the forward toilets. The retracted airstairs are stowed between three equipment racks. The bay has a fiberglass tray and a rubberized-fabric shroud to protect the equipment racks from moisture. The yaw-damper coupler is on the forward (E1) equipment rack.

Boeing 737 Forward-section Layout Showing Electronics-and-equipment Bay



Source: U.K. Air Accidents Investigation Branch

Figure 3

"Other measures were taken to prevent fluid spilled above the floor from dripping into the E&E bay, principally [by] sealing the floor panels and toilet [and] galley areas," said the report.

"It would appear that for any fluid leak to drip onto the subject connector, it is necessary to penetrate the rubberized-fabric shroud which is fitted above it. Once through this, [fluid] may drip onto the [avionics] cooling plenum, whose forward lip coincides with the array of connectors at the back of each unit on the E1 rack, particularly the [connectors for the] yaw-damper coupler, which is at the top [of the rack]."

The AAIB said that the avionics cooling plenum had traces of dried fluid, but there was no evidence of leakage from the shroud.

"Notwithstanding this, [the aircraft] operator has developed a modification which puts an aluminum tray between the plenum and the shroud," said the report. "[The tray] completely covers the forward face of the E1 rack, thus preventing any fluid which penetrates the shroud from dripping onto the connectors.

"A Boeing modification to achieve a similar standard of protection already existed but was not applicable to aircraft fitted with airstairs."

The report said that in January 1996 Boeing formed an E&E Bay Assessment Team to investigate potential contamination problems.

"The team's findings and recommendations were extensive," said the report. "Much of the [team's] report deals with detail improvements both to hardware and maintenance practices.

"The team found a wide variation in operator experience, but the findings may have been influenced by a lack of appreciation by some operators that they had an E&E bay fluid-contamination problem. For example, one aircraft [had] a history of [a malfunctioning] avionics [component] being returned from the repair shop repeatedly with reports of fluid contamination. Clearly, the operator had failed to make the connection between the high removal rate of this component and a persistent leak somewhere in the aircraft.

"[The E&E Bay Assessment Team also found] variation in operator expectation regarding the condition of the under-floor area, with some, including the operator of [the incident aircraft], apparently [believing] that evidence of blue staining is inevitable after a few years [of] service, while others managed to achieve high standards of cleanliness.

"The report's conclusion [was] that most problems with E&E bay contamination [are] related to … aircraft maintenance and servicing, rather than [to] how components are originally designed and installed. The report also did not uncover any evidence that a specific fluid leakage event will produce a near-term, unexpected, aircraft flight-path deviation," said the AAIB.

Based on its investigation, the AAIB made the following recommendations to the U.S. Federal Aviation Administration (FAA):

- "Require as soon as practical a visual inspection of all Boeing 737 aircraft E&E bays to check for fluid ingress into avionics components, their connectors and associated wiring. Such inspection should involve the minimum disturbance of equipment and connectors commensurate with a thorough examination for contamination. Where such contamination is found, the component should be removed and [sent] to workshops for examination; [and,]

- "Require as soon as practical an inspection of the area in and around the E&E bay for evidence on the structure and fittings of recent fluid leakage such as wet corrosion, staining and crystallized deposits. Such evidence should be investigated to ensure that, where the source of the leak is not apparent or readily rectifiable, no potential exists for it to impinge upon the avionics components, their connectors or wiring."

The AAIB made the following recommendations to the FAA and to Boeing:

- "Conduct an urgent review of the measures incorporated into the Boeing 737 to prevent fluid ingress into the E&E bay, its equipment, connectors and wiring, and, as necessary, require modifications to ensure that the equipment, connectors and wiring are provided with protection consistent with reliable operation; [and,]

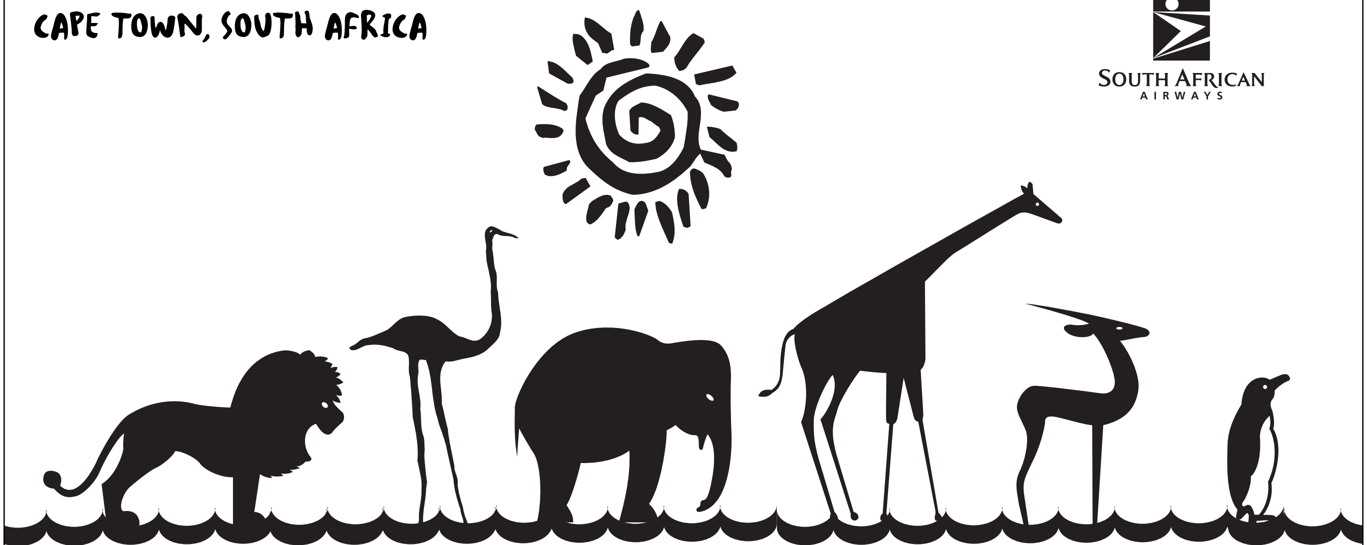
- "Conduct a review of the aircraft maintenance manual to ensure that clear and specific instructions are contained therein to enable evidence of fluid ingress, even if not apparently directly impinging on electrical equipment, to be identified during routine maintenance. It should also be ascertained that any routine testing for leaks in the toilet, galley and airstairs system should be done with the systems functioning fully throughout their normal operational cycle to ensure that any leaks which only occur during, for example, draining or replenishment cycles are detected."

The AAIB made the following additional recommendations:

- "The Boeing Co. [should] promulgate the findings of the E&E Bay Assessment Team to all operators and [publish] the recommendations … [in] service bulletins to maximize the protection from fluid ingress of bay-housed electronic components in current aircraft; [and,]

- "The CAA, with the FAA, [should] review FARs [U.S. Federal Aviation Regulations] and JARs [Joint Aviation Requirements] with a view to requiring that the location of electronic equipment be arranged during the aircraft design so as to minimize the potential for contamination by fluid ingress, with the intention of ensuring that the equipment, connectors and wiring are provided with protection consistent with reliable operation less heavily dependent on maintenance practices."♦

Editorial note: This article was based on *Report on the Incident to Boeing 737-236 Advanced, G-BGJI, 15 Nautical Miles Northwest of Bournemouth International Airport on 22 October 1995*, Aircraft Incident Report 1/98, prepared by the U.K. Air Accidents Investigation Branch. The 88-page report contains diagrams, photographs and appendixes.



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