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Erroneous Roll-attitude Indication Cited In Loss of Control of B-747 Freighter

During an instrument departure from London, England, the captain and the first officer received warnings about roll indications from the attitude-comparator system and from the flight engineer. The airplane was in a left turn, banked nearly 90 degrees, when it descended and struck the ground.

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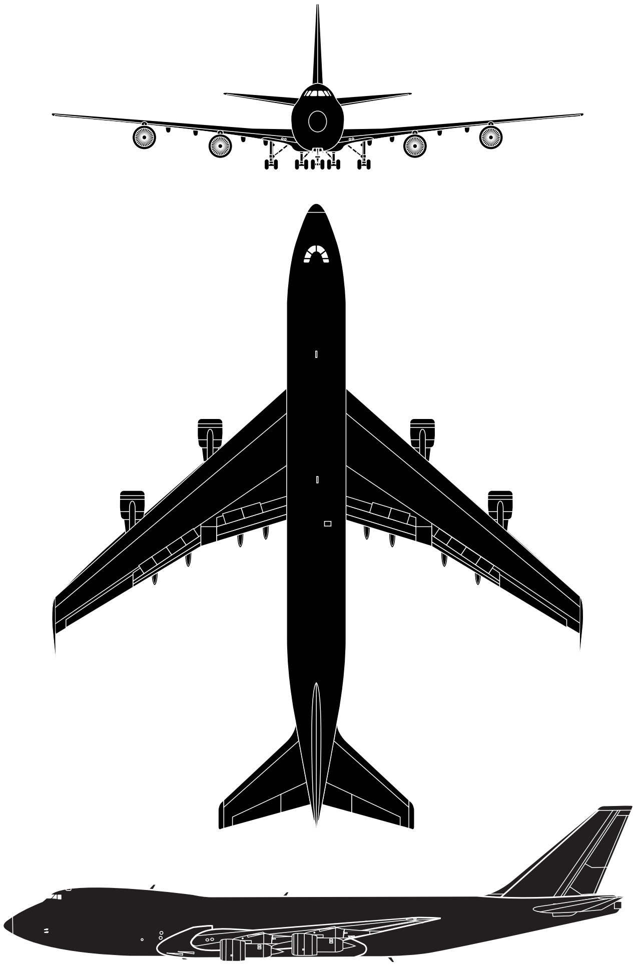
FSF Editorial Staff

At 1838 local time Dec. 22, 1999, a Boeing 747-200F, operated by Korean Air on a cargo flight, struck terrain near Great Hallingbury, England, during departure in instrument meteorological conditions from London Stansted Airport. The four occupants — the captain, first officer, flight engineer and ground engineer — were killed. The airplane was destroyed.

The final report on the accident, issued in 2003 by the U.K. Air Accidents Investigation Branch (AAIB), said that a malfunction of the captain's attitude director indicator (ADI) had been reported by the crew who had flown the airplane to London and that maintenance had been performed on the ADI before the accident crew's departure. The report said that the accident's causal factors were the following:

- "The pilots did not respond appropriately to the [attitude-] comparator warnings during the climb after takeoff from Stansted, despite prompts from the flight engineer;
- "The commander [captain], as the handling pilot [pilot flying], maintained a left roll-control input, rolling the aircraft to approximately 90 degrees of left bank, and there was no control input to correct the pitch attitude throughout the turn;
- "The first officer either did not monitor the aircraft attitude during the climbing turn or, having done so, did not alert the [captain] to the extreme unsafe attitude that developed;
- "The maintenance activity at Stansted was misdirected, despite the fault having been correctly reported using the *Fault Reporting Manual*. Consequently, the aircraft was presented for service with the same fault experienced on the previous sector; the no. 1 INU [inertial navigation unit] roll signal driving the captain's ADI was erroneous; [and,]
- "The agreement for local engineering support of the operator's engineering personnel was unclear on the division of responsibility, resulting in erroneous defect identification and misdirected maintenance action."

The crew who had flown the airplane, registered as HL-7451, to London received an aural warning and visual warnings from the attitude-comparator system during departure from Tashkent, Uzbekistan, in daylight, visual meteorological conditions. (The warnings result when the comparator detects, for more than one second, a difference of more than four degrees between the pitch/roll indications provided by the captain's ADI and



Boeing 747-200F

The Boeing 747-200F is a freighter version of the B-747-200 wide-body commercial transport. Introduced in 1972, the freighter can carry up to 250,000 pounds (113,400 kilograms) of cargo in containers or on pallets loaded through the airplane's nose, which is hinged just below the flight deck and pivots upward when opened. An additional cargo door on the side of the fuselage was available as an option. Production was discontinued in 1990.

The airplane was designed to be flown by three flight crewmembers, who board through two doors on the forward, left side of the fuselage.

Several engine models were available, including variants of the General Electric CF6-50 and CF6-80, Pratt & Whitney JT9D-7 and Rolls-Royce RB.211-524. Thrust ratings range from 48,570 pounds to 55,700 pounds (216 kilonewtons to 248 kilonewtons).

Depending on which engines are installed, maximum takeoff weight varies from 775,000 pounds to 833,000 pounds (351,540 kilograms to 377,849 kilograms). Maximum landing weight is 630,000 pounds (285,768 kilograms). Maximum range with a 200,000-pound (90,720-kilogram) payload and fuel reserves varies from 3,450 nautical miles to 4,250 nautical miles (6,389 kilometers to 7,871 kilometers).♦

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

the pitch/roll indications provided by the first officer's ADI. The aural warning is generated by horns. The visual warnings comprise a red "INST WARN" light on the panel and an amber light above each ADI.)

The captain compared the indications on his ADI with the indications on the standby attitude indicator and the first officer's ADI. He found that the pitch indications on his ADI were correct but that the roll indications were not correct. He transferred control of the airplane to the first officer.

Later, during climb to cruise altitude, the captain reset the attitude-and-compass-stabilization selector switch from "NORM" (normal) to "ALT" (alternate), which changed the source of attitude information for his ADI from the no. 1 INU to the no. 3 INU. The captain's ADI then showed correct roll indications, and no further warnings were generated. (When the attitude-and-compass stabilization selector switch on the first officer's panel is selected to "NORM," the first officer's ADI receives roll-attitude information from the no. 2 INU.)

After landing at Stansted at 1505, the captain reset the attitude-and-compass stabilization selector switch from "ALT" to "NORM."

The flight engineer told investigators that he made a technical-log entry that the captain's ADI was "unreliable in roll" and that he consulted the *Fault Reporting Manual* (FRM) for the correct terminology and fault code to enter in the technical log.

The technical log was destroyed during the accident. International Civil Aviation Organization (ICAO) standards and U.K. aviation regulations require that copies of technical-log entries be retained at ground facilities; nevertheless, a copy of the technical-log entry about the captain's ADI was not retained by the airline's handling agent at Stansted.

"Since no copy of the technical log was left at Stansted, [the flight engineer's statement about the technical-log entry] cannot be verified, but a review of previous entries in the aircraft logbook showed that Korean Air crews routinely used the FRM, and the words 'not reliable' are those used in the manual to describe the fault."

The ground engineer on the accident flight was present when the airplane arrived at Stansted. He was briefed about the ADI malfunction by the incoming flight engineer. The flight engineer told investigators that the briefing included the fact that the ADI functioned properly after the captain reset the attitude-and-compass stabilization selector switch to "ALT."

"The inbound flight crew then left the aircraft without meeting the outbound [accident] crew, who were due to operate HL-7451 to Milan [Italy] (Malpensa) Airport later that day," the report said.

Korean Air operated one scheduled freight operation each week at Stansted and had a contract with a local company, FLS Aerospace, to provide maintenance services. While cargo was being offloaded and loaded on the accident airplane, the ground engineer and two engineers from FLS Aerospace performed maintenance on the ADI. The engineers did not have a *Fault Isolation Manual* (FIM), which contains information on specific maintenance actions required for each fault code in the FRM.

Maintenance performed by the engineers included cleaning the ADI electrical connectors, reseating a connector socket and testing the ADI. The engineers selected the "TEST" button on the ADI and observed correct test indications — which include comparator warnings — with the attitude-and-compass stabilization selector switch selected to "NORM" and to "ALT." Although the tests showed that the ADI, itself, was functioning properly, the tests provided no information about the source of data for the instrument.

The report said that the engineers likely believed that reseating the displaced connector socket had solved the problem. Nevertheless, the fact that the ADI functioned correctly after the inbound captain selected the no. 3 INU showed that the fault was not with the instrument or with its connections but with the attitude data supplied to the ADI by the no. 1 INU. The displaced connector socket had nothing to do with the reported ADI malfunction.

"Cross-reference to the FIM during the defect investigation would have led to identification of the correct maintenance response, which was the replacement of the no. 1 INU," the report said. "Alternatively, the aircraft could have been dispatched [in compliance with maintenance/operating provisions in the airplane's minimum equipment list] with the captain's ADI receiving attitude data from INU no. 3 by selecting 'ALT' on the attitude-and-compass stabilization selector switch."

The outbound captain and first officer arrived at the airport about 1630. Investigators did not determine whether the ground engineer briefed them about the reported ADI malfunction and the maintenance that had been performed.

The captain, 57, had 13,490 flight hours, including 8,495 flight hours in type. The first officer, 33, had 1,406 flight hours, including 195 flight hours in type. The flight engineer, 38, had 8,301 flight hours, including 4,511 flight hours in type. The ground engineer, whose age was not reported, earned a maintenance engineer license in 1980 and had ratings for the B-747 and the Airbus A300.

The airplane was manufactured in 1980 and had accumulated 83,011 airframe hours and 15,451 landings. It was powered by four Pratt & Whitney JT9D-7Q turbofan engines.

The captain's ADI correctly indicated pitch attitude but incorrectly indicated a wings-level attitude throughout the accident flight.

The load sheet signed by the captain indicated that the airplane's takeoff weight was 548,352 pounds (248,733 kilograms), including 68,300 pounds (30,981 kilograms) of fuel and 140,452 pounds (63,709 kilograms) of cargo. The airplane's maximum authorized takeoff weight was 820,000 pounds (371,952 kilograms). The center of gravity was within authorized limits.

"At 1727, the aircraft was ready to depart," the report said. "However, there were delays caused by various factors outside the crew's control, and they were not cleared to taxi until 1825."

Air traffic control (ATC) had not received a flight plan, and there was a delay while the company's agents filed a flight plan. There also was a delay in providing a tug for the airplane. The tug did not have sufficient power to complete the pushback, and ground personnel were called to marshal the airplane to the taxiway.

"It is not unusual for crews to be subjected to some delays or distractions during clearance and ground movement at airports, but the delay experienced by the crew of HL-7451 was greater than normal and would have resulted in an understandable degree of frustration in the [captain]," the report said. "Content of the CVR [cockpit voice recorder] indicated that the [captain] was showing signs of frustration. After personally handling ATC communication a number of times prior to and during engine start ([the airline's] standard procedure is for the first officer to handle ATC radio calls), he suddenly reprimanded the first officer for not responding to a radio call. On the taxi call, he faulted the first officer for not advising him to taxi to the centerline; then, on receiving the line-up clearance [for takeoff], told the first officer that a 'roger' alone was sufficient [for a readback].

"By making these comments, it is considered that the [captain] contributed to setting a tone which discouraged further input from the other crewmembers, especially the first officer."

The surface wind was from 190 degrees at 18 knots at 1836, when the crew was cleared to take off on Runway 23.

"The tower controller considered that the takeoff was normal, and the aircraft disappeared from sight as it entered the cloud base at about 400 feet AGL [above ground level]," the report said.

Investigators determined that the captain's ADI correctly indicated pitch attitude but incorrectly indicated a wings-level attitude throughout the accident flight. The CVR indicated that comparator warnings were generated about 17 seconds after takeoff, as the airplane was being flown through 600 feet AGL.

"There was no audible response from any member of the crew to this warning," the report said.

The airplane was being flown through 1,200 feet when comparator warnings again were generated. Soon thereafter, the first officer told the captain, "We should turn at 1.5 DME." (The departure procedure called for a left turn at a 1.5-nautical-mile [2.8-kilometer] distance-measuring equipment (DME) navigational fix.)

The captain said, "DME is not working." At this time, comparator warnings were generated a third time, and the first officer told the captain to turn to a heading of 158 degrees.

"[The captain's] concern over the DME indications [may have] had the effect of concentrating his attention on that indication and navigation, to the detriment of monitoring attitude," the report said. "[His] apparent fixation on the DME-defined turning point, to the detriment of monitoring other flight indications, may have been a self-imposed pressure to strictly comply with the [departure procedure] to avoid a 'violation' in an area with an active noise-monitoring program."

The airplane was at about 1,940 feet AGL when the control wheel was turned about 30 degrees left and the airplane began a left turn that continued through the remainder of the flight. The captain's ADI indicated wings level and an increasing nose-down pitch attitude. The report said that the captain's flight director likely was engaged and would have been commanding a climbing right turn.

"There is no evidence that the [captain] responded to the flight director or [to] the aircraft nose-down pitch-attitude indication [on the ADI]," the report said.

Comparator warnings again were generated after the left turn was begun, and the flight engineer said, in Korean, "Bank is not working." At this time, the tower controller told the crew to establish radio communication with London Control.

The first officer acknowledged the controller's instruction and then was told by the captain to request radar vectors from ATC. About this time, the flight engineer said "bank, bank." The report said that this statement likely was meant to alert the captain that bank angle had exceeded 30 degrees (a standard callout).

The first officer said nothing to the captain about the warnings from the comparator and from the flight engineer or about the attitude indications shown on his ADI.

"It remains a matter of conjecture as to whether [the first officer] was so distracted by other duties that his instrument scan broke down to the extent that he was unaware of the aircraft attitude and did not appreciate the significance of the comparator warnings, or he felt inhibited in bringing the situation to the attention of the [captain]," the report said. "He was an inexperienced first officer … and had been criticized a number of times by the [captain] prior to the takeoff."

The flight engineer made another statement that included the words "standby indicator." The report said that this statement likely was meant to draw the captain's attention to the standby attitude indicator.

"His last remark before impact also contained the word 'bank' and appeared to be said with resignation for what was about to happen," the report said. "At no time throughout the short flight did either of the pilots refer to the warnings or comment about the aircraft attitude or performance."

"At no time throughout the short flight did either of the pilots refer to the warnings or comment about the aircraft attitude or performance."

Recorded ATC radar data indicate that the airplane descended at more than 5,000 feet per minute. The airplane was in an approximately 40 degrees nose-down pitch attitude and was banked nearly 90 degrees left when it struck the retaining earthworks of a man-made lake. Indicated airspeed was 250 knots to 300 knots on impact. Tower controllers observed an explosion south of the airport and began emergency procedures.

"Burning fuel from the aircraft affected an area up to a distance of approximately 500 meters [1,641 feet] from the crater," the report said. "Wreckage was deposited into the lake, across several fields and into the western side of Hatfield Forest."

The report said that of the 15 cargo pallets loaded aboard the airplane at Stansted, two pallets contained dangerous goods, including "35.4 liters [37.4 quarts] of flammable liquid and toxic substance, 2.0 kilograms [4.4 pounds] of solids, 2.39 kilograms [5.27 pounds] of explosives (comprising components for military aircraft ejection systems, including detonating cords)."

The report said that Part 5 of the ICAO *Technical Instructions for the Safe Transport of Dangerous Goods by Air* states the following:

> The operator of an aircraft carrying dangerous goods which is involved in an aircraft accident must, as soon as possible, inform the state [country] in which the aircraft accident occurred of the dangerous goods carried … and the quantity and location on board the aircraft.

"There was no indication of any action by the operator to comply with the ICAO requirement," the report said. "However, the wording of the requirement was such that it would have been difficult for an operator to address the information to those who needed it, as there was no direction on who to contact in the state where the accident occurred.

"In addition to the declared [dangerous goods], there was other hazardous material in the cargo which did not fall into the category classified as [dangerous goods] and therefore required no specific [dangerous goods] packing or marking," the report said. "This was a consignment of medical-diagnostic kits containing small phials of 'Iodine 125' classified as 'Radioactive — Excepted Package.' Information on this material was not identified for several days because of the large volume [of paperwork] and variety of paperwork associated with the cargo load."

The balance weights in the accident airplane's outboard elevators and upper rudder were made of depleted uranium clad with nickel and cadmium.

"If the clad layer is sufficiently damaged by fire or corrosion, small amounts of removable uranium oxide can result," the report said. "The primary hazard from the oxide is the potential for internal exposure. This would require intimate contact with the oxide, transferring it to the mouth from contaminated hands, for example. Separate studies by Boeing and [by] the U.S. Army have shown that no danger exists from the [depleted-uranium] balance weights in the event of an aircraft crash."

Nevertheless, the report said that aircraft-construction materials can become "mixed and modified" by impact and/or fire during an accident.

In 1999, ICAO formed the Hazards at Accident Sites Study Group to develop a system for gathering and disseminating information on hazardous materials used in aircraft construction and the risks the materials pose in aircraft-accident investigations, and to develop guidance to control, reduce or eliminate the risks.

"It was anticipated that the work of the study group would be completed within two years," the report said.

An internal evaluation of Korean Air was conducted at the airline's request by Flight Safety Foundation (FSF) in April 1998.

"[The evaluation] determined that the safety programs in place at the time were not designed to support the safety of the operations structure," the report said. "Specifically, it found weak points and deficiencies in the captain-promotion system, the training curriculum, the integration of foreign crewmembers, the remedy for pilot-induced incidents, and operations standardization."

As a result of the FSF internal evaluation, Korean Air from May 1998 to October 1999 "entered a consulting implementation project with a major U.S. … air carrier," the report said. The project resulted in several recommendations for changes and "in the company's motivation for safety improvement." The company also retired two older B-747 freighters and two A300 freighters.

The report said that Korean Air launched several safety initiatives after the accident, including more stringent requirements for promotion from first officer to captain, specific recurrent training in instrument failures, improved flight operations standardization, establishment of a flight quality assurance department, assignment of additional maintenance technicians to overseas stations, equipping all airplanes with FIMs, and improved training of maintenance technicians.

Based on the findings of the investigation, AAIB made the following recommendations:

- "Korean Air [should] continue to update their training and flight quality assurance programs, to accommodate crew resource management evolution and industry developments, to address issues specific to their operational environment, and [to] ensure adaptation of imported training material to accommodate the Korean culture;

- "Korean Air [should] continue to review its policy and procedures for maintenance support at international destinations with a view to deploying [enough] of its own full-time engineers at the outstation or [to] delegating the entire task to another operator or third-party maintenance organization locally based at the destination (full technical handling). If neither of these approaches is practicable, then the support arrangements must be detailed and of such clarity as to preclude confusion;

- "Korean Air [should] review its policy and procedures to ensure that a copy of the relevant pages of the technical log and any other transit-certification documents are left on the ground at the point of departure;

- "ICAO *Technical Instructions* [*for the Safe Transport of Dangerous Goods by Air*] Part 7, Chapter 4.6.1 [should] be amended to [state]: 'The operator of an aircraft carrying dangerous goods which is involved in an aircraft accident must, as soon as possible, inform the appropriate authority in the state in which the aircraft accident occurred of the dangerous goods carried … and the quantity and location on board the aircraft';

- "ICAO [should] consider an initiative to review the current methods of tracking air cargo and further consider improved systems, utilizing electronic data storage and transmission, with a view to providing timely information on the cargo carried by any aircraft involved in an accident; [and,]

- "The ICAO Hazards at Accident Sites Study Group [should be] supported and resourced to enable it to meet its target date for delivery of the necessary data and risk-management advice."

[At press time, the FSF editorial staff had not received information from AAIB on responses to the recommendations.]♦

[FSF editorial note: This article, except where specifically noted, is based on the U.K. Air Accidents Investigation Branch report "No. 3/03 — Boeing 747-2B5F, HL-7451, near Great Hallingbury." The 103-page report contains illustrations and appendixes.]

Further Reading From FSF Publications

FSF Editorial Staff. "Faulty Wire Installation Cited in A320 Control Problem." *Aviation Mechanics Bulletin*. Volume 51 (November–December 2003).

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