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Flight Control System Failure Cited in Fatal Logging Accident

The Transportation Safety Board of Canada said that the failure of an analog switch caused the automatic flight control system computer to malfunction; as a result, the pilots of the Boeing Vertol Model 234 were unable to counteract a right yaw, and the helicopter struck terrain.

FSF Editorial Staff

About 1615 local time Oct. 30, 1997, a Boeing Vertol Model 234 helicopter entered several rapid turns to the right, descended and struck the ground during a heli-logging operation on Vancouver Island, British Columbia, Canada. The helicopter was destroyed, and the two pilots were killed.

The Transportation Safety Board of Canada (TSB) said, in its final report, that an analog switch in the yaw axis of the no. 2 automatic flight control system (AFCS) computer failed, sending an "instantaneous extension signal to the no. 2 yaw dual-extensible-link actuator [ELA]." (ELAs provide AFCS inputs to the mechanical flight control system.)

The report said, "The rapid ELA extension in the yaw flight control system almost certainly caused the yaw LBA [dual-lower-stick-boost actuator, which eliminates control-weight forces and friction forces] to burst and broke the yaw connecting link, preventing the pilot from countering a right-yaw condition. Without yaw control, the pilots likely became disoriented and could not prevent the helicopter from striking the terrain."

On the day of the accident, the helicopter was flown for 3.9 hours in the morning. Maintenance technicians examined the helicopter during a morning refueling break, after the pilots complained that the lower hook on the 250-foot (76-meter) external line was operating intermittently and that the associated circuit breaker was opening during periods of heavy rain. The maintenance technicians found no discrepancies, and the pilots resumed the flights and reported no further difficulties with the system.

After a lunch break, the pilots flew the helicopter 1.9 hours before refueling and changing seats. At 1541, the pilots began another cycle (defined by TSB as a "continuous series of log-transportation movements"). They conducted 10 uneventful turns (picking up a log, delivering it to the drop point and returning to the pick-up point for another log; each turn took about three minutes).

During the 11th turn, at 1615, ground personnel attached a 16,000-pound (7,258-kilogram) log to the hook at the end of the external line.

"The helicopter had lifted the log two-thirds of the way off the steep terrain, with one end still in contact with the ground, when witnesses observed the helicopter commence a rapid right turn," the report said. "In the next five [seconds] to 10 seconds, the helicopter continued to turn rapidly to the right several times, traveled laterally, then descended in a nearly level attitude and struck the ground."

The helicopter was descending rapidly when it struck 60-degree sloping terrain at 1,800 feet south of Comox Lake and broke into three sections: the cockpit, forward rotor and transmission; the main fuselage; and the aft fuselage, aft rotor, engines and aft transmission. Strike marks left by the forward-rotor blades on the mountainside indicated a flat fuselage attitude when the helicopter struck the ground. Fuel spilled from the ruptured fuel tank, and there was a small fire.

The pilot-in-command was the pilot flying when the accident occurred. He had accumulated 18,000 flight hours in helicopters, including 1,000 flight hours in Model 234s and 11,000 flight hours in Boeing Vertol Model 107s, a similar tandem-rotor helicopter. He possessed a Canadian airline transport helicopter license (ATPL-H), a medical certificate and endorsements for flying other helicopter models. He had accumulated 11,000 flight hours in vertical-reference flying[1] and heli-logging operations, and had been employed for 15 years by the operator of the accident helicopter, Helifor Industries of Vancouver, British Columbia.

The pilot-not-flying was serving as copilot on the accident flight. He was a senior captain for Helifor and an assistant chief pilot for the Model 234. He had been employed by the company for 19 years. He had accumulated more than 20,000 flight hours, with all but 100 flight hours in helicopters, 1,200 flight hours in Model 234s and 16,000 flight hours in other tandem-rotor helicopters. He held an ATPL-H, a medical certificate and endorsements for other helicopter models.

Both pilots had completed their most recent pilot proficiency checks in March 1997; the report said that, in both instances, the flights were conducted "with a high degree of competence, as … on previous occasions."

The accident helicopter was manufactured in 1981 by Boeing Vertol and was leased to Helifor by Columbia Helicopters of Portland, Oregon, U.S. The helicopter was imported into Canada in 1997. Maintenance records showed no deficiencies or discrepancies at the time of the accident. The helicopter was maintained according to a progressive maintenance schedule and was inspected in March 1997 at 15,044 flight hours. When the accident occurred, the helicopter had accumulated 16,570 flight hours.

The empty weight of the helicopter was about 22,500 pounds (10,206 kilograms). When the accident occurred, the total weight was 24,400 pounds (11,068 kilograms), including the flight crew and 1,500 pounds (680 kilograms) of fuel. The maximum certificated weight of the Model 234 with an external load is 51,000 pounds (23,134 kilograms). The accident helicopter would have weighed 40,400 pounds (18,325 kilograms) if the attached log had been lifted completely off the ground. The accident helicopter's center of gravity was estimated to have been within acceptable limits.

The report described weather at the time of the accident as "unremarkable, relative to other heli-logging operations and sites." Visual meteorological conditions prevailed, and immediately before the accident, the wind was light, skies were overcast, and there were occasional light rain showers. Weather was not considered a contributing factor in the accident; neither was the operating terrain.

The helicopter was not equipped (and was not required to be equipped) with a cockpit voice recorder or a flight data recorder.

An examination of the wreckage revealed no pre-impact anomalies with the airframe, rotor systems, drive-train system, transmissions, synchronizing shafts, drive shafts or engines. The two fuel tanks had contained adequate amounts of fuel; samples revealed no contamination.

Examination of the accident helicopter and its systems revealed that the only anomaly was in the yaw axis of the flight controls — in the U12 analog switch in the yaw axis of the no. 2 AFCS computer.

The flight controls include a hydraulic flight control system composed of two independent hydraulic systems that provide hydraulic assistance (boost) for flight control movements initiated by the pilots. Both the no. 1 hydraulic system and the no. 2 hydraulic system operate at a pressure of 3,000 pounds per square inch (psi; 211 kilograms per square centimeter [ksc]), and each system has a hydraulic tank, pump, valves, filters and fittings. The actuators are dual assemblies.

The hydraulic system powers three types of actuators: dual upper-boost actuators (UBAs), which eliminate rotor loads from the control systems; LBAs and ELAs. The report said that there are "two UBAs in both the forward [pylon] and aft pylon"; four LBAs — one each for the pitch axis, the roll axis, the yaw axis and thrust (or collective); and three ELAs — one each for the pitch axis, the roll axis and the yaw axis.

Pressurized fluid flows from the hydraulic tanks to the pumps and the actuators, and then back to the hydraulic tanks. Each system provides hydraulic pressure to operate each actuator.

"Since each actuator is a dual element, the flight controls can be operated on a single system," the report said. "However, it is impossible to control the helicopter without hydraulic system power."

The yaw LBA (part no. 234HS560-3) comprises an upper actuator, which is supplied with hydraulic pressure by the no. 2 hydraulic system, and a lower actuator, which is supplied with hydraulic pressure by the no. 1 hydraulic system. Examination of the yaw LBA on the accident helicopter showed that the seal around the actuating rod in the no. 1 (lower) yaw LBA was broken and that the seal leaked slightly. The examination also showed that the no. 2 (upper) yaw LBA did not maintain hydraulic pressure and that there was a one-inch (2.5-centimeter) rupture in the cylinder wall.

The report said that further examinations of the actuator showed that the cylinder wall "exhibited no signs of progressive failure in the form of pre-cracking, and it is believed to have burst in a single, instantaneous manner."

The hydraulic systems on the accident helicopter would have maintained suitable hydraulic pressure for one minute or two minutes after damage occurred to the yaw LBA, the report said.

The helicopter manufacturer said that a flight control system relief valve is set for 1,950 psi (137 ksc) and that, under normal operating conditions, the valve relieves excessive pressure in the stick-boost actuator when the servo control is closed or partly open. About 10,000 psi (703 ksc) would be required to burst the actuator.

The report quoted the manufacturer as saying, "[U]nder extremely rapid application of overload to the actuator, when the servo valve is closed or only partially open, very high pressures can be generated within the cylinder due to trapped fluid condition. In such a situation, the trapped/restricted fluid will never reach the relief valve to be relieved."

Simulations showed that the system could achieve the amount of pressure required to burst the LBA cylinder wall.

When the cylinder burst, the piston was "in a position that was consistent with normal and static right-yaw pedal input made by the pilot," the report said. "This action would have positioned the associated servo valve in the closed [position] or slightly open position. Fracture analysis shows that when the LBA cylinder burst, the piston moved down from a nearly centered position to bottom and fractured the yaw connecting link."

The report said that the cylinder wall probably burst as a result of normal yaw input when the pilot began to turn the helicopter to the right.

"When the U12 analog switch in the yaw axis of the AFCS failed, 11 volts direct current [VDC] was applied directly to the no. 2 yaw ELA," the report said. "As a result, the no. 2 yaw ELA rapidly and fully extended. It could not be determined why the cross-coupling function of the AFCS did not counter the erroneous signal, but it is possible that the rate of this signal exceeded the cross-coupling capability of the no. 1 AFCS."

The yaw connecting link (part no. 114C1013-34) was broken in half; one end was attached to the LBA, and the other end was attached to the yaw transfer bellcrank. The fracture was accompanied by a 50-degree bend in the fracture surfaces.

"Independent engineering examinations of the link confirmed that it had broken in column-loading and determined that the rapid downward force when the cylinder burst was sufficient to break the link at its midpoint and introduce plastic deformation at the fracture site, similar to the bend found," the report said. "The pitch, roll and thrust connecting links were not damaged. Had the yaw connecting link broken as a result of impact, the adjacent links would have been similarly damaged."

Post-accident examination of the two AFCS computers showed no discrepancies in the no. 1 AFCS computer and one discrepancy in the no. 2 AFCS computer — the U12 analog switch, an integrated circuit component on the A4 axis circuit card, which failed during the examination. The failure allowed an output of 11 VDC to the no. 2 yaw ELA.

"Analysis of the switch determined that it had failed as a result of electrical overstress of unknown origin," the report said. "Since the U12 switch also controls the rate at which the voltage is applied to the ELA, such a failure would cause almost instantaneous ELA movement."

Each AFCS computer is equipped with built-in test equipment; checks of the AFCS systems by maintenance personnel on the morning of the accident and by the pilots during last takeoff detected no anomalies. An examination of the wreckage showed that both AFCS computers had been selected "ON."

The report said, "During disassembly and examination of the yaw ELA, investigators noted that the lock pistons were in the locked position, consistent with low system hydraulic pressure. It was further noted that the piston slot was torsionally distorted around the lock piston, indicating that the piston was in the slot when the distortion occurred. All of this shows that the ELAs were damaged during airframe destruction and had lost hydraulic pressure before they were damaged."

The report said that damage to the yaw pedals and the injuries to the pilots indicated that the pilots were attempting to overcome the right yaw when the accident occurred.

"Had the connecting link still been intact, any left-pedal input would have been transmitted to the LBA, and even with the burst cylinder, flight control movement would have been transmitted to the rotor systems with effect," the report said. "Furthermore, full left pedal would have caused the servo valve to remain open, thereby removing one of the conditions for bursting the LBA cylinder. However, the helicopter did not respond to the pilots' corrective action because the broken yaw link prevented their left yaw input from reaching the LBA."

The report said that both pilots received fatal injuries from "the disruption and impact forces of the aircraft around them." Both pilots had been wearing lap belts but not shoulder harnesses, and the report said that use of a shoulder harness is "physically impossible" for pilots of the Model 234 and other helicopters used in vertical-reference flying because the pilots must lean to one side to clearly see the extended line and the suspended load beneath the helicopter.

"Pilots in this industry have uniformly adopted a practice of using the lap belt portion, leaving the shoulder harness free," the report said. "This practice allows the upper torso to lean markedly under the centrifugal forces of a rapid hovering turn. This movement away from the flight controls could make it difficult for a pilot to effectively manipulate the helicopter, and if the centrifugal forces were sufficiently great, it could prevent the pilot from returning to a normal, seated flying position."

The aircraft destruction that resulted from impact forces was so great that this accident was considered unsurvivable, and the report said that use of shoulder harnesses probably would not have reduced either pilot's injuries.

Nevertheless, the report said, "the benefits of the torso restraint were greatly compromised, which likely reduced either pilot's ability to effectively control the helicopter.

"Accident investigation and research carried out by the TSB has consistently shown that the use of the shoulder harness portion of the seat-restraint system is effective in reducing or preventing injury during moderate impact forces. Given that vertical-reference flying requires upper-body freedom of movement, the practice of not using the shoulder harness will continue to be widespread. The risk associated with this practice is that pilots will not be restrained effectively in the event of an in-flight emergency."

After the accident, Columbia Helicopters determined — and The Boeing Co. agreed — that the likelihood of a recurrence of the malfunction was so small ("a probability of failure of 10^{-9}," the report said) that no action was required to reduce further the likelihood of a recurrence. Nevertheless, the operator initiated research to identify additional causal elements of the malfunction.♦

[FSF editorial note: This article, except where specifically noted, is based on the Transportation Safety Board of Canada *Accident Investigation Report, A97P0303, Flight Control System Malfunction, Columbia Helicopters Inc., Boeing Vertol BV-234 (Helicopter) C-FHFH, Comox Lake, British Columbia, 30 October 1997.* The 19-page report includes diagrams and tables.]

Note

1. The Transportation Safety Board of Canada (TSB) describes vertical-reference flying as a "highly demanding flight regime" that involves "maneuvering the helicopter, with a long-line cable [external line] attached to the fuselage, by using the cable and the ground directly below the helicopter as primary sources of hover reference."

Correction

The May–June issue of Helicopter Safety should have cited, on page 2, 1987 as the manufacture date of the Aerospatiale AS 350BA that was destroyed in an accident March 7, 2000, on Mount Karioi, New Zealand.

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