National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: December 15, 2004

In reply refer to: A-04-68 and -69

Honorable Marion C. Blakey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On May 11, 2003, approximately 1533 central daylight time, a Bell 407 helicopter, N491PH, registered to and operated by Petroleum Helicopters, Inc. (PHI), of Lafayette, Louisiana, was substantially damaged during an autorotative water landing in the Gulf of Mexico, following a loss of engine power while in cruise flight. The airline transport pilot and his three revenue passengers were not injured. Visual meteorological conditions prevailed and a company flight plan was filed for the flight. PHI was operating the accident flight under the provisions of 14 *Code of Federal Regulations* Part 135 as an on-demand air taxi flight. The flight originated from an offshore platform about 1453 and was en route to Morgan City, Louisiana.

The pilot reported that the helicopter was in straight and level cruise flight (about 800 feet above the water) when the aural warning indicating failure of the full authority digital electronic control (FADEC)[1] system sounded. The FADEC failure aural warning was followed closely by the low rotor rpm warning horn. Simultaneously, cockpit caution lights illuminated indicating low rotor rpm, FADEC failure, and a FADEC fault. As the rotor speed began to decay through 90 percent, the pilot attempted to regain rotor speed by lowering the collective,[2] but rotor speed did not increase. However, as a result of lowering the collective, the helicopter began to descend. The lighted FADEC AUTO/MANUAL[3] indicator switch showed engine

[1] The Bell 407 helicopter is equipped with a Rolls-Royce 250-C47B series IV engine, which incorporates a FADEC system that electronically controls engine fuel flow via a hydromechanical unit (HMU) and an electronic control unit (ECU). This FADEC is installed in all Rolls-Royce 250 series IV engines. Other single-engine applications include the McDonnell Douglas (Boeing) MD-600 helicopter, which is equipped with a Rolls-Royce 250-C47M engine, and the U.S. Army version OH-58 helicopter, which is equipped with a Rolls-Royce 250-C30R/3 engine.

[2] The collective is a helicopter flight control that adjusts the blade pitch for all rotor blades symmetrically. When lowered, the collective decreases both total power required and total lift produced.

[3] The FADEC system can operate in automatic or manual mode. The AUTO/MANUAL indicator switch is lighted green when the system is in automatic mode and amber when it is in manual mode. The FADEC operates in automatic mode by default, determining the engine fuel metering requirements necessary to maintain efficient engine operation, provide adequate power, and maintain a constant output rpm. When operated in the manual mode, electromechanical metering of the fuel is eliminated, and the fuel flow is hydromechanically controlled via the throttle position and the HMU.

control to be in automatic mode.[4] The pilot then depressed the AUTO/MANUAL switch to ensure the FADEC would change to the manual mode. While descending, the pilot attempted to increase the throttle three times; each attempt was accompanied by an uncommanded right yaw[5] within 5 to 10 seconds of the throttle input. During the third uncommanded right yaw, the ENGINE OUT aural warning sounded and the ENGINE OUT light illuminated. The pilot entered a full autorotation[6] as the helicopter was passing through 400 feet above the water and activated the skid-mounted emergency float system. The helicopter landed upright on the water.

Discussion

Postaccident examination of the helicopter engine cockpit gauges revealed that the Measured Gas Temperature (MGT) Litton gauge recorded five MGT exceedances, which were stored in the gauge's nonvolatile memory. The exceedances occurred within an 80-second period, and the highest exceedance recorded was 1,102 degrees. Consistent with these findings, postaccident examination of the Rolls Royce series IV engine and the FADEC system recovered from the wreckage revealed that the top of the engine cowl and the turbine section of the engine were thermally damaged. The engine compressor/gas generator turbine and power turbine appeared to be locked when hand rotation was attempted.

In addition, the electronic control unit (ECU) and its power supply were inoperative, and the HMU was found capable of producing fuel metering and control. Examination of the ECU power supply circuitry showed a failed capacitor in the 15-volt power circuit. Removal of the failed capacitor (with no replacement capacitor installed) allowed the power supply to function normally.[7] The ECU did not record any faults nor did it record any of the overtemperature conditions recorded by the Litton gauge. Examination of the FADEC system architecture revealed that the system is designed to recognize a failed ECU as a fault condition, which would cause the system to automatically switch to the manual mode.

During the course of the accident investigation, it was unclear to National Transportation Safety Board investigators whether the pilot acted too quickly (that is, within the 1.6 to 5.8 seconds the HMU requires to transition to the manual mode) in his attempt to switch to manual control, or whether the system did not respond appropriately to the ECU failure by automatically switching into manual (because the ECU shut itself off, no faults were recorded, and it was not possible to determine the sequence of the faults). A review of the accident pilot's training records indicated that he was fully trained and had completed Bell 407 emergency recurrent training. As mentioned earlier, the pilot failed to recognize that the right yaw that followed each

[4] The FADEC failure that occurred on this flight should have caused the system to automatically switch to manual mode (the system is designed to do so if it detects certain faults). The pilot may also choose to switch to manual mode by pushing the AUTO/MANUAL indicator switch. In either case, the full effect of the transition to manual mode may take from 1.6 to 5.8 seconds, depending on the altitude and power setting of the engine. During the transition time, the pilot cannot make power changes.

[5] The right yaws indicated an increase in power (consistent with the pilot's throttle inputs), but at no point during the emergency did the pilot recognize the indication.

[6] The pilot later reported that he did not notice any overtemperature indications and stated that he entered the autorotation when he felt the helicopter's engine was not responding to the control inputs.

[7] Review of the manufacturing history of the circuit boards in the accident ECU showed that the circuit board was built by the original vendor. According to the ECU manufacturer, later revisions to the manufacturing processes by a different vendor have resulted in more reliable circuitry.

of his attempts to increase the throttle indicated an increase in power. The repeated throttle adjustments eventually resulted in the engine overheating due to the loss of overspeed/temperature protection in manual mode.

Investigators examined the flight crew training program at PHI's main facility to determine how the accident pilot was trained to cope with this kind of emergency. PHI owns and operates a Bell 407 cockpit simulator, which it uses for much of its pilot training.[8] Safety Board investigators flew the simulator in various altitude/airspeed combinations in which the ECU was failed and noted an immediate drop in main rotor rpm and activation of the caution/warning lights and aural warning horns. They observed that flying the helicopter and dealing with the emergency resulted in substantial increase in pilot workload. Specifically, Safety Board investigators found that the simulator was realistic and provided accurate responses to all control inputs, including the nearly 6-second delay required before pilot response to the emergency (via power changes) is permitted. During their evaluation of the simulator training, investigators found that it was counterintuitive to wait the required amount of time before taking corrective action and concluded that, despite being exposed to this delay during simulator emergency FADEC failure training, pilots likely would not wait the required 6 seconds before responding to a FADEC failure in real-world conditions.

The Safety Board notes that not all operators of helicopters powered by the Rolls-Royce Model 250 series IV engine have simulators to train their pilots nor do all operators require in-flight training to prepare their pilots to deal with in-flight ECU failure emergencies. Additionally, when flying in low-altitude, cruise-flight conditions (altitudes that are typical of those flown in the Gulf of Mexico off-shore helicopter industry), pilots have little time to attempt to rectify and/or cope with in-flight emergencies similar to the one that occurred in this accident. Because a FADEC failure emergency will result in an increase in pilot workload and some pilots may not recognize and properly respond to the emergency regardless of simulator or other training, the Safety Board believes that the FAA should conduct a review of the emergency procedure training for pilots of helicopters equipped with the Rolls-Royce Model 250 series IV engine to evaluate pilots' propensity to take inappropriate action in response to an in-flight failure of the FADEC system and require any necessary changes to emergency procedures and training to better prepare pilots to cope with in-flight FADEC failures.

A search of the Safety Board's and the Federal Aviation Administration's (FAA) accident and incident databases revealed seven cases, including the PHI accident, in which failure of the FADEC system was indicated as an initiating event to a Bell 407 accident or incident. Recent accidents involving Bell 407 helicopters also show that failure of a single component (for example, a capacitor device) can result in complete loss of the FADEC system. For example, a May 13, 1998, incident involved a FADEC failure that was attributed to an incorrectly installed capacitor. Additionally, a shorted capacitor was the cause of the FADEC failure that led to the May 11, 2003, PHI accident discussed in this letter. Therefore, until primary FADEC system reliability is significantly improved, a reliable and effective backup system is necessary to ensure safe operation of the Bell 407 helicopter. A review of the circumstances in the cases cited above, however, suggests that the manual mode of the FADEC system in Rolls-Royce Model 250 series

[8] PHI conducts engine and airframe emergency procedure training in its Bell 407 simulator, including engine out, tail rotor malfunction, ECU malfunction, and transmission malfunction.

IV engines, which is intended to provide backup redundancy when the primary FADEC function fails, is not effective. For example, in all but one of the seven cases, the pilots were uncertain of the nature of the emergency and chose to autorotate or forcefully landed the helicopter rather than manually fly it to a more suitable landing location following transition to the manual mode.

According to FAA Advisory Circular (AC) 27-1B, "Chapter 3 Airworthiness Standards Normal Category Rotorcraft, Miscellaneous Guidance (MG)," modified or new backup systems for FADEC-equipped engines should "be available immediately following loss of the primary system, be independent such that failure in the primary portion of the system will not propagate to the backup portion, and provide the pilot with a means to verify its availability at will." The Safety Board is concerned that the manual mode of the FADEC system in Rolls-Royce Model 250 series IV engines does not meet these guidelines. Therefore, the Safety Board believes that the FAA should require Rolls Royce to modify the Model 250 series IV engine control system so that backup engine control is available immediately following loss of primary FADEC function and such that the backup system does not impose undue workload on the pilot.

On May 27, 2003, as a result of its concern about the reliability of potentiometers[9] in Model 250 series IV engine FADEC systems, the Safety Board issued Safety Recommendation A-03-20[10] urging the FAA to restrict the operating envelope of helicopters equipped with the Rolls-Royce Model 250 series IV engine until it is shown that the operation of these engines provides an adequate margin of safety. In an April 15, 2004, response, the FAA noted that "the operation of a single-engine helicopter within the 'avoid' area of the height-velocity (H-V) diagram is a known risk that must be considered by helicopter pilots" and that it did not believe "the rotorcraft service history warrants the need to mandate compliance with the H-V diagram." Safety Recommendation A-03-20 is currently classified "Open—Unacceptable Response."

Although Safety Recommendation A-03-20 was issued as a safeguard against the unknown failure mode of potentiometers in these FADEC systems, the circumstances of the May 11, 2003, accident discussed in this letter demonstrate that an ECU failure is also hazardous and warrants similar defense. The ability of the pilot to recognize the failure and take proper corrective action is simply not sufficient, regardless of simulator or other training. The Safety Board is aware of ongoing programs at Rolls-Royce to add backup features internal to the ECU that would provide immediate backup electronic control of the HMU, is independent of the existing ECU circuitry, and is an intermediate step before manual mode is activated. These modifications to the FADEC system are crucial to providing the necessary reliability and control of the engine, especially in crucial situations where an emergency power-off landing is not possible. However, until these modifications are implemented, the Board continues to believe that helicopters using this FADEC system should operate in only those altitude/airspeed regions that allow for a successful autorotation in the event of a power loss. Therefore, the Board reiterates its recommendation that the FAA prohibit the operators of single-engine helicopters

[9] The potentiometer generates a signal that assists in the HMU's control of fuel flow.

[10] Safety Recommendation A-03-20 was issued as a result of a Bell 407 accident that occurred on March 7, 2003, following an engine power loss. This investigation also prompted Safety Recommendations A-03-18, -19, and -21, which respectively asked the FAA to issue a flight standards information bulletin, require the modification of the FADEC system on helicopters equipped with Rolls-Royce Model series IV engines, and to require the testing and replacement of faulty HMU potentiometers.

equipped with Rolls-Royce Model 250 series IV engines from operating in those altitude/airspeed combinations under which a safe autorotational landing is not probable until it is shown that the operation of these engines provides an adequate margin of safety.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Conduct a review of the emergency procedure training for pilots of helicopters equipped with the Rolls-Royce Model 250 series IV engine to evaluate pilots' propensity to take inappropriate action in response to an in-flight failure of the full authority digital electronic control (FADEC) system and require any necessary changes to emergency procedures and training to better prepare pilots to cope with in-flight FADEC failures. (A-04-68)

> Require Rolls Royce to modify the Model 250 series IV engine control system so that backup engine control is available immediately following loss of primary full authority digital electronic control function and such that the backup system does not impose undue workload on the pilot. (A-04-69)

The National Transportation Safety Board reiterates the following recommendation to the FAA:

> Prohibit the operators of single-engine helicopters equipped with Rolls-Royce Model 250 series IV engines from operating in those altitude/airspeed combinations under which a safe autorotational landing is not probable until it is shown that the operation of these engines provides an adequate margin of safety. (A-03-20)

Chairman ENGLEMAN CONNERS, Vice Chairman ROSENKER, and Members HEALING and HERSMAN concurred with these recommendations. Member CARMODY did not participate.

Original Signed

By: Ellen Engleman Conners
Chairman