



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: March 5, 2008

In reply refer to: A-08-04 through -09

The Honorable Robert A. Sturgell
Acting Administrator
Federal Aviation Administration
Washington, D.C. 20591

The investigation of a July 27, 2006, GE Aviation (GE) CF34-3 turbofan engine undercowl fire has determined that the fire resulted from secondary engine damage experienced during a fan blade separation (or “fan blade off” [FBO])¹ event and that the blade failure was related to the forging process used to manufacture certain fan blades installed in GE CF34-1/-3 turbofan engines.² The National Transportation Safety Board is concerned that, until the fan blades with the forging problem are removed from service, undercowl fires are likely to result from damage caused during these events. Further, although no airplane structural damage resulted, the severity of the engine and nacelle damage exhibited by this and a subsequent Bombardier Canadair Regional Jet (CRJ)-200 FBO event suggests that CF34-1/-3 engine installations could sustain other damage during an engine unbalance event that may lead to, or prolong, an engine fire.

Background

Event Descriptions

On July 27, 2006, Air Nostrum flight IB8174, EC-IJF,³ a CRJ-200, experienced a contained FBO event and engine fire in the No. 1 (left) engine, a GE CF34-3B1 turbofan, as the airplane was climbing through 23,000 feet after departing from Barcelona International Airport (BCN), Barcelona, Spain. The pilots reported that they heard a loud bang and experienced severe vibration, followed by a No. 1 engine fire warning. The flight crew discharged both fire bottles and declared an emergency. The fire warning continued for 9 minutes 39 seconds as the airplane

¹ The release of a fan blade in a turbofan engine results in structural loading from both the impact of the blade onto the containment ring and the subsequent instantaneous unbalance of the rotating components.

² Airplanes powered by GE CF34-1 or CF34-3 engines are the Bombardier Aerospace Challenger 601, Challenger 604, Canadair Regional Jet (CRJ)-100, CRJ-200, and CRJ-440.

³ Air Nostrum is a Spanish-certified regional air carrier affiliated with Iberia Airlines of Spain.

returned to BCN and ended as the airplane approached the airport. An uneventful single-engine landing was made, and no injuries were reported.⁴

Postincident inspection found that a fan blade on the No. 1 engine had fractured and separated below the platform⁵ in the disk attachment area. The severe loading caused by the blade separation and the loss of fan blade material resulted in considerable engine mechanical damage, including a crack in the engine accessory gearbox and failure of the low pressure turbine (LPT) case-to-turbine transition case (TTC) flange. The flange failure allowed the LPT to rotate relative to the TTC, which caused two oil lines to separate. There was extensive thermal damage to the engine accessory section, core cowl, and exhaust nozzle fairing; fire damage was also noted in the ignition zone aft of the engine fire seal, where the oil lines were separated. The primary source of the fire could not be positively identified due to thermal damage. According to maintenance records, the failed fan blade, part number (P/N) 6018T30P14, serial number (S/N) MAE35246, a titanium Ti 8-1-1⁶ forging, was manufactured by Teleflex, San Luis Potosi, Mexico,⁷ and was installed when the engine was manufactured. At the time of the incident, the blade had accumulated 8,899 cycles since new (CSN) and 10,896 hours since new (TSN). A fractographic examination of the failed blade revealed a subsurface origin in an area of quasi-cleavage⁸ structure at the aft end of the middle tang, near the pinhole. A cross-section through the fracture origin showed significant areas of unfavorably oriented aligned alpha colonies⁹ in the microstructure, from which the crack had propagated in low cycle fatigue.

A second fan blade failure occurred on May 24, 2007, when an Atlantic Southeast Airlines (ASA) Bombardier CRJ-200, N933EV, experienced a contained FBO event in the No. 2 (right) engine, a GE CF34-3B1 turbofan, while in cruise flight at 23,000 feet. The pilots reported hearing a loud bang and experiencing immediate severe vibration. The pilots declared an emergency and diverted the airplane to Regional Airport, Blountville, Tennessee, where they landed without further incident. Postflight inspection revealed that a fan blade in the No. 2 engine had fractured and separated below the platform in the blade attachment area. The inspection also found that the LPT case-to-TTC flange had separated, and the LPT case had shifted aft and rotated slightly.

⁴ The Comisión de Investigación de Accidentes e Incidentes de Aviación Civil of Spain is conducting the investigation of this incident. In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the National Transportation Safety Board and the Transportation Safety Board of Canada are participating in the investigation representing the State of Manufacture for the engines and airframe, respectively.

⁵ The platform is an integral part of the fan blade that serves as the base for the airfoil. The CF34 fan blade design includes three tangs underneath the platform that attach the blade to the fan disk. The blade is attached to the fan disk by a pin that slides through holes in each tang.

⁶ Ti 8-1-1 is a creep-resistant, near-alpha titanium alloy that includes 8 percent aluminum and small additions of beta stabilizers molybdenum (1 percent) and vanadium (1 percent).

⁷ Teleflex Aerospace Manufacturing (previously Sermatech Mal Tool) was acquired by GKN Aerospace, Cincinnati, Ohio, on July 3, 2007.

⁸ Cleavage refers to fracture along crystallographic planes and is characterized by a faceted fracture surface. Quasi-cleavage is a mixed fracture consisting of cleavage with ductile tear ridges at the edges of the facets.

⁹ This titanium alloy consists of a mixture of two homogeneous parts, alpha and transformed beta, each having a different crystal structure and different mechanical properties. Aligned alpha colonies are concentrations of alpha grains in the titanium microstructure where the crystallographic planes of the grains are similarly oriented. This results in a region with reduced deformation capability from which fatigue cracks can initiate.

The failed fan blade, P/N 6018T30P14, S/N MAE49663, was also manufactured by Teleflex. According to maintenance records, the blade was installed when the engine was manufactured and had accumulated 4,717 CSN and 5,845 TSN at the time of the incident. Metallurgical examination revealed that the primary fracture had initiated from a subsurface origin in the aft corner of the front tang, near the pin hole. As with the Air Nostrum blade, unfavorably oriented aligned alpha colonies and quasi-cleavage fracture features were present at the origin. However, unlike the Air Nostrum fracture, nearly the entire fracture surface on one side of the pin hole displayed the quasi-cleavage morphology, and no typical fatigue fracture features could be identified. Additional testing is underway to facilitate the interpretation of these features as they relate to crack propagation from the origin area.

Dwell Time Fatigue and CF34-1/-3 Fan Blade Manufacturing

The unfavorably oriented aligned alpha colonies and quasi-cleavage fracture features observed at the origin of both the Air Nostrum and the ASA blade fractures are characteristics of dwell time fatigue,¹⁰ a phenomenon that occurs in titanium alloys with relatively high-volume fractions of alpha grains, including near-alpha titanium alloys such as Ti-8-1-1. Dwell time fatigue is related to reduced plastic strain capacity and slip along crystallographically aligned alpha colonies in the material microstructure. When colonies of alpha grains are similarly aligned with the basal plane oriented perpendicular to the primary loading direction, the colonies can serve as an initiator for early fatigue cracking.

Material processing is critical to minimizing the aligned alpha colonies from which dwell time fatigue initiates. When Ti 8-1-1 billets¹¹ are produced from the mill, large colonies of aligned alpha grains dominate, and it is up to the forging process to break up the colonies and randomize the grain orientations. Reducing the billet size from which the blades are forged generally results in more random orientation of finer alpha grains because more deformation of the material is required to produce the final part.

A review of the CF34-1/-3 fan blade manufacturing process found that inadequate restrictions were placed on the size of the billet the vendor could use. Teleflex manufactured the blades from a 3.5-inch billet, a larger diameter billet than used by any previous vendors.¹² Investigators found that the material was not sufficiently worked during the Teleflex forging process because less work is required to form the blade from a 3.5-inch billet. As a result, aligned alpha colonies carried over into the microstructure of finished Teleflex fan blades.¹³ These

¹⁰ Dwell time fatigue is a fracture mechanism in which sustained loads at low temperature result in lower fatigue life than predicted from conventional (continuously cycled) fatigue tests.

¹¹ A billet is a semifinished cast product solidified from the melt, which is further shaped during subsequent forming processes such as forging.

¹² GE has used four vendors to supply CF34-1/-3 fan blades. The blades were first manufactured by Utica from 2-inch billet. Subsequent vendors were Snecma, which used 3.15-inch billet; Textron, which used 2.75-inch billet; and Teleflex, which uses 3.5-inch billet. In 2004, GE produced a validated blade life (18,000 CSN) analysis based on in-service inspection data. However, less than 1 percent of the validation data (20 Teleflex blades, having between 1,000 and 2,000 CSN) were from Teleflex blade inspections. Teleflex is currently the sole vendor of CF34-1/-3 fan blades.

¹³ All of the CF34-1/-3 fan blades manufactured by Teleflex, about 28,765 of approximately 92,500 produced, were made from 3.5-inch billet. The Safety Board is aware that GE is working with Teleflex to change the

aligned alpha colonies can serve as initiation sites for dwell time fatigue cracks and result in premature blade failures.

Discussion

Identifying Suspect Blades

Because all Teleflex blades were manufactured using 3.5-inch billet, any of the approximately 28,000 Teleflex CF34-1/-3 fan blades in service could have aligned alpha colonies in their microstructure and be susceptible to premature fatigue failure. However, there is no practical means of determining which blades are vulnerable because the presence of aligned alpha colonies can only be established using destructive inspection. Therefore, the only means of detecting impending dwell time fatigue failure is to identify cracks after they have initiated. The Safety Board questions whether sufficient data exist to identify cracks before failure can occur.

The ASA fracture differed considerably from the Air Nostrum fracture in that it lacked typical fatigue fracture features and that nearly the entire fracture surface on one side of the pin hole displayed quasi-cleavage morphology—a variation that has not been adequately explained. In addition, the ASA fan blade fractured after 4,717 cycles and 5,845 hours, demonstrating that dwell time fatigue failure can occur early in a blade's service life. Consequently, the Safety Board does not believe that the safe life of fan blades with aligned alpha colonies is known at this time. Because fan blades have already failed in service from dwell time fatigue and one failure has resulted in an engine fire, the Board considers the safety risk associated with this condition to be unacceptably high. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should require GE to define a reasonable maximum cycle limit below 4,717 CSN for Teleflex-manufactured CF34-1/-3 fan blades, considering the two failures and available data, and require that the blades be removed from service before that limit is exceeded.

Vendor Process Approval

The Safety Board notes that this safety issue could have been avoided if GE's manufacturing approval process for CF34-1/-3 fan blades included a requirement for dwell time fatigue testing. Near-alpha titanium has been known for some time to be susceptible to dwell time fatigue. In fact, GE performed extensive testing following several dwell time fatigue failures in 1995.¹⁴ Despite advancements in the understanding of dwell time fatigue, no tests for dwell time fatigue resistance were required or conducted when significant changes were made to the forging process with each of several revalidations of the CF34-1/-3 fan blade manufacturing process, although these changes were known in the aerospace industry to potentially increase the susceptibility of titanium forgings to dwell time fatigue. Although GE is working with Teleflex to eliminate the aligned alpha colony microstructure weakness by modifying the manufacturing process to require that blades be forged from smaller-diameter billet, the Safety Board is

CF34-1/-3 fan blade manufacturing process and qualify a new part number blade, P/N 6018T30P15, which will be manufactured from a smaller-diameter billet size.

¹⁴ In a 1999 presentation to the Safety Board and the FAA, GE identified reducing billet diameter to decrease aligned alpha colonies and put more strain into the material as a process improvement to help eliminate dwell time concerns.

concerned that the elimination of aligned alpha colonies cannot be verified unless a dwell time fatigue test is included in the CF34-1/-3 fan blade vendor manufacturing validation requirement. Therefore, the Safety Board believes that the FAA should require GE to include dwell time fatigue testing in the CF34-1/-3 fan blade manufacturing process requirements to verify that any modified manufacturing process adequately reduces the possibility of the presence of aligned alpha colonies in the finished part.

Factors Potentially Contributing to an Engine Fire Following a Fan Blade Off Event

Title 14 *Code of Federal Regulations* (CFR) Section 33.94, “Blade Containment and Rotor Unbalance Tests” requires, in part, that an engine be capable of containing damage during an FBO event without catching fire. In addition, 14 CFR Section 33.75, “Safety Analysis,” requires that analyses show that any probable single or multiple failure will not cause the engine to catch fire, burst, exceed ultimate loads, or lose the capability of being shut down. The Air Nostrum FBO event resulted in an intense and prolonged engine fire, demonstrating that the CF34-3 engine did not meet the intent of Sections 33.75 and 33.94 with regard to preventing a fire during an engine unbalance event.¹⁵ Consequently, the Safety Board is concerned that the structural and unbalance loads experienced by a CF34-1/-3 engine during an FBO event may not be well understood.

For example, unlike the results of the CF34-1 FBO certification test in which the engine accessory gearbox and the major engine flanges remained intact, the engine accessory gearbox in the Air Nostrum event cracked, releasing engine oil mist into the undercowl area—possibly initiating the engine fire—and the LPT case-to-TTC flange separated and rotated, breaking two oil lines and permitting engine oil to enter the undercowl area, fueling a fire aft of the engine fire seal. The engine damage observed in this event suggests that the CF34-1/-3 engine design should be examined to better understand the cause of the gearbox damage and the separation of the oil lines and the design should be modified to preclude such hazards. Therefore, the Safety Board believes that the FAA should require GE to make modifications to the CF34-1/-3 engine design to ensure that an engine unbalance event will not cause the engine to catch fire.

Postincident inspection of the Air Nostrum No. 1 engine also found that the elbow fitting of the main fuel control aft actuator rod hose was not oriented properly and failed at some point following the FBO event. The line had been installed with the elbow fitting that attaches at the main fuel control rotated clockwise 90°, an orientation that reduced the available slack in the installed hose. Failure of the aft actuator rod hose, which carries pressurized fuel from the main fuel control to an engine case-mounted actuator, will result in pressurized fuel being sprayed onto hot engine surfaces. According to GE, additional length is designed into the hose specifically to prevent its overload failure should the engine accessory gearbox drop or experience excessive movement during a rotor unbalance event.¹⁶ The Safety Board’s materials

¹⁵ The CF34-3 engine FBO case certification was based on similarity of the CF34-3 and CF34-1 model engines. A CF34-1 FBO certification test was successfully performed in June 1982.

¹⁶ The mounting system for the engine accessory gearbox, which is located underneath the engine case, includes a secondary retention system to prevent its separation from the engine during severe unbalance events. The gearbox is designed to drop onto lanyard cables when severe unbalance loads are experienced. The intent of this design is to prevent the loss of engine shutdown capability due to the separation or severe misalignment to the engine fuel

laboratory determined that the hose did not fail in overload but from thermal damage and was, therefore, not the primary source of the fire. It was nonetheless noted that the amount of slack in the aft actuator rod hose could be critical to preventing hose failure and resultant undercowl fire.

The Safety Board notes that the increased length designed into the aft actuator rod hose permits the hose to be installed with its elbow fitting oriented incorrectly on the main fuel control, as it was installed on the Air Nostrum event engine. As a result, the line can be installed with reduced slack, making it vulnerable to an overload failure during an FBO event, which could result in the release of flammable fluids into the undercowl area. Review of the CF34-1/-3 engine manual revealed that the fuel control installation instructions are not clear regarding the need for adequate slack in the aft actuator rod hose or the effect that the orientation of the hose elbow could have on this slack and, therefore, on hose integrity.¹⁷ Because the CF34-1/-3 engine manual does not advise the mechanic of the critical nature of the hose position, there may be CF34-1/-3 engines in service with improperly oriented aft actuator rod hose elbow fittings. A one-time inspection of all CF34-1/-3 aft actuator rod hose installations would ensure they are positioned as intended. Therefore, the Safety Board believes that the FAA should require GE to revise the CF34-1/-3 engine manual so that it clearly specifies the aft actuator rod hose elbow orientation and the requirement for adequate slack in the hose. The FAA should also require a one-time inspection of aft actuator rod hoses installed on all CF34-1/-3 engines to ensure hose integrity during an unbalance event.

CRJ-100/-200 Airframe Throttle Gearbox Retention Integrity

Postincident inspection of both airplanes found that the screws securing the throttle gearbox¹⁸ to a bracket on the top of the affected engines were not intact. Specifically, the No. 1 engine throttle gearbox on the Air Nostrum airplane was found loose in its retention bracket. One of the three retaining screws was missing, and a second screw was in place but sheared. Although the gearbox remained in the bracket and the engine shutoff linkage was not grossly affected, it was possible to pivot the gearbox on the remaining bolt. The No. 2 engine throttle gearbox on the ASA airplane was not loose; however, one of the three retaining screws was missing, and a second screw was backed off 1/8-turn. These findings are of concern because improper alignment or continuity of the engine fuel shutoff linkage could result in the loss of engine shutdown capability.

The Safety Board notes that Section 33.75 requires that any engine or component failure will not cause the loss of engine shutdown capability. The Safety Board is concerned that the throttle gearbox retention screws cannot withstand the extreme vibration loads that result from an FBO event and that this could result in the loss of engine fuel shutoff capability. Therefore, the Safety Board issued Safety Recommendation A-08-03 to Transport Canada asking that

shutoff valve linkage and to prevent flammable fluids from being released into the undercowl area due to fracture of the gearbox housing or its accessories.

¹⁷ The assembly drawing (assembly 03) in figure 1021 of the CF34-3B1 Engine Manual depicts the orientation of the fuel hose elbow.

¹⁸ An airframe component of the aircraft's engine shutoff mechanism, the throttle gearbox transfers the linkage position from the airframe linkage to the engine fuel control throttle arm, which controls the engine fuel shutoff valve. The same throttle linkage mechanism is used on both the CRJ-100 and CRJ-200 airplanes.

Bombardier be required to redesign the retention feature of the CRJ-100/-200 aircraft engine throttle gearbox to ensure that it can withstand the loads generated by a fan blade separation or similar event. Once the retention feature is redesigned as recommended, the Safety Board believes that the FAA should require that all operators of CRJ-100/-200 airplanes incorporate Bombardier's redesign of the engine throttle gearbox retention.

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

Require GE Aviation to define a reasonable maximum cycle limit below 4,717 cycles since new for Teleflex-manufactured CF34-1/-3 fan blades, considering the two failures and available data, and require that the blades be removed from service before that limit is exceeded. (A-08-04)

Require GE Aviation to include dwell time fatigue testing in the CF34-1/-3 fan blade manufacturing process requirements to verify that any modified manufacturing process adequately reduces the possibility of the presence of aligned alpha colonies in the finished part. (A-08-05)

Require GE Aviation to make modifications to the CF34-1/-3 engine design and ensure that an engine unbalance event will not cause the engine to catch fire. (A-08-06)

Require GE Aviation to revise the CF34-1/-3 engine manual so that it clearly specifies the aft actuator rod hose elbow orientation and the requirement for adequate slack in the hose. (A-08-07).

Require a one-time inspection of the aft actuator rod hoses installed on all CF34-1/-3 engines to ensure hose integrity during an unbalance event. (A-08-08)

Require that all operators of Bombardier Canadair Regional Jet-100/-200 airplanes incorporate Bombardier's redesign of the engine throttle gearbox retention as recommended in Safety Recommendation A-08-03. (A-08-09)

Chairman ROSENKER, Vice Chairman SUMWALT, and Members HERSMAN, HIGGINS, and CHEALANDER concurred with these recommendations.

[Original Signed]

By: Mark V. Rosenker
Chairman