National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 31, 2005

In reply refer to: A-05-19 and -20

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

On January 16, 2002, about 0920 coordinated universal time (UTC), Garuda Indonesia Airlines flight 421, a Boeing 737-300 (Indonesian registration PK-GWA) equipped with two CFM56-3-B1[1] turbofan engines, experienced a dual-engine flameout (power loss) during approach to the city of Yogyakarta on Java Island in Indonesia. After several unsuccessful attempts to restart the engines, the flight crew performed an emergency ditching into the Bengawan Solo River near the city of Solo on Java Island. The airplane was substantially damaged during the ditching. Of the 60 occupants on board, one flight attendant was killed, 12 passengers received serious injuries, and 10 received minor injuries. Daylight instrument meteorological conditions prevailed at the time of the power loss.[2]

Flight 421 departed from the resort island of Lombok in Indonesia about 0800 UTC. According to information gathered during the investigation, the takeoff, climb, and cruise portions of the flight were conducted in clear skies and were uneventful. The pilots reported that during the initial descent from flight level (FL) 310 (approximately 31,000 feet), they decided to deviate from the normal flight route because they saw thunderstorms along their planned route. These thunderstorms were also depicted on the airplane's on-board color weather radar.

Analysis of digital flight data recorder (DFDR) information and imagery obtained from a U.S. National Oceanic and Atmospheric Administration (NOAA)-12 satellite indicates that the flight had already entered a thunderstorm cell when the crew began deviating from the normal route of flight to Yogyakarta. Specifically, this data indicated that the airplane encountered an area of severe turbulence and thunderstorm activity about 0918 UTC.[3] Sounds consistent with

[1] CFM, Inc., is a consortium of General Electric Engines and Snecma, a French engine manufacturer.

[2] The National Transportation Safety Committee, Department of Communications, Republic of Indonesia conducted the investigation of this accident. In accordance with Annex 13 to the Convention on International Civil Aviation, the United States, as the State of manufacture of the accident airplane and engines, participated in the investigation. The U.S. team included representatives from the National Transportation Safety Board, the Federal Aviation Administration, Boeing Commercial Airplane Company, and CFM, Inc.

[3] NOAA-12 satellite imagery indicates that the tops of the thunderstorms were about 62,000 feet above mean sea level.

extremely heavy precipitation and hail were recorded on the cockpit voice recorder (CVR) concurrent with the encounter. Data from satellite imagery, the CVR, the DFDR, and the pilots' statements indicate that shortly before the airplane entered the thunderstorm, the airplane turned southward and flew towards a gap between two storm cells. The pilots reported that they were attempting to fly through a gap in between two red cells that were displayed on their color weather radar. About 90 seconds after entering the thunderstorm, as the airplane descended through about FL 180 at a flight idle power setting, both engines flamed out, and both the CVR and DFDR stopped recording data due to a loss of electrical power from the engines' generators.

The flight crew later told investigators that they made three unsuccessful attempts to restart the engines followed by one unsuccessful attempt to start the auxiliary power unit (APU). The flight crew's reported actions to restart the engines and APU are contrary to the procedures contained in the Boeing 737 Operations Manual. The procedures titled "Loss of Thrust on Both Engines" indicate that the flight crew should "not wait for successful engine start(s) prior to starting [the] APU." The procedures also noted that "in moderate to heavy rain it may take up to 3 minutes to accelerate to idle [engine speed], but the flight crew reported that they waited only about 1 minute between each restart attempt. The pilots reported that, as the airplane descended below an overcast cloud layer at about 8,000 feet, they observed the Bengawan Solo River and decided to attempt to ditch the airplane into the river with flaps and landing gear retracted.

On the basis of the circumstances of this accident, the National Transportation Safety Board is concerned about the adequacy of current Federal Aviation Administration (FAA) airplane certification standards concerning rain and hail ingestion and the adequacy of procedural guidance and information relating to heavy rain and hail that is currently available to pilots of airplanes equipped with turbofan engines.

Previous Engine Flameout Events in Rain and Hail

On August 21, 1987, an Air Europe 737-300, equipped with two CFM56-3-B1 engines, experienced a dual-engine flameout while descending through a rain and hail storm near Thessaloniki, Greece. Both engines were at a flight idle power setting. The pilots were able to restart both engines and land safely.[4]

On May 24, 1988, a TACA Airlines 737-300, equipped with two CFM56-3-B1 engines, experienced a dual-engine flameout while descending through heavy rain, hail, and turbulence. Again, both engines were at a flight idle power setting during the descent into the storm. The pilots were able to start the APU, which restored electrical power, then they were able to restart both engines. After being restarted, neither engine produced more than idle power; consequently, the pilots shut down both engines and made a successful emergency landing on a levee near New Orleans, Louisiana. The Safety Board determined that the power loss was due to water and hail ingestion.[5]

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[4] The Safety Board did not investigate this incident but was informed of the investigative findings.

[5] The description of this incident, FTW88IA109, can be found on the Safety Board's Web site at <http://www.ntsb.gov>.

Following the TACA dual-engine flameout event, the FAA issued Telegraphic Airworthiness Directive (AD) T88-11-51 on May 27, 1988, establishing a minimum engine fan speed (N1) of 40 percent when 737 aircraft equipped with CFM56 engines were operated during flight in or near heavy precipitation. This AD was superseded on June 14, 1988, by AD T88-13-51, which raised the minimum N1 limitation to 45 percent. The purpose of the AD was to ensure that the engine would continue to operate in the presence of heavy concentrations of rain and hail.

On July 26, 1988, the Safety Board investigated an incident involving a Continental Airlines 737-300 equipped with two CFM56-3-B1 engines, in which one engine lost power.[6] The pilots were able to land the airplane safely. The Board determined that the captain elected to descend into precipitation with the engine at flight idle power despite the copilot’s warnings that such a flight idle descent was contrary to the recently published AD, which required maintaining a minimum of 45 percent N1 in or near heavy precipitation.

By mid-1991, CFM had developed and tested engine modifications that were designed to improve the rain and hail ingestion capability of the CFM56,[7] thus permitting the engine to operate in heavy rain and hail at flight idle speed (approximately 32 percent N1) without losing power. As a result, in 1993, AD T88-13-51 was superseded by AD 93-05-05, which mandated the incorporation of the engine modifications and eliminated the 45 percent N1 limitation imposed by AD 93-05-05. The Safety Board notes that both CFM56 engines on the Garuda accident airplane had these hardware modifications incorporated.

FAA Certification Standards for Rain and Hail Ingestion

As a result of the Air Europe, TACA, and Continental events, the FAA initiated rulemaking for new rain and hail ingestion certification standards in August 1996.[8] According to the notice proposing the new rule, “rain and hail ingestion standards embodied in [the] rule represent an extremely remote probability of encounter ($1x10^{-8}$).[9] They are based on current assessments of atmospheric and meteorological conditions and aircraft engine service experience.” Additionally, the notice stated that “[b]oth the FAA and [Joint Aviation

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[6] The description of this incident, FTW88IA141, can be found on the Safety Board’s Web site at <http://www.ntsb.gov>.

[7] These modifications included a cutback fan/booster splitter fairing, an improved variable bleed valve (VBV), an elliptical spinner, and a revised schedule for VBV operation.

[8] The engines involved in the Air Europe, TACA, and Continental flameout events were certificated to older standards for rain and hail ingestion, which were contained in 14 *Code of Federal Regulations* Section 33.77, “Foreign Object Ingestion.” Those requirements stipulated that ingestion of rain or hail should not result in sustained power or thrust loss or require the engine to be shut down. The CFM-56-3-B1 engine was required to withstand a short duration volley ingestion of one 1-inch and one 2-inch diameter hailstone for each 150 square inches of inlet.

[9] During the early phase of defining the environmental threat, for both rain and hail, engineering judgment suggested that expressing rainwater content and hail water content as a function of a joint probability was an appropriate method. That joint probability is the product of the prior probability of a storm occurring at a given point and the conditional probability of a given water concentration value occurring within that storm. Given the potential for a pilot to avoid a storm and the ability for an engine to recover sufficiently for continued safe flight, a joint probability of 10^{-8} was determined adequate for establishing the certification standards for rain and hail.

Authorities] agree that the need for revised standards should be considered as additional service and atmospheric data warrant."

The new engine certification standard, 14 *Code of Federal Regulations* Section 33.78, "Rain and Hail Ingestion," went into effect on March 26, 1998. This standard requires that all engines be capable of acceptable operation when subjected to sudden encounters with certain specified atmospheric concentrations of rain for 3 continuous minutes and hail for 30 continuous seconds, without experiencing flameout, rundown, continued or nonrecoverable surge or stall, or loss of acceleration and deceleration capability. The specified atmospheric concentrations and size distribution of rain and hail vary according to altitude. For rain, the highest specified water content is 20 grams per cubic meter of air from sea level to 20,000 feet. For hail, the highest specified water content is 10 grams per cubic meter of air from 12,000 to 15,000 feet.[10] Although the CFM56 series engine was certificated to the FAA standard that existed before 1998 (for foreign object ingestion), the Safety Board's and FAA's review of the CFM test data indicated that the CFM56 hardware improvements required by AD 93-05-05 exceeded the current FAA certification standards in Section 33.78 for rain and hail ingestion.

Analysis of the flight recorders and the meteorological data from the flight 421 accident (as compared to previous CFM56 hail encounters), coupled with the inability of the CFM56 to handle the hail (even with the hardware improvements required by AD 93-05-05) indicates that the hail encountered by flight 421 exceeded the current certification level for hail ingestion. Because the flight 421 accident clearly demonstrates that meteorological conditions exist that can cause engine flameout if a turbofan-powered aircraft inadvertently encounters them, the Safety Board is concerned about the validity of the current certification standard. The Board notes that the current standard is based on service and atmospheric data gathered in the 1980s and that significant technological advances in weather prediction have occurred since then. Furthermore, the Board notes that important technological advances in meteorology have occurred since 1996 that have given rise to a significant amount of new atmospheric data[11] and that aircraft engine service experience has increased significantly since the rule was issued.[12]

The Safety Board is aware that, as a result of the accident involving flight 421, industry experts initiated a study during the summer of 2004 to review the current turbofan engine certification standards for rain and hail ingestion and that the FAA is participating in this review. Project objectives include reviewing recent in-service events to define the actual rain/hail environment encountered in those circumstances, reviewing and developing an understanding of the basis that established the current certification standard, determining whether the rain/hail environments encountered during the in-service events and the risks of encountering these conditions are outside of the current certification standard, and recommending revisions to the current certification standard, if appropriate. The Safety Board is pleased that this effort has been initiated but is concerned that it has been more than 3 years since the flight 421 accident

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[10] The data source for the rain and hail concentrations is the Aerospace Industries Association Propulsion Committee Study Project PC 338-1, dated June 1990.

[11] For example, a Japanese satellite launched in 2001 has provided new information regarding meteorological phenomena such as lightning strike density, which has advanced scientific understanding of thunderstorm activity.

[12] For example, according to Boeing data, commercial air traffic in Asia has increased significantly over the last 5 years.

occurred, and, according to the project chairman, significant analysis has yet to be performed. Therefore, the Safety Board believes that the FAA should complete the review of the current turbofan engine certification standards for rain and hail ingestion and, if necessary, revise the standards in consideration of recent service experience and atmospheric data.

Guidance to Pilots Regarding Turbine Engine Instability in Significant Rain and Hail Conditions

All engine flameout events cited in this letter occurred as the airplanes were descending through a thunderstorm with the throttles set at a low power setting. A low power setting, in combination with high airspeeds, can adversely affect engine operation in intense rain and hail because, typically, there is less centrifugal slinging of rain and hail away from the engine core at slower fan rotation speeds and higher airspeeds. The subsequent evaporation of the water from rain or hail inside the engine will have detrimental effects on the combustion process and drive the engine toward a flameout or loss of power.

Basic pilot training instructs pilots to avoid thunderstorms because thunderstorms may contain a variety of hazardous conditions, including lightning, wind shear, severe turbulence, and severe precipitation. Advisory Circular 00-24B "Thunderstorms," advises pilots to "avoid by at least 20 miles any thunderstorm identified as severe or giving an intense radar echo." Similarly, the procedures contained in the "Adverse Weather" section of the Boeing 737 Operations Manual state that "flights should be conducted to avoid thunderstorm or hail activity by overflight or circumnavigation. To the maximum extent possible, moderate to heavy rain should also be avoided." The procedures also indicate that in moderate to heavy rain, the engine start switches should be set to the continuous ignition setting.[13] However, the pilots of the Garuda flight flew a course that made entering into the storm unavoidable.

Because the flight crew of Garuda Indonesia Airlines flight 421 not only attempted to fly through a gap between two known areas of precipitation but also failed to adhere to the guidance provided in the 737 Operations Manual during their attempts to restart the engines, the Safety Board is concerned that flight crews of airplanes equipped with turbofan engines may not be adequately familiar with procedures related to encounters with severe weather conditions. As a result of the flight 421 accident, the FAA issued Special Airworthiness Information Bulletin (SAIB) NE-02-28 on May 23, 2002, to all operators, pilots, and principal operations inspectors informing them of the circumstances of the accident and reminding pilots that "flight in moderate to heavy rain, hail, sleet, or turbulence could adversely affect engine operation, especially at lower engine power levels." The SAIB recommends that, whenever possible, severe weather conditions should be avoided, but, if such conditions are encountered, pilots should comply with the minimum power setting procedures contained in the aircraft operations documents. The SAIB also notes that, for most turbofan applications, "maintaining an increased minimum thrust setting will improve engine tolerance to water and hail ingestion" if inclement weather is unavoidable.

[13] The position of the engine start switches during the Garuda Indonesia encounter is unknown because of the flight crew's many attempts to restart the engines.

The Safety Board is concerned that the information in SAIB NE-02-28 is not sufficiently detailed to address the numerous issues associated with dual-engine power loss, nor is it the appropriate mechanism to disseminate information in a way that would significantly impact flight crew awareness. For example, the SAIB does not advise pilots on how to recognize potentially hazardous precipitation such as heavy rain or hail, nor does it address procedures for a dual-engine restart. Further, the SAIB may not reach professional pilots because it is simply posted on the Internet as an information tool that provides nonregulatory guidance and recommendations for issues typically related to small general aviation aircraft. Because it is important that flight crews are able to recognize potentially hazardous precipitation conditions and are aware that higher power settings will provide a greater margin for ensuring that engine operation can be sustained if extreme precipitation levels are encountered, the Safety Board believes that the FAA should require that all turbofan engine and turbofan-powered aircraft manufacturers, working with operators of such aircraft, develop effective operational strategies (for example, effective techniques for recognizing and avoiding extreme precipitation, including hail; appropriate procedures for handling inadvertent encounters with extreme precipitation, including hail, such as increasing engine power; appropriate procedures and altitude and airspeed envelopes for dual-engine restart; and the effect that altitude, airspeed, and power setting have on the likelihood of an engine flameout) and related guidance materials to minimize the chance of a dual-engine power loss; the FAA should then verify that these strategies and guidance materials are incorporated into operating manuals and training programs in a timely fashion.

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

> Complete the review of the current turbofan engine certification standards for rain and hail ingestion, and, if necessary, revise the standards in consideration of recent service experience and atmospheric data. (A-05-19)
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> Require that all turbofan engine and turbofan-powered aircraft manufacturers, working with operators of such aircraft, develop effective operational strategies and related guidance materials to minimize the chance of a dual-engine power loss; the FAA should then verify that these strategies and guidance materials are incorporated into operating manuals and training programs in a timely fashion. (A-05-20)

Acting Chairman ROSENKER and Members ENGLEMAN CONNERS and HERSMAN concurred with these recommendations.

By: Mark V. Rosenker
Acting Chairman

Original Signed