Accident / Incident Summary
Lessons Learned Training and Infrastructure Development

Accident TACA International Airlines B737-300

Location New Orleans, Louisiana

Date May 24, 1988

Introduction

The TACA International Airlines event was important to propulsion engineers because it helped drive Industry and the FAA into recognizing engine power loss in inclement weather as a safety threat to aircraft. FAA and Industry worked together to study this threat and eventually revised the corresponding FAA certification standards for turbine engine rain and hail ingestion.

This was an all engine power loss event due to a severe hail encounter during descent for landing into New Orleans Airport and was one of three power loss events that occurred within a year on the same type of aircraft/engine due to inclement weather. Design changes were made to the engine to correct the problem and were mandated by the FAA.

This event also showed that the true environmental conditions and threat must be understood and accounted for in the engine design and certification tests. The understanding of the hail threat and the certification tests conducted on the CFM56 engines installed on the TACA airplane were inadequate in recognizing and accounting for the hail threat and its potential adverse affects for engine operation such as rollback or flameout due to excessive water to air ratio into the core.

This event also showed the importance for flight crews to avoid severe weather which includes understanding and recognizing the limitations of aircraft radar systems so they can make sound interpretations of the display targets.

Accident Summary

A TACA International Airlines B737 flight No. 110, from San Salvador, El Salvador, to New Orleans with a stop in Belize City, Belize, encountered extremely severe weather at 16,000 feet during descent into New Orleans Airport.

The aircraft was a Boeing B737-300 airplane powered by two CFM International (CFMI) CFM56-3B model turbofan engines.

There were 38 passengers and a crew of seven on this flight.

During descent from 35,000 feet for landing into New Orleans Airport the aircraft encountered severe weather. The flight crew attempted to avoid the most severe storm cells but penetrated momentarily into massive precipitation.

At approximately 16,000 feet, the airplane encountered 30 seconds of heavy hail when both engines experienced a simultaneous complete power loss following a roll back. In this discussion, the term engine “flame out” is used interchangeably with “complete power loss”. The TACA event and other similar engine hail ingestion events of severe intensity have resulted in an engine roll-back that rapidly led to complete power loss. The flight crew declared mayday at 12,000 ft. and radioed ATC “we’re in the middle of the storm....we lost an engine".

The flight crew started the APU and were successful in relighting both engines but the engines did not accelerate due to a combination of continued heavy rain and damage resulting from operating sub-idle after the roll-back.

The No. 2 engine was damaged due to extended sub-idle operation which allowed raw fuel to burn in the turbine area. The flight crew realized that a landing was not possible at the airport and started preparations to ditch. After breaking out of the cloud layer they spotted a small levee and made a successful off airport deadstick landing. There were no injuries.

The No. 2 position engine experienced severe turbine over temperature and was not suitable for further flight. The engine was replaced and by the aircraft was flown off the levee to New Orleans Airport. The No. 1 position engine was changed at New Orleans Airport where other aircraft checks and maintenance were performed and the aircraft was subsequently returned to service.

Accident Summary - Continued

Investigation into the cause of the dual engine flameout indicated the aircraft had encountered a very heavy area of rain and then 30 seconds of heavy hail. The storm intensity was estimated to be a liquid water content (LWC) of 25 to 30 grams/meter3 which equates to approximately 30 inches rain/hour.

The direct cause of the dual engine flameout was the ingestion of hail into the engine core. Unlike rain, hail is much more effective at entering the core due to it either going between the fan blades and directly entering the core or bouncing off the spinner and fan blades and entering the core.

At the time the CFM56 engine was certified the FAA engine hail ingestion certification standards were focused on foreign object damage (FOD) to engine hardware and not engine operability effects. It was believed that conducting a severe rain ingestion test covered the hail threat. The unique behavior of hail relative to engines was not well understood. In addition, the water ingestion tests being conducted on engines at the time to simulate severe storm encounters did not provide a representative threat to the engine. The investigation determined the storm which the TACA aircraft encountered was estimated to be the same rain intensity as the certification standards. However, the tests were conducted with large water droplets and low simulated forward speeds that resulted in maximum centrifuging by the fan and very little water entering the core. This was not recognized prior to the TACA event.

The initial CFM56 engine water ingestion tests demonstrated 400% margin compared to the FAA certification requirement which gave a false sense of security. The belief that a severe rain ingestion test provided adequate coverage for the hail threat relative to engine operability was not a valid assumption.

Severe hail ingestion into an engine results in certain risk factors that can cause adverse engine operation such as flameout or rollback due to an excessive water to air ratio in the engine core:

- High altitude increases the hail/air ratio
- Low fan RPM’s promote hail ingestion into the core
- High aircraft airspeeds increases the hail/air ratio
- At some fan speeds/aircraft air speed combinations, ingestion into the core is greatly increased (hail misses the fan blades and goes directly into the core, called the venetian blind effect).

Accident Summary - Continued

Following the TACA event, CFMI conducted an extensive investigation that included multiple engine tests and detailed analysis to determine the root cause of the TACA flameouts, inability of the engines to recover and to determine the necessary corrective actions. CFMI made several design changes to the engine to increase its robustness in severe rain and hail weather conditions.

The objective of these design changes were to reduce the water/air ratio into the engine core and included the following:

- Spinner profile change from conical to a combination elliptical/conical (spinner shape called coniptical) to guide the hail radially outward.
- Cutback splitter that allows more ingested rain/hail to be centrifuged out by the fan rotor away from the core and into the fan bypass flow. The CFM56 engine had the “closest” core design for engines in revenue service.
- Increased number of variable bleed valve (VBV) doors that allowed additional rain/hail to be extracted from the core flowpath.

The FAA issued Airworthiness Directives (AD) to mandate these design changes on the CFM56 engines and mandated B737 flight manual procedure changes to address aircraft and engine operation procedures in inclement weather. CFMI incorporated the lessons learned into their design practice for CFM56 design changes and for future engine designs.

CFMI also identified and incorporated additional design changes in their follow on engine designs that provided improvements and margin to adverse effects of engine operation in inclement weather, these included:

- Adaptive engine start logic for Full Authority Digital Electronic Adaptive engine start logic for Full Authority Digital Electronic Controlled (FADEC) engines (the TACA engines were not FADEC control) that improves the chances of starting in marginal situations and reduced the risk of engine damage during a start sequence.
- Introduced improvements to the flowpath contour (i.e., S - shape turn) to increase the effectiveness of VBV doors to remove material from the core flowpath.

Accident Summary - Continued

There was considerable delay before the flight crew recognized both engines had flamed out. The flight crew attempted to windmill restart both engines but was unsuccessful because the aircraft was outside the engine windmill restart envelope. The flight crew then attempted to start the engines using the APU starter assist. They were successful in getting both engines to relight however the engines did not start properly due to a combination of continued heavy rain ingestion and for the No. 2 engine, turbine damage resulting from operating sub-idle. The engines did not respond or accelerate to throttle inputs made by the flight crew.

Due to the limited aircraft data and engine information available certain aspects of engine operation during this event such as when the No. 2 engine damage occurred were not clearly defined.

During this event one of the two engines sustained extensive turbine damage from being exposed to elevated gas path temperatures (similar to a hot start). Engines are much harder to start in precipitation than to keep running. The flight crew recognizing there was no throttle response elected to shut down both engines and prepare for an emergency landing. Due to the limited data and engine information available certain aspects of engine operation during this event such as when the No. 2 engine damage occurred were not clearly defined.

For the TACA event the CFM56 engine windmill in-flight restart envelope is relatively small when compared to the B737 aircraft operating envelope. The FAA certification regulations require a windmill in-flight start envelope be defined by the manufacturer but does not provide criteria for how large it needs to be. Having a larger windmill in-flight start envelope may provide a greater opportunity of being able to restart an engine that has flamed out especially in situations when the APU is not functional for starter assisted engine starts. Conversely, design measures to increase robustness to inclement weather (and avoiding multiple engine power loss) have the effect of making windmill starts more difficult. This is an example of the type of information that needs to be considered to obtain an airplane level awareness when addressing a potential safety of flight problem.

Accident Summary - Continued

The delay in the flight crew recognizing both engines flamed out may be attributed to several factors. The flight crew had a high workload maintaining control of the aircraft in a severe storm. The cockpit noise levels were extremely high from the intensity of the hail impacting the forward cockpit area of the aircraft making flight deck communication difficult and adding a distraction to the flight crew. In addition, some cockpit configurations may provide information of an engine flameout that can be initially misinterpreted by the flight crew as other aircraft problems, such as an aircraft electrical problem.

When the TACA event occurred, the Industry and FAA were starting to recognize engine power loss in inclement weather as a safety threat to the aircraft. An Aerospace Industries of America (AIA) task force group was organized with representatives from airframe and engine manufacturers to investigate multiple engine power loss in inclement weather.

The FAA and industry worked together to study this threat and eventually revise the corresponding FAA certification standards for turbine engine rain and hail ingestion. The results of the study indicated there were a number of multiple turbine engine power loss and instability events, forced landings and accidents in revenue service attributed to operating airplanes in extreme rain or hail conditions. Investigations revealed that ambient rain or hail concentrations can be amplified significantly through the engine core at high flight speeds and low engine power conditions. Rain or hail through the engine core may degrade compressor stability, combustor flameout margin and fuel control run down margin. Ingestion of extreme quantities of rain or hail through the engine core may ultimately produce engine surging, power loss and engine flameout. In 1998 a revised FAA engine rain and hail standard was issued as 14 CFR 33.78.

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Accident Board Findings

Prior to the new standard becoming a rule industry began complying with the revised standards. The following are recent videos of an engine hail ingestion and water ingestion FAA certification tests that were conducted to the revised certification standards. These videos shows the typical engine tests that must be successfully completed for rain and hail ingestion as part of the FAA certification process.

Certain weather radar displays can be misleading and show the highest intensity (worse than red) as "clear" on the radar screen. In addition, selection of radar range settings is important to provide the pilots the best short and long range picture of weather in the vicinity of the aircraft.

It's important that pilots understand and recognize the limitations of aircraft radar systems so they can make sound interpretations of the displayed targets. The NTSB issued a factual report No. FTW88IA109, dated Sept. 7, 1990 on the TACA event. This event was not categorized as an aircraft accident by the NTSB so an Accident Report with NTSB findings was not issued.

Relevant Regulations

1) At the time the CFM56 certification hail was viewed as foreign object ingestion "damage" threat and not a continuous operating threat.

2) Water ingestion (simulating heavy rain) was the only continuous operating threat tested.

3) It was generally felt that conducting severe rain ingestion testing covered the hail threat.

    - The unique behavior of hail was not well understood.

4) 14 CFR 33.77 Amendment 6 (1974) - "Foreign Object Ingestion".

    - Bird ingestion - small, medium, large (FOD).
    - Ice ingestion - shed encounter from the inlet (FOD).
    - Hail ingestion - volley based on inlet area (FOD).
    - Water ingestion - ingested at 4% engine airflow (continue to run during 3 minute ingestion).
    - Gravel/Broken Rotor/Tire tread - FOD/containment.

Relevant Regulations - Continued

5) 14 CFR 33.77 "Foreign Object Ingestion", divided into 3 new parts via amendment 19 in 1998. Revised rain and hail certification standards.

   - NPRM issued August 2, 1996, Final Rule for new rain and hail standards issued March 20, 1998.
   - 33.76, "Bird Ingestion", new requirements for bird ingestion to address the bird hazard threat.
   - 33.77 "Foreign object ingestion - ice", retained the ice ingestion requirement for inlet ice sheds.
   - 33.78, "Rain and Hail Ingestion" - added a new Appendix B defining rain and hail concentrations.

6) New 14 CFR 33.78 Rain and Hail ingestion requirements

   - Increased severity for water ingestion tests (i.e., rain and hail).
   - Implemented by engine manufacturers from 1989 onward.
   - New test standard based on a 1 x 10^{-8} storm encounter. This number represents the probability per flight (one in a 100 million flights) of an aircraft encountering a rain or hail storm that considers various factors such as time duration, aircraft operation and environmental water concentrations that are reflected in the new certification standard.

7) The FAA certification basis for the CFM56-3 engine can be found in TCDS No. E2GL and is the following: 14 CFR 33 Amendment 1 though 6, emissions requirements of SFAR No. 27-5, and the following exemptions: No. 2641 for 33.88, No, 2850 for 33.7, No. 83-ANE-001E for 33.14.

Prevailing Cultural/Organizational Factors

1) A prevailing factor that played a role in this incident was the fact that the engine's hail performance was undetermined at time of certification. The hail standards were incomplete and only focused on foreign object damage to engine hardware and not engine operability affects.

Unsafe Conditions

Engine flamed out during severe rain and hail encounter:

- Actual storm intensity consistent with existing standards relative to rain ingestion requirements, however, the rain ingestion certification test did not provide a representative threat to the engine.
- The hail certification standards were incomplete at time of certification and only focused on foreign object damage to engine hardware and not engine operability affects.

Safety Assumptions

Some of the key design and safety assumptions that proved to be flawed in this event are listed below.

1) Actual engine certification properly simulated severe storm conditions:
   - Mismatched inflow stream tube speed/fan speed during testing resulted in very little water reaching core. Not recognized prior to the TACA event.
   - Engine demonstrated 4x margin compared to certification requirement - gave false sense of security.
2) Rain considered primary “continue to run” threat per the regulations.
3) Hail only considered FOD threat and not an operability threat:
   - Large hail particles less influenced by flow stream.
   - Hail bounces off of solid surfaces such as spinner.
4) Engines would not be damaged and would restart after exiting the extreme weather.
5) Pilots would successfully avoid extreme weather.

Precursors

There was one precursor and another engine power loss event attributed to inclement weather that occurred shortly after the TACA incident:

1) Air Europe B737-300 airplane, flt. No. 579 approaching Salonica, Greece with CFM56-3 engines experienced a simultaneous dual engine flameout during descent at 8,900 feet on August 21, 1987.

   - Aircraft was in light to moderate turbulence, moderate to heavy rain and sudden intense hail when the flameouts occurred. Pilot report "wall of ice". Flameouts not recognized at first.
   - Both engines were windmill started and the aircraft landed uneventfully.
   - Investigation into the cause of the flameouts concluded that extreme weather exceeded flameout margin of engine and that water concentration encountered has low probability of encounter. Focus was primarily on rain and not hail.
   - First known report of thrust loss in severe precipitation in the B737/CFM 56 fleet. (3+ years of revenue service, 40 operators, apprx. 1.5 million aircraft flight hours)
   - Following this event Boeing revised the Operations Manual Bulletin for the B737-300 for engine operation in severe precipitation.
   - The industry was starting to recognize engine power loss in inclement weather as a threat. An AIA task force was organized with representatives from airframe and engine manufacturers to investigate multiple engine thrust loss in inclement weather.

2) Continental Airlines B737 with CFM56-3 engines experienced a single engine flameout during initial descent through 19,200 feet on July 26, 1988.

   - This event occurred after the TACA event and was not a precursor to TACA but was another event of an engine powerloss attributed to inclement weather. This aircraft suddenly encountered moderate turbulence and very heavy rain when the flameout occurred.

Regulatory and Policy Changes

As a result of the Taca event, the following changes were made.
1) 14 CFR 33.77 Amendment 6 (1974) - “Foreign Object Ingestion"

- Bird ingestion - small, medium, large (FOD).
- Ice ingestion - shed encounter from the inlet (FOD).
- Hail ingestion - volley based on inlet area (FOD).
- Water ingestion - ingested at 4% engine airflow (continue to run during 3 minute ingestion).
- Gravel/Broken Rotor/Tire tread - FOD/containment.

2) 14 CFR 33.77 revised by being divided into 3 new parts via amendment 19 in 1998. The NPRM for the rule change was issued August 2, 1996 and the final rule was issued March 20, 1998.

- 33.76, “Bird Ingestion”, new requirements fro bird ingestion to address the bird hazard threat.
- 33.77 “Foreign object ingestion - ice”, retained the ice ingestion requirement for inlet ice sheds.
- 33.78, “Rain and Hail Ingestion” - added a new Appendix B defining rain and hail concentrations.

3) New 14 CFR 33.78 Rain and Hail ingestion certification standards.

- Increased severity for water ingestion tests (i.e., rain and hail).
- Implemented by engine manufacturers from 1989 onward.
- New test standard based on a 1 x 10-8 storm encounter.
- New AC 33.78-1 issued to supplement the new 33.78 rule.

Airworthiness Directives Issued

Six Airworthiness Directives were issued following the Taca event.

1) Telegraphic AD T88-11-51 issued on May 30, 1988 that revised the B737-300 airplane flight manual procedures to reduce the possibility of engine flameout in severe rain and hail conditions. These actions were considered interim actions until final corrective actions were defined and included.
2) AD T88-11-51 issued on October 6, 1988. Requires revision to airplane operation limitations when flying in moderate to heavy precipitation to prevent potential engine flameouts.
3) AD T88-11-51 issued on December 1, 1988. Clarifies AFM wording and installation
4) AD 89-NM-225 issued on November 15, 1989. Requires modification of the engine idle circuitry to inhibit the in-flight low idle capability. Increase the engine minimum percent N1 flight idle and increases the engines flameout margin and reducing the possibility of engine flameout during heavy precipitation. For B737-300 and 400 series airplanes.
5) AD 91-02-10 requires installation of a new fan splitter, fairing, and new VBV configuration on CFM56-3 engines to prevent power loss or flameout in heavy precipitation. NPRM was issued on December 4, 1989. Incorporates by reference CFMI SB’s: 72-450 R1 and 72-462 R1.
6) AD 93-05-05 issued April 29, 1993. Requires update to aircraft flight manual of certain B737 model airplanes to include procedures for operation in inclement weather.

Lessons Learned

Let's take a look at the lessons to be learned from the Taca event.

1) Certification testing did not recognize critical in-service threats (e.g., sustained hail, effects of mismatched water testing):

   - The real operational environment and threat must be understood and accounted for in the design and certification tests.
   - Hail more efficient at entering the core than water.
   - Low water entry speeds of tests allow fan to centrifuge away from the core - not representative of service.

2) Crews may not be able to avoid peak rain/hail shaft:

   - Columns of very high LWC precipitation form rapidly.

3) Crews with high workload may not recognize all engine flameouts immediately; it may look like an electrical problem especially with some cockpit configurations. Annunciation criteria for providing critical information to the flight crew is important.

Lessons Learned - Continued

4) Weather radar displays can be misleading:

- Show highest intensity (worse than red) as "clear".
- Pilots may perceive a gap in the weather where none exists.
- It's important that pilots understand and recognize the limitations of aircraft radar systems so they can make sound interpretation of the displayed targets

5) All engine flameout events due to environmental threats and other causes may occur at a very low probability during the life of the fleet. The certification and engine design standards for an environmental threat such as hail is driven in part by the probability of encountering a hail storm of a certain severity. This approach recognizes that there are hail storms of greater severity that may be encountered (at a very low probability) during the life of the fleet. Additional actions to mitigate the risks associated with an all engine flameout event include:

- Engine inflight start capability to consider all engine out event.
- Airplane must remain controllable.
- Cockpit displays should provide clear annunciation and display of information to flight crew of an all engine out event.
- Flight crew training on recognition and avoidance of severe environmental threats and procedures for engine recovery.

Related Accident

On January 16, 2002 a Garuda B737-300 experienced a dual engine flameout at 18,400 feet in intense rain/hail. The flight crew was unable to restart the engines. The location was Solo City, Indonesia. The aircraft ditched in the river and there was one fatality. Some of the factors involved in this accident included:

- Flight crew navigating through severe weather but turned aircraft directly into thunderstorm. Weather radar displays can mislead - show highest intensity (worse than red) as “clear”. Pilots may perceive a gap in the weather where none exists.
- Both CFM56-3 engines flamed out due to intense hail. Engines incorporated design changes and improvements for rain and hail.
- Flight crew attempted 2 engine restarts, the first was a quick relight procedure and was unsuccessful. The second was an APU start, the battery failed concurrent with APU start attempt. Loss of battery resulting in inability to start APU and no power to engine igniters.
- Battery exhaustion prevents engine restart. Event did not result in engine hardware damage.
- Engines were confirmed to exceed latest hail 33.78 certification standard, however, the aircraft encountered a hail threat that may have exceeded certification standard. Threat not unique to B737 or CFM56 engines.
- Post event actions: FAA issued special airworthiness information bulletin to highlight that pilots are to avoid severe weather. NTSB issued safety recommendations requesting review and update of engine rain and hail ingestion standards.

In 2006, the FAA is continuing to work with AIA Propulsion Committee to determine if the current engine rain and hail certification standards should be revised.

Conculsion

This concludes our review of the Taca International Airlines, B-737-300, event in New Orleans, Louisiana. As you have learned, the TACA event was important to propulsion engineers because it helped drive Industry and the FAA into recognizing engine power loss in inclement weather as a safety threat to aircraft. FAA and Industry worked together to study this threat and eventually revised the corresponding FAA certification standards for turbine engine rain and hail ingestion.