NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

November 20, 2017

POWERPLANT GROUP CHAIRMAN'S FACTUAL REPORT

NTSB No: ENG14IA005

A. INCIDENT

Location:	St. Louis, Missouri
Date:	December 23, 2013
Time:	Approximately 1605 local time
Aircraft:	Southwest Boeing 737-3H4, Registration Number N360SW

B. POWERPLANTS GROUP

Safety Board Group Chairman:	Harald Reichel National Transportation Safety Board Washington, DC
GE Aviation Member:	Les McVey Flight Safety Investigator Cincinnati, Ohio
FAA Member:	Darren Pittacora Southwest Airlines Certification Management Dallas, Texas
Southwest Airlines Member:	Jeff Grenier Southwest Airlines, Senior Safety Investigator Dallas, Texas

C. SUMMARY

On December 23, 2013, at approximately 1615 central standard time a Boeing 737-344, registration number N360SW, operated by SWA as flight 1091, and powered by two CFM56-3 turbofan engines, experienced a bird strike and ingestion[1] on the No. 2 or right-hand engine (RHE) after takeoff from Lambert-St. Louis International Airport (STL), Missouri. As the aircraft climbed through 1,700 feet, it impacted multiple birds causing damage to the RHE and wing. The pilot declared an emergency and returned to STL for an uneventful landing. There were no injuries reported to the 110 passengers, 2 flight crew and 3 flight attendants. The incident flight was a 14 *CFR* Part 121 domestic passenger flight from STL to Kansas City International Airport, Kansas City, Missouri (MCI). Day visual meteorological conditions prevailed at the time and an instrument flight rules flight plan was filed.

Examination of the airplane revealed a hole in the leading edge of the wing with its immediate surroundings splattered with red colored organic debris (Photo 1). The inner barrel of the RHE inlet cowl exhibited multiple impacts, gouges, and through-holes. One fan blade fragment penetrated through the outer skin of the outboard side of the inlet creating a 7-inch long penetrated tear, in the shape of a fan blade chord (Photo 2 & Photo 3).

Examination of the RHE revealed that all the fan blades were extensively damaged with two adjacent engine fan blades fractured transversely across the airfoil below the mid span shrouds. No penetration or breaches were observed in any of the engine cases, but the fan case exhibited several bulges that corresponded to hard impacts and missing fan blade rub strip material exposing the parent material below.

The engine and nacelle were sent to the Southwest Airlines Maintenance Training Building in Dallas, Texas for examination. The team met January 9 - 10, 2014 to examine the engine and nacelle.

A United States Department of Agriculture Wildlife Biologist collected tissue and feathers from the leading edge of the wing and sent them to the Smithsonian Institution *National Museum of Natural History* Division of Birds - Feather Identification Laboratory in Washington, D.C. for analysis. The analysis of the remains of this bird identified it as a male mallard duck. The feathers and tissue from a second bird were collected by the Powerplant Group from the No. 2 engine and similarly analyzed. The remains of the second bird were identified as coming from a female mallard duck. The average weight of the male mallard is 1246 grams or 2.75 pounds; the average weight of the female mallard is 1095 grams or 2.4 pounds.

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[1] Although collisions between aircraft and birds make up about 98% of all wildlife strikes and pose the greatest risk, they are not the only animals involved in collisions with aircraft. Deer, coyotes, and even alligators wandering onto runways can create serious problems for departing and landing aircraft. When aircraft collide with wildlife is it commonly referred to as a wildlife strike and if it is a bird it is referred to as a bird strike. When a bird enters a turbofan engine, it is referred to as a bird ingestion.

D. DETAILS OF THE INVESTIGATION

D.1 Engine Information

D.1.1 Engine History

The No. 2 engine was a CFM56-3B1, serial number (S/N) 720265 and was built on July 1985. According to SWA, the time since new (TSN) was 82,270 hours and cycles since new was (CSN) 73,926 cycles. The engine had 15,115 cycles since its last overhaul (CSO).

D.1.2 Engine Description

The CFM56-3 is a high bypass, dual-rotor, axial flow turbofan engine. A single-stage high-pressure turbine (HPT) drives the 9-stage high-pressure compressor (HPC). A 4-stage low pressure turbine (LPT) drives an integrated fan and low-pressure compressor (booster). The annular combustion chamber increases the HPC discharge air velocity to drive the HPT and LPT. An accessory drive system provides drive requirements for engine-mounted aircraft accessories.

CFM is a partnership between General Electric (GE) in the USA and SAFRAN Aircraft Engines, formerly SNECMA Moteurs. CFM is not an acronym; however, the company (CFM) and product line (CFM56) receive their names by a combination of the two parent companies' commercial engine designations: GE's CF6 and Safran's M56. The division of engine hardware is such that Safran is responsible for the fan and LPT modules while GE is responsible for the remainder of the engine – HPC, combustion, and HPT.

E. ENGINE FINDINGS

E.1 General External Condition

The engine was externally intact and undamaged (Photo 4). The fan could be turned with normal effort and when turned, no grinding or other abnormal sounds could be heard emanating from the engine core. The electronic control unit (ECU) and accessory gearbox (AGB) were still sessile, as were the constant speed drive (CSD), main engine control unit (MEC), external oil tank and air turbine starter (ATS). The engine pylon mount hardware was intact and undamaged. There were no leaks in any of the oil or fuel lines. There were no oil leaks evident by the 6 o'clock[2] fan strut on the inside of

[2] All directional references to front and rear, right and left, top and bottom, and clockwise and counterclockwise are made aft-looking-forward (ALF) as is the convention. Top is the 12 o'clock position. The direction of rotation of the engines fan spool is clockwise. All numbering in the circumferential direction starts with the No. 1 position at the 12:00 o'clock position, or immediately clockwise from the 12:00 o'clock position and progresses sequentially clockwise ALF.

the fan duct. There was some slight oil wetting on the AGB and some piping; however, this was believed to have come from oil spilled from quick disconnect fittings above when the engine was removed from the aircraft.

The front spinner cone was attached, undamaged, and exhibited only operational erosion to the paint. The splitter frame exhibited multiple small dents and scores on the outside surface from the 6 to 10 o'clock location.

The constant speed drive (CSD) oil cooler appeared to be undamaged but the front surface was covered with an orange colored fibrous material consistent with fiberglass from the forward and mid acoustic panels (Photo 5). Organic material and feathers were collected, by the powerplant Group, from the front of the CSD oil cooler and were hand-delivered to the Smithsonian Institution *National Museum of Nature History* Division of Birds - Feather Identification Laboratory in Washington, D.C. by the NTSB.

The 4th stage of the LPT was undamaged (Photo 6).

E.2 Fan

The fan blades were numbered sequentially with a marker in a clockwise (aft-looking-forward) direction using the spinner reference mark as number 1. The two fractured blades were No. 14 and 15 (Photo 7, Photo 8 & Photo 9). All the other fan blades were battered, nicked, deformed and torn with associated material loss (Photo 10, Photo 11 & Photo 12). Most of the damage was towards the outer span of the blades. Three fan blade fragments were recovered (Photo 15) from the engine; however, because the engine had been removed from the airplane, their original location where they were found was unknown.

Blade 15 was the leading blade in the operational direction of rotation (Photo 13). A typical blade for the CFM56-3 is approximately 17 inches long at the mid chord. Blade 15 was fractured in a jagged manner at approximately 6 inches outboard from the blade platform. Visual examination of the fracture surface appeared consistent with overload failure. No evidence or features consistent with fatigue were found. There were no nicks on the blade; however, there was a tear on the trailing corner. The leading edge exhibited 3 large-radius ripples, consistent with soft-body damage[3] (Photo 9). Matching fracture surfaces of the recovered fan blade fragments with the fracture surface of blade 15 revealed that one of the fragments corresponded with the outer portion of the blade. The fragment of the No. 15 blade was in a lozenged shape approximately 6 inches x 4 inches. It was battered on all surfaces and did not include the mid-span shroud (Photo 15).

[3] Large radius curvature or deformation is associated with impact from soft material such as rubber or fleshy animal tissue. Small radius deformation is characterized as small radius dents or sharp-edged tears is indicative of hard body impact such as ice or metal.

Blade 14 was the trailing blade in the operational direction of rotation (Photo 14). It was fractured in a jagged manner at approximately 6 inches length outboard of the blade platform and exhibited a single chord-wise large-radius ripple that was evident from the leading edge to the trailing edge. A large-radius bend on the leading edge was observed just below the fracture (Photo 9). Like the fragment fracture surface-matching conducted on blade 15, a fragment shaped in an uneven manner and approximately 6 inches x 4 inches matched that of the fracture surface of blade 14. One mid-span damper was still attached to the segment (Photo 15).

The five recovered significant fan fragments were weighed, and the results are summarized on (Figure 1) below.

Figure 1 – Weights of Recovered Fan Fragments

E.3 Outlet Guide Vanes

All the outlet guide vanes (OGV) were present and intact (Photo 16), however approximately 90 percent were dented, torn and fractured on the leading edge with the most severe damage being on the outer 50 percent of the vane span. The largest tear was approximately 1 inch long while several vanes were folded over on the leading edge (Photo 17). One vane contained an embedded fragment of metallic debris in the leading edge at approximately 70 percent of the span (Photo 18).

E.4 Fan Acoustic Panels

The 12 forward fan acoustic panels were all battered and fractured (Photo 19). Two entire sections were missing from the lower quadrant from 6 to 9:30 o'clock; however, their fasteners were still in place, but the fastener heads were fractured.

The 12 mid acoustic panels were all present, however they were scored and dented. The panels at the 9 o'clock and 3:30 to 4 o'clock locations were fractured, exposing the supporting structure below.

The aft acoustic panels were all present and exhibited only normal operational wear.

E.5 Fan Case, Fan Abradable Shroud and Acoustic Panels

Approximately 75 percent of the fan abradable shroud material was missing (Photo 20), while the remaining abradable material was battered. The abradable material was completely missing at the 4 to 6:30 o'clock and 7 to 7:30 o'clock locations, exposing the steel containment ring material of the fan case. There was a dent in the plane of rotation of the fan rotor in the containment ring at the 5:30 o'clock location, the leading edge of which resembled a blade tip chord impact (Photo 21) and measuring approximately 6 inches circumferentially x 3 inches axially and 0.25 inches radially. There was also an impact mark in the shape of the fan blade chord through the abradable material at the 7:30 o'clock location (Photo 22).

The fan case was also dented at the 1:45 o'clock location in the plane of the forward acoustic panel (Photo 23). The dent size was approximately 1 inch circumferentially x 1 inch axially x 0.05 inches radially.

E.6 Booster Inlet Guide Vanes (IGV)

The booster IGV were all intact; however, 2 vanes at the 5 o'clock location were bent along the span in the direction of rotation (Photo 24), consistent with soft-body damage. Three other vanes had small tears at the leading edge, consistent with small particle hard-body damage.

E.7 Booster and Compressor Examination with Borescope

Borescope examination of the 2nd and 3rd stage booster and the 1st stage HPC revealed evidence of hard-body material ingestion into the booster; there were cuts and tears on several rotor blade leading edges on each stage (Photo 25).

E.8 T 12 Sensor Electrical Cable

The T12 (inlet temperature) sensor cable was severed approximately 5 inches ahead of the A-flange (Photo 26). The corresponding end of the fractured cable was found in the correct location on the airframe inlet. This is consistent with the exiting trajectory of a liberated blade.

E.9 Inlet Cowl

The inlet nose cowl had a dent at 5:30 o'clock on the outer surface of the inlet lip, approximately 8 inches circumferentially x 4 inches axially x 0.5 inches deep (Photo 27).

According to the Boeing Structural Repair Manual, the inlet inner barrel is constructed from a perforated aluminum sheet, aluminum honeycomb, and prepreg fiberglass fabric. The inlet inner barrel (Photo 28 & Photo 29) had multiple small punctures on the inner skin (airflow) side and two large thru-holes; the one at 2:30 o'clock location was approximately 3 inches axially x 2 inches circumferentially in size and the other at 3:00 o'clock was approximately 5 inches axially x 4 inches circumferentially (Photo 30) in size. The T12 sensor cable is fastened to the nacelle at this latter location and was severed. Several scrape marks, in a spiral pattern were observed on the inner skin and the forward acoustic panels (Photo 31).

The nacelle outboard fan cowl had a hole at 3:00 o'clock which aligned with the hole in the inner barrel at similar clock location (Photo 32). The hole was approximately 7 inches circumferentially x 0.5 inches wide and shaped similarly to a fan blade chord section, consistent with a piece of fan blade passing thru edgewise. The exiting direction of the uncontained fan blade particle was outboard and no damage to the fuselage was reported.

The cowl latch hooks and the upper hinges did not show evidence of unusual wear due to vibration. The inlet nacelle inboard fan cowl was not available, SWA personnel stated that it was undamaged and therefore reused it on the new engine installed on the event aircraft which returned to service December 27th.

The A-flange bolts which secure the inlet to the engine fan case were not available. SWA technicians stated that they believed they were reused, thus implying they were undamaged but this could not be confirmed. No evidence of fretting or unusual wear could be seen on either the A-flange or inlet mount flange holes, indicating that this was likely.

F. Fan Blade Particle Trajectory Review

Locations of the penetration holes on the inlet cowl were measured and recorded on Figure 2, Figure 3, and Figure 4. Boeing engineering used these measurements to estimate the external trajectory of the uncontained fan blade.

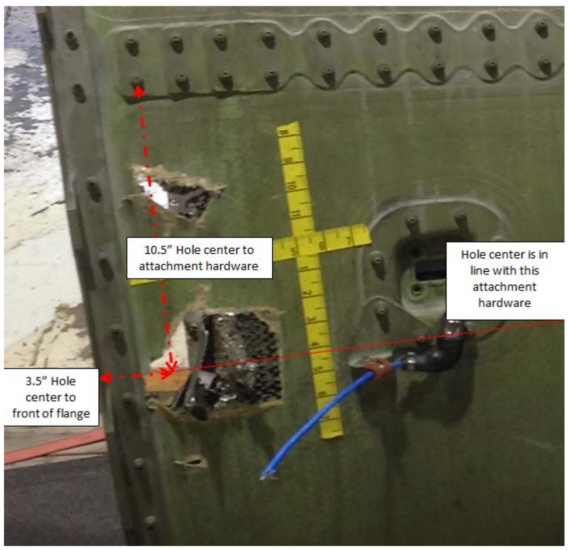


Figure 2 – Hole Locations in Inner Cowling

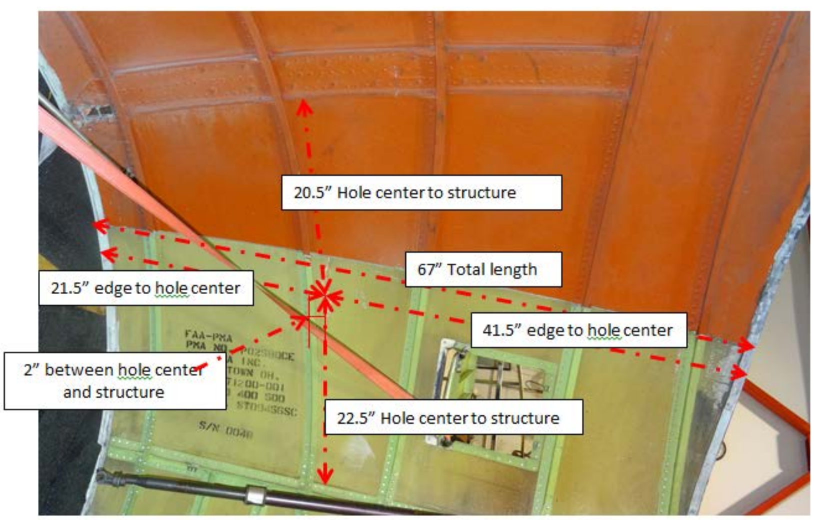


Figure 3 – Hole Locations in Outer Cowling

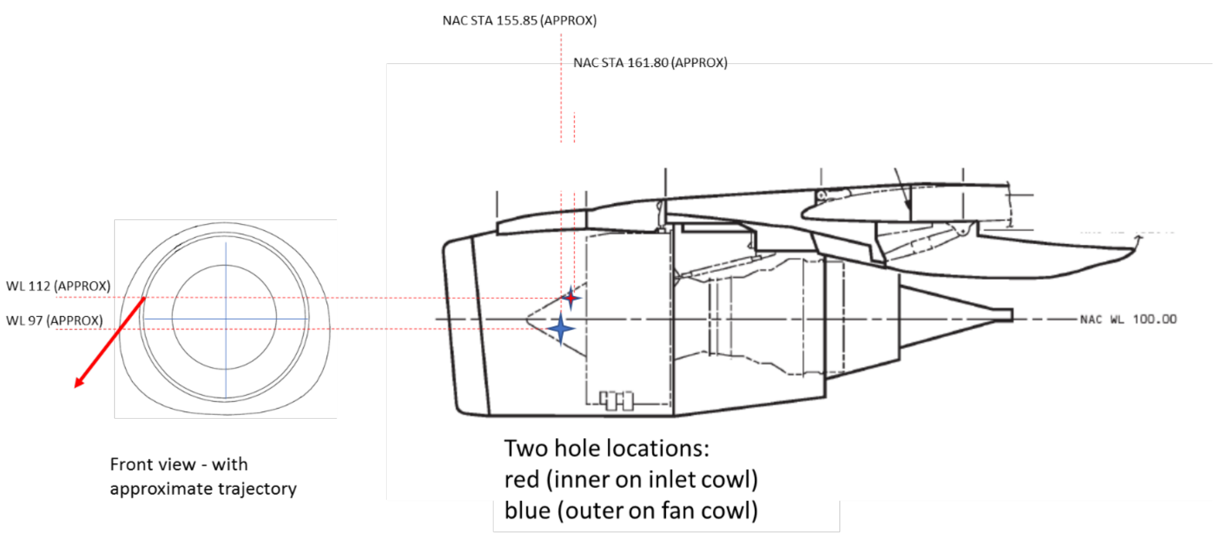


Figure 4 – Front and Side View of Uncontained Fan Blade Particle Trajectory

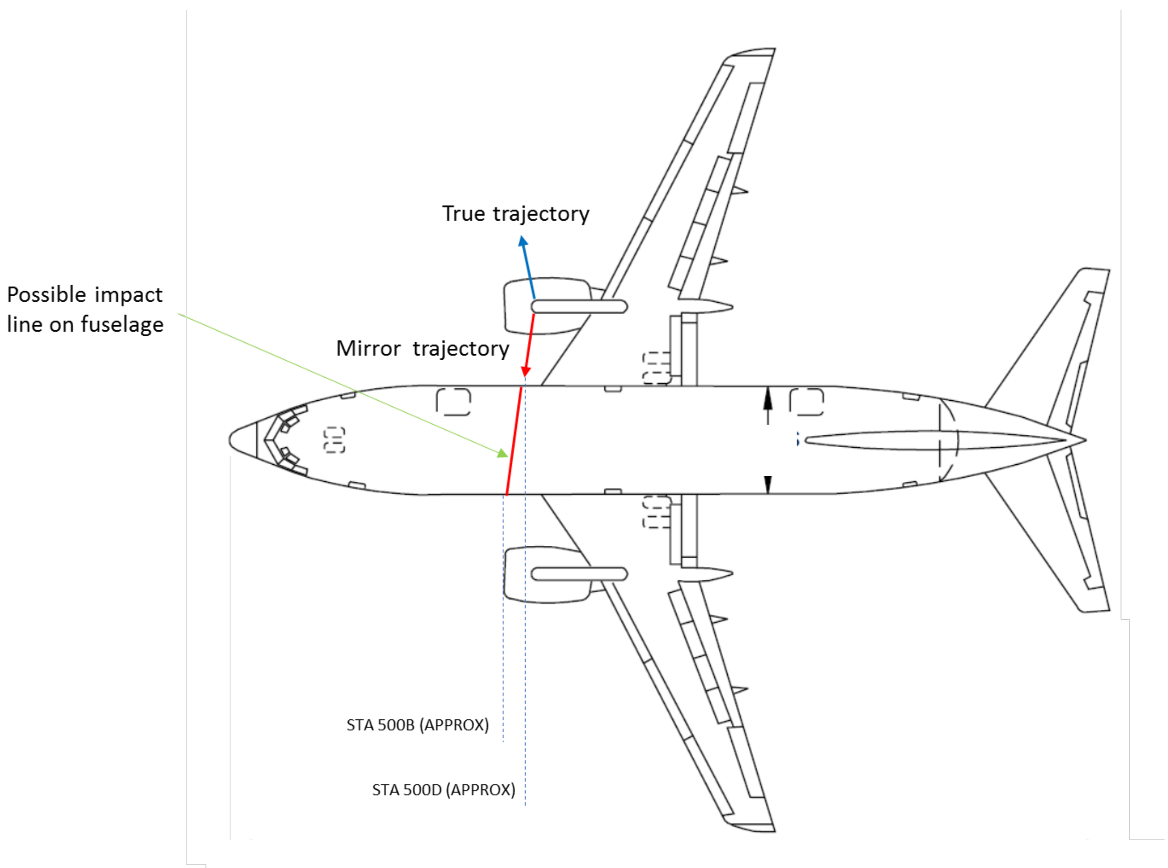


Figure 5 – Top View of Uncontained Fan Blade Particle Plane

G. Flight Data Recorder Information

The digital flight data recorder (DFDR) was sent to the NTSB Headquarters in Washington, D.C. and was readout by the Vehicle Recorder Group. A sequence of events timeline was created based on data from the DFDR for the incident flight. See Table 1 for the plot of the No. 2 engine parameters during the event. Refer to the DFDR Group Chairman's Report (Appendix I) for additional data.

The FDR data was correlated to the event local time, CST.

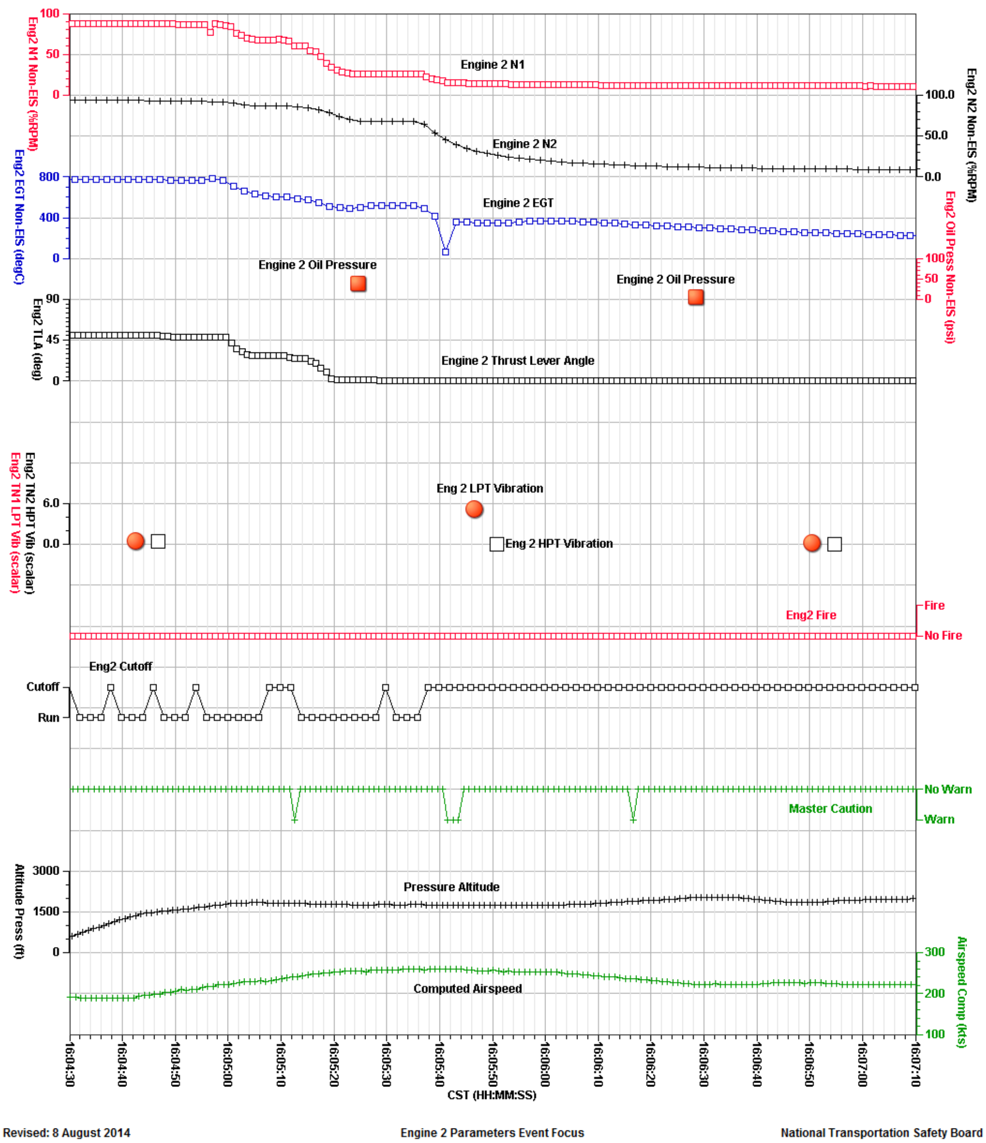


Table 1 – Plot of Engine No. 2 Parameters During the Engine Event

A review of the noteworthy events:

Time (CST)	Note
16:04:10	Airplane Takeoff from STL Runway 30L
16:04:54	Flap position reaches zero.
16:04:56	Assumed time that bird ingestion occurred. N1 drops from 85% to 77%. EGT increases by approximately 25°C. Airplane was at approximately 1700 feet above the ground and traveling at 218 knots.
16:05:00	The thrust lever for right engine begins to decrease and N1 responds.
16:05:37	The fuel cutoff valve is commanded to cutoff position and engine shuts down.
16:16:25	Airplane lands

The event flight lasted approximately 12 minutes.

H. Bird Identification

A local United States Department of Agriculture Wildlife Biologist collected tissue and feathers from the leading edge of the wing and sent them to the Smithsonian Institution National *Museum of Natural History* Division of Birds - Feather Identification Laboratory (SFIL) in Washington, D.C. for analysis. During the engine examination, additional remains were gathered from the engine by the Powerplant Group and sent to the SINM. An SFIL report, No. 2013-12-23-024513, was submitted to the FAA Wildlife Strike Database for this incident. The report can be found on the FAA website at http://wildlife-mitigation.tc.faa.gov/wildlife/default.aspx. The FAA Wildlife Strike Database contains records of reported wildlife strikes since 1990. Strike reporting is voluntary; therefore, the database only represents information received from airlines, airports, pilots, and other sources.

The SFIL, using feather identification and deoxyribonucleic acid (DNA) analysis, identified the first shipment of bird remains as coming from a male mallard duck. The SFIL identified the second shipment of bird remains as coming from a female mallard duck. The average weight of the male mallard is 1246 grams or 2.75 pounds; the average weight of the female mallard is 1095 grams or 2.4 pounds.

I. Engine Certification Basis with Respect to Bird Ingestion

The Certification Basis for the CFM56-3 engine is the Code of Federal Regulations Title 14, Part 33 effective February 1, 1965, with Amendments 33-1 through 33-6.

The bird ingestion requirements in Amendment 33-6 are given in Sec. 33.77, the "Foreign Object Ingestion" rule:

(a) Large Single Bird - Ingestion of a 4-pound bird, …. under the conditions set forth in paragraph (f) of this section, may not cause the engine to--
   (1) Catch fire;
   (2) Burst (penetrate its case);
   (3) Generate loads greater than those specified in Sec. 33.23; or
   (4) Lose the capability of being shut down.

(b) Ingestion of 3-ounce birds, 1 1/2-pound birds, ……. under the conditions set forth in paragraph (f) of this section, may not cause more than a sustained 25 percent power or thrust loss or require the engine to be shut down.

………….

(f) The prescribed foreign object ingestion conditions are as follows:

Birds	Test Quantity	Speed of Bird	Engine Operation	Ingestion
3-oz size	One for each 50 sq. in. of inlet area or fraction thereof up to a maximum of 16 birds. 3-oz bird ingestion not required if a 1 1/2-lb. bird will pass the inlet guide vanes into the rotor blades.	Liftoff speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter.
1½ lb size	One for the first 300 sq. in. of inlet area if it can enter the inlet, plus one for each additional 600 sq. in. of inlet area or fraction thereof up to maximum of 8 birds.	Initial climb speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter.
4lb size	One if it can enter the inlet.	Maximum Climb speed.	Maximum cruise.	Aimed at critical area.

In the CFM56-3 Medium Bird Certification test, 5 seagulls ranging from 1.5 to 1.57 lbs. were ingested in a volley at takeoff thrust and the engine sustained minor damage, losing approximately 3% thrust.

In this event, during climb the aircraft hit a flock of birds at approximately 1700ft above ground level (agl). The event engine obeyed throttle movements for approximately 40 seconds after ingestion until it was shut-down by the flight crew due to high vibrations. It windmilled for the remainder of flight.

Since the birds ingested weighed more than 1.5lbs each, the engine was not required to continue to produce thrust after the ingestion per 33.77(b) above.

J. <u>Engine and Airplane Containment Requirements</u>

The engine containment standards are found in 14 *CFR* Part 33 Subpart B - Design and Construction; General, Section 33.19 Durability. Engine manufacturers are required to design compressor and turbine rotor cases for the containment of damage from rotor blade failure. Section 33.19(a) states in part that:

The design of the compressor and turbine rotor cases must provide for the containment of damage from rotor blade failure. Energy levels and trajectories of fragments resulting from rotor blade failure that lie outside the compressor and turbine rotor cases must be defined.

Engine manufacturers design cases to contain a blade failure which is substantiated by an engine blade-out test or by analysis based on rig testing, component testing, or service experience. FAA Advisory Circular (AC) 33-5 provides guidance and acceptable methods by which engine manufactures test and certifies that the engine complies with the containment provisions in 14 *CFR* Part 33. Part 33.19(a) requirements defining the energy levels and trajectories resulting from a blade failure was intended to address only the initial blade(s) release, not the subsequent medium-to-small blade fragments that are created during blade failures. Examination of the engine revealed that the fan case sustained no penetrations or uncontainments.

No containment requirements exist that call for airplane manufacturers (commuter airplanes Part 23 or transport category Part 25) to design inlets or nacelles to contain engine debris. Therefore, the requirement for containment of fan blades stops at the interface between the engine structure, in the case of the CFM56, the A-flange and the airplane inlet structure. The inlet functions as an aerodynamic device to guide the flow into the engine and is not intended to provide or incorporate structure to prevent fan blade forward liberation. Although the airplane manufacturers are not required to design structure to contain engine debris, they are responsible for the overall safety of the airplane and do have some responsibility of managing liberated engine debris as outlined AC 20-128A, “Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure.” The AC describes how to best mitigate the threat of the debris causing a potential hazardous or catastrophic condition to the airplane or harm to the occupants on board by requiring design precautions based on service experience and tests. Currently, airplane manufactures use redundancy, separation, and isolation to minimize the hazards from large, single, uncontained engine fragments. Because of the direction of the liberated fan blade fragment, it did not strike the fuselage, wing, or passenger windows, and therefore did not pose a hazard to the airplane or passengers.

Harald Reichel
Aerospace Engineer - Powerplants

Photo 1 – Wing Leading Edge and Red Organic Debris

Photo 2 – Right Engine Inlet Cowl – Outboard Side

Photo 3 - 7-inch Long Penetration Tear - Detail

Photo 4 - CFM56-3 Side View

Photo 5 – Constant Speed Drive Oil Cooler

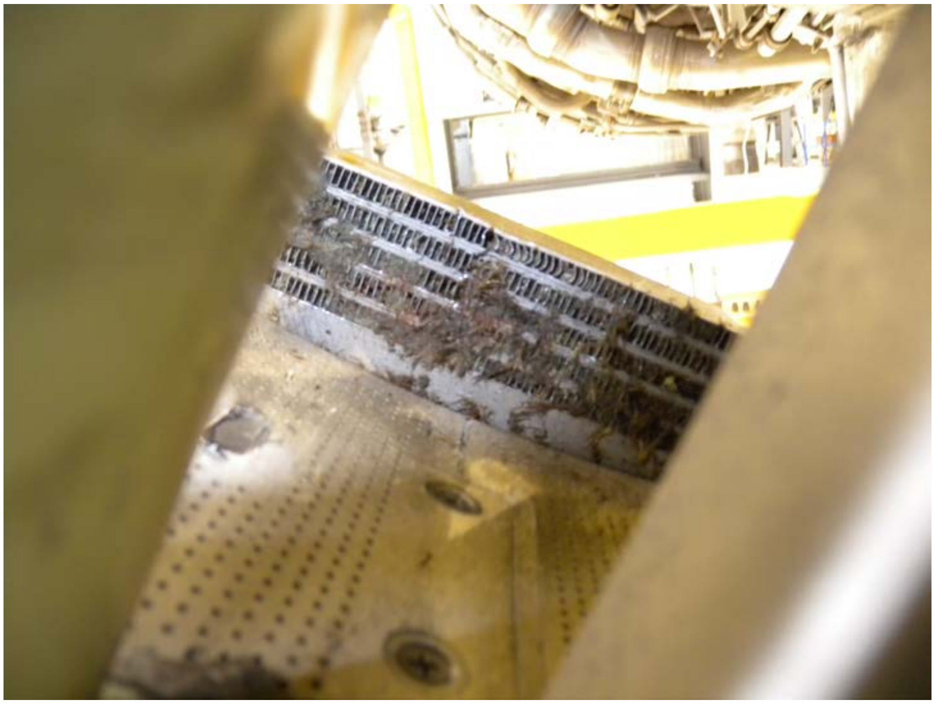


Photo 6 – Low Pressure Turbine - Last Stage

Photo 7 – Fan – Front View

Photo 8 – Fractured Fan Blades – Close-up

Photo 9 - Fractured Fan Blades – Close-up

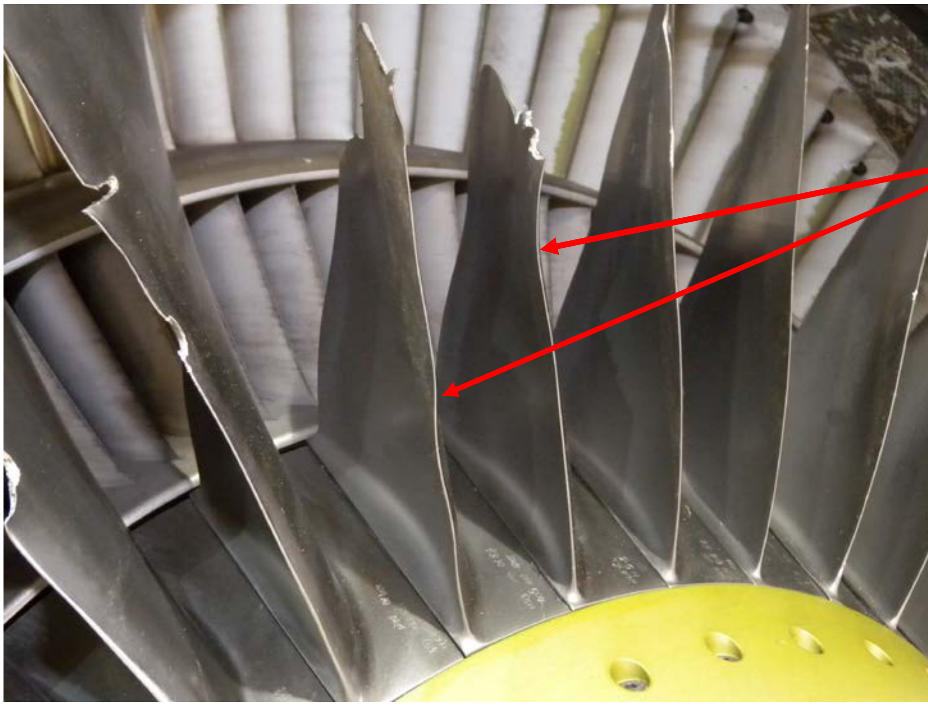


Photo 10 – Fan Blades - Details

Photo 11 – Fan Blades - Details

Photo 12 – Fan Blades - Details

Photo 13 – Fan Blade No. 15

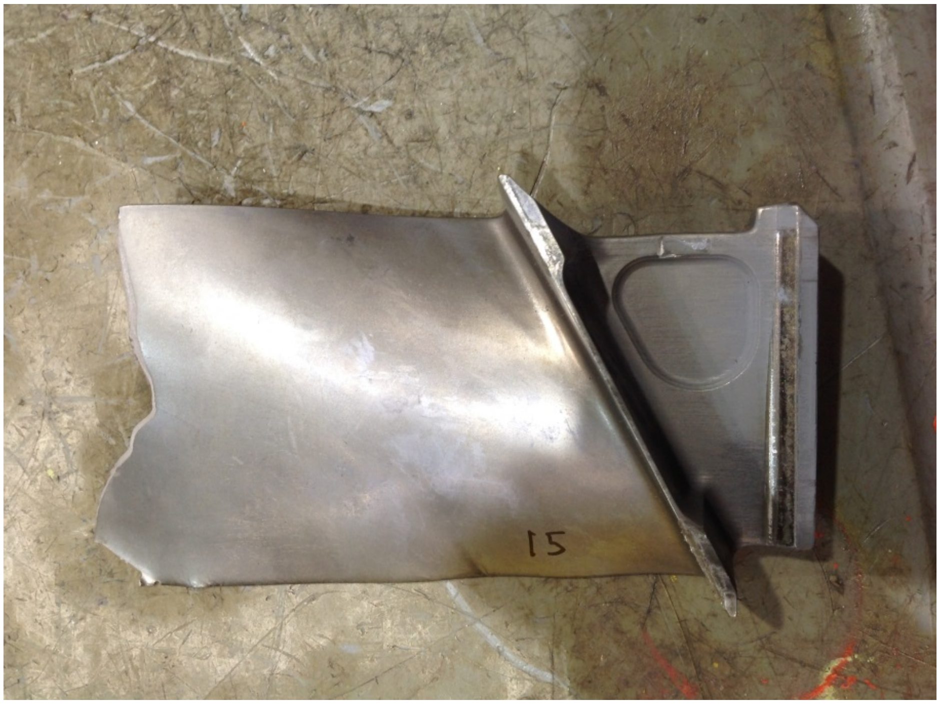


Photo 14 – Fan Blade No. 14

Photo 15 – Fan Blades No. 14 & 15 with Found Matching Fragment

Photo 16 – Outlet Guide Vanes

Photo 17 – Outlet Guide Vanes – 1-inch Tear of Leading Edge

Photo 18 – OGV with embedded metallic debris

Photo 19 – Front and Mid Acoustic Panels

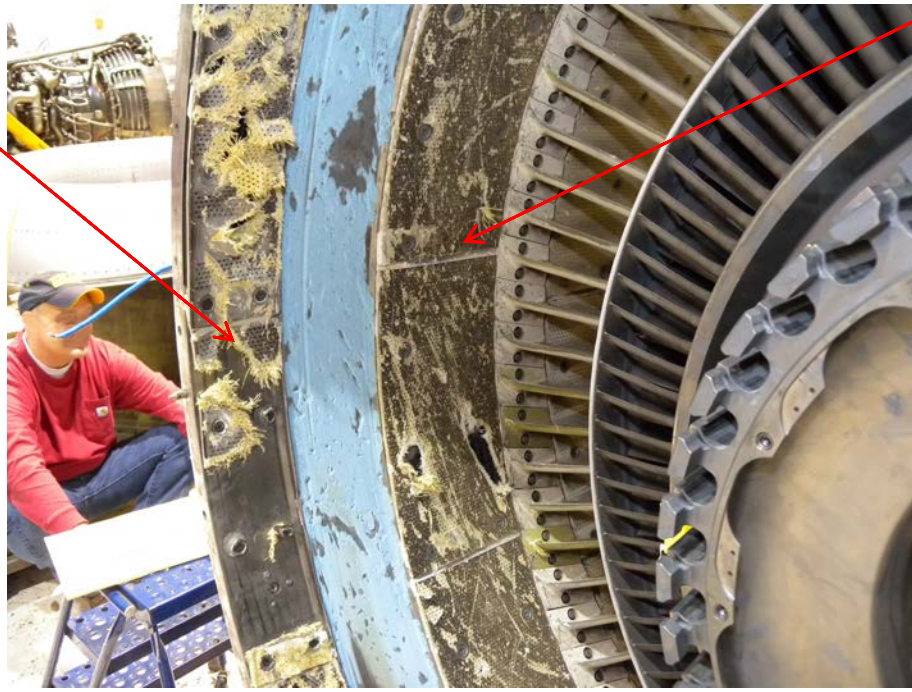


Photo 20 – Abradable Material at 6 o'clock Location

Photo 21 - Abradable Material at 6 o'clock Location (Detail)

Edge of dent resembles a fan blade chord shape

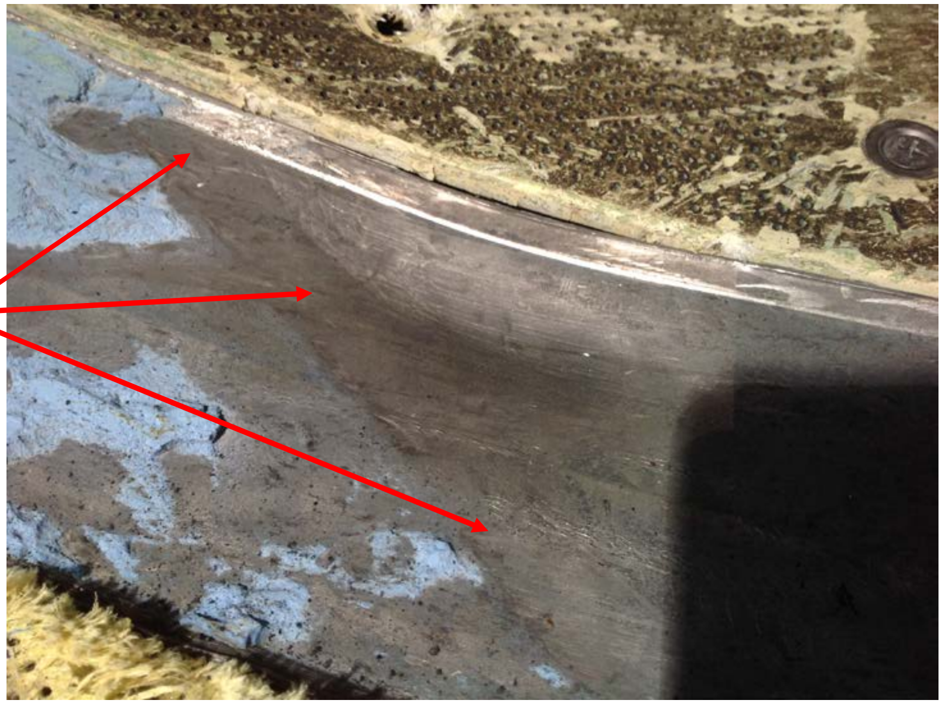


Photo 22 – Impact Through Abradable Material at 7:30 o'clock Location

Photo 23 – Dent in Plane of Forward Acoustic Panel

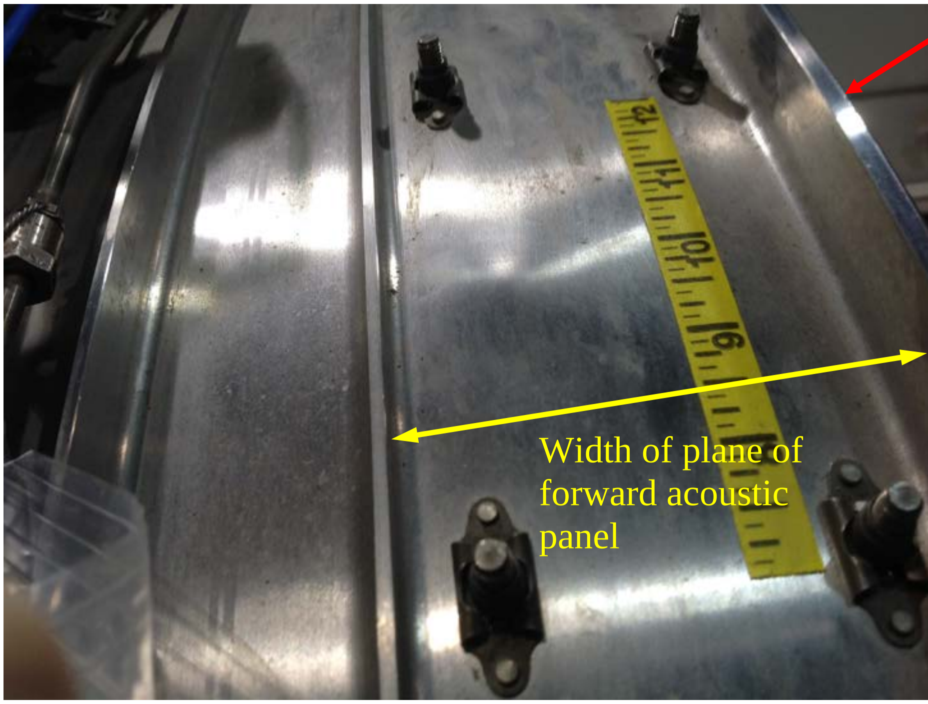


Photo 24 – Booster Inlet Guide Vanes - Bent

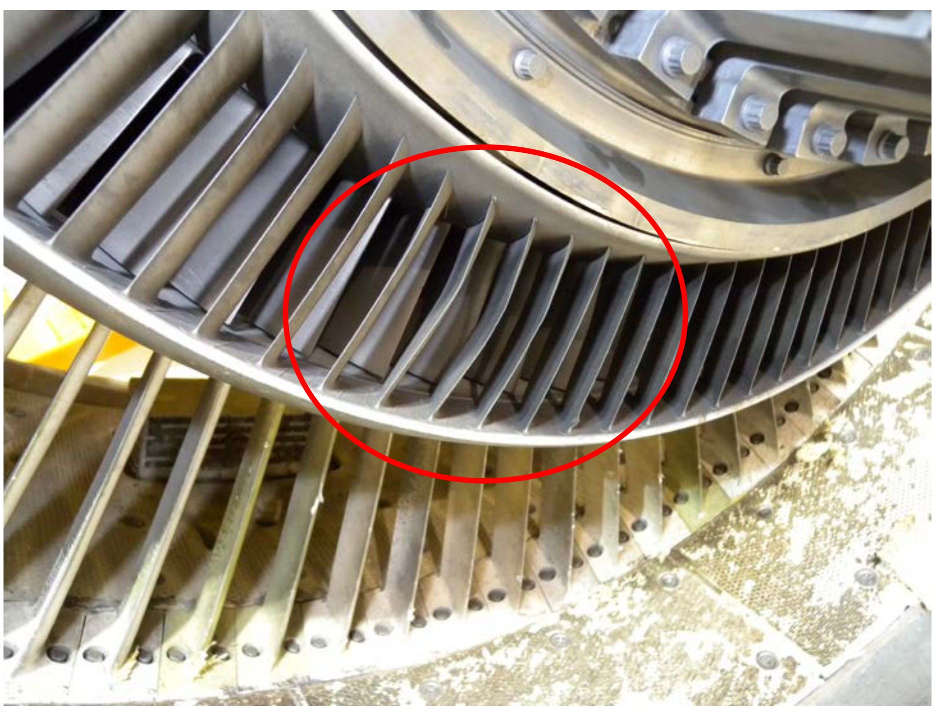


Photo 25 – Damage to 3rd Stage Booster Blade

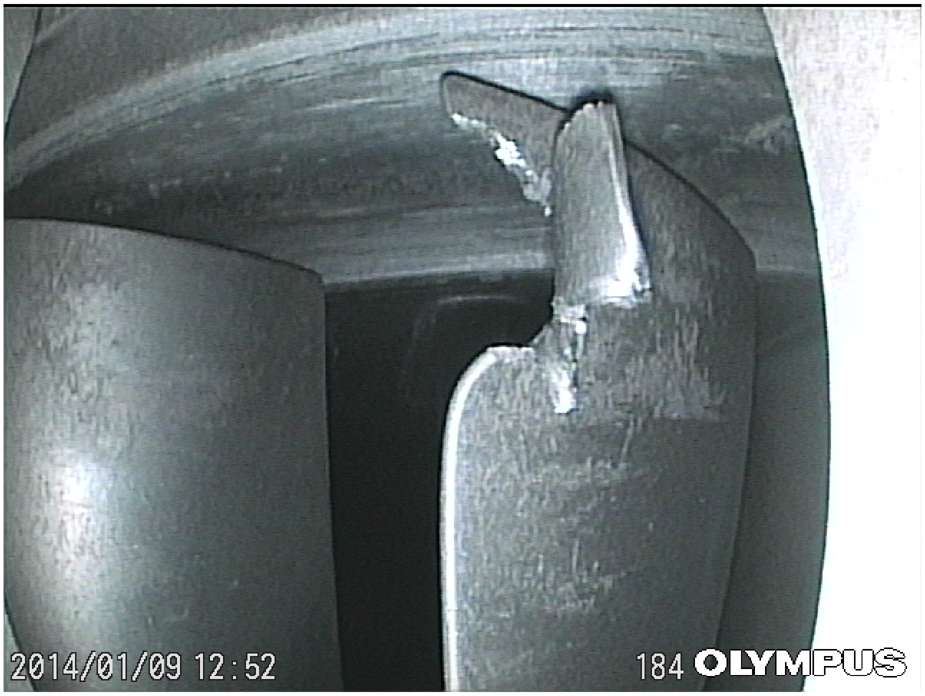


Photo 26 – T12 Cable (blue) Fractured

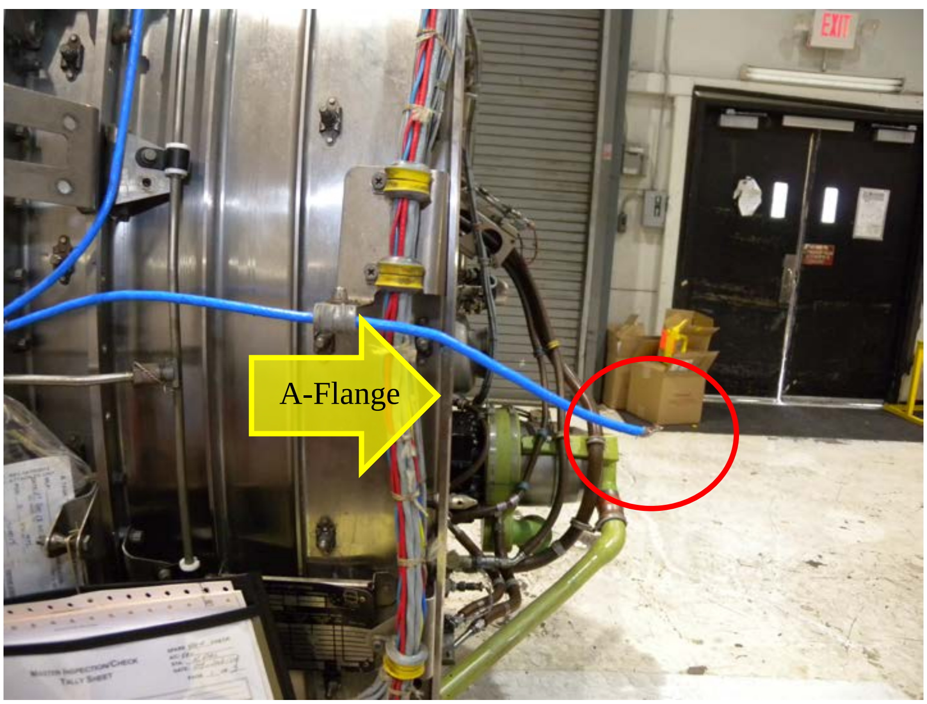


Photo 27 – Dent on Inlet Lip Skin

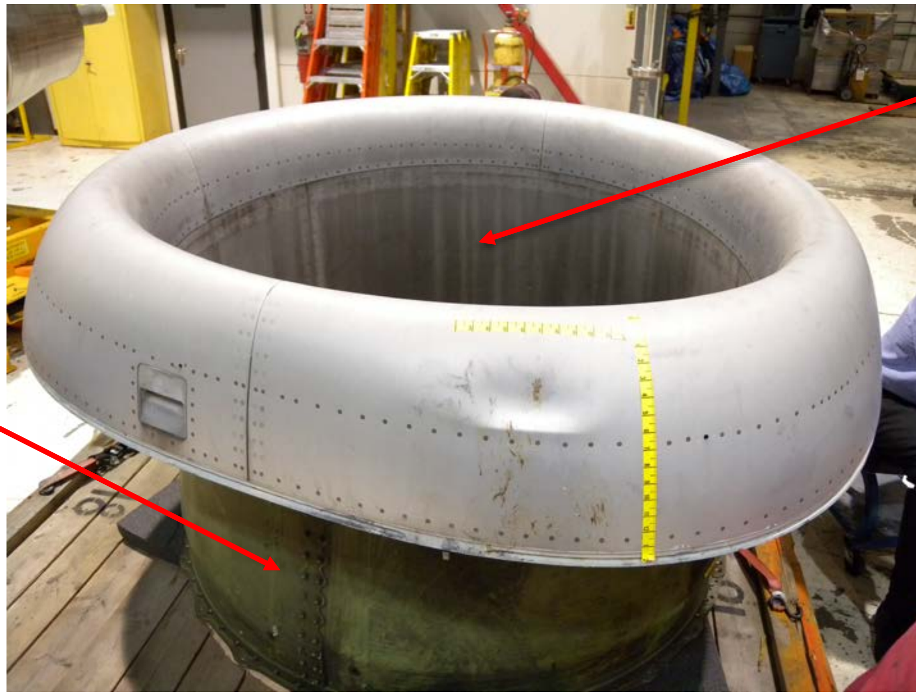


Photo 28 – Inlet Inner Barrel – Back Sheet - Left Side

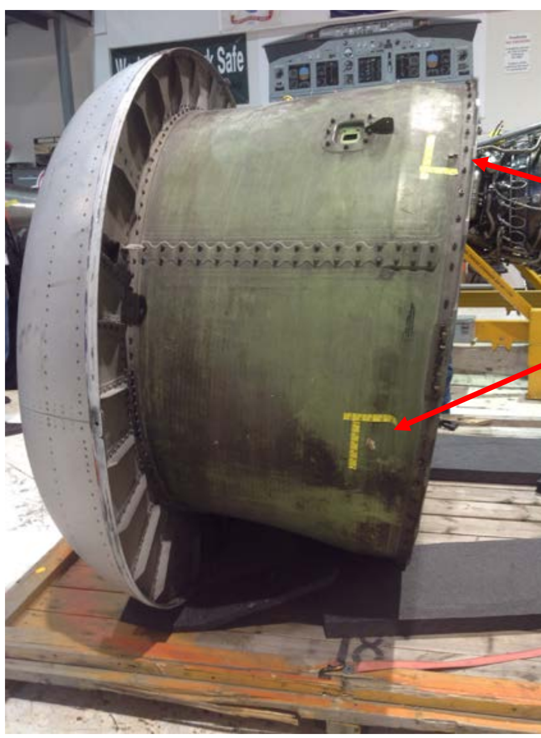
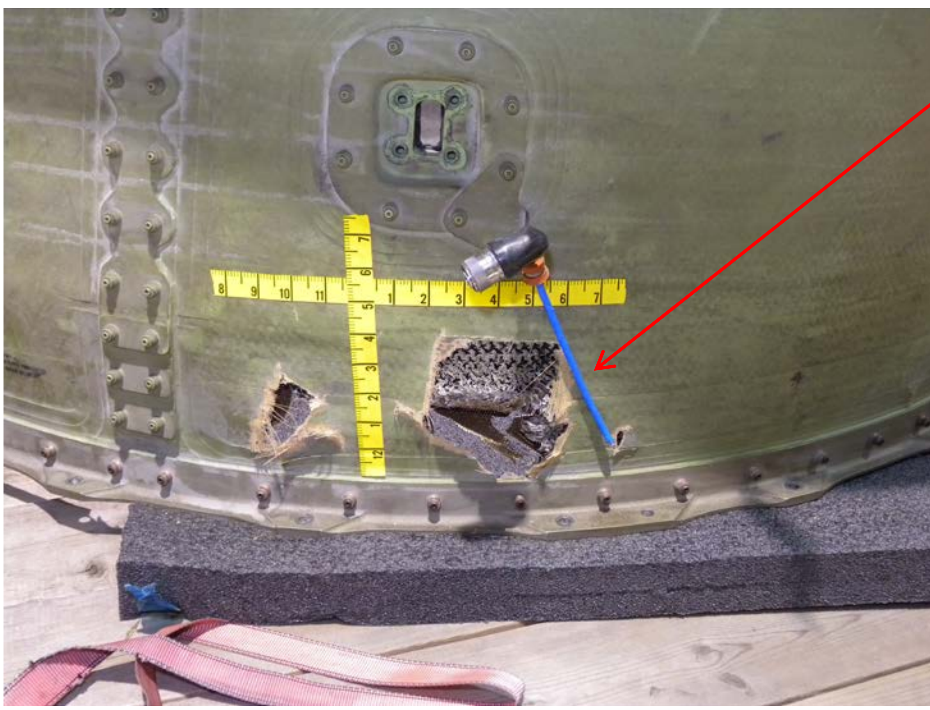


Photo 29 - Inlet Inner Barrel - Back Sheet – Right Side

Fractured Fiberglass on Back Sheet - Not Penetrated.

Penetrated Holes on Back Sheet at 2:30 and 3:00 o’clock

Photo 30 – Inlet Inner Barrel Back Sheet - Two Through Holes - Detail



Severed T12 Cable

Photo 31 – Inlet Inner Barrel Face Sheet - Forward of A-Flange

Photo 32 – Hole in Outboard Fan Cowl