



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

November 16, 2021

POWERPLANTS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB No: CEN20LA215

A. ACCIDENT

Location: Sioux Falls, South Dakota

Date: June 7, 2020

Time: 04:25 central daylight time (CDT)

Aircraft: Mitsubishi MU2B, N44MX, McNeely Charter Service, Inc.

B. POWERPLANTS GROUP

Group Chairman: Robert Hunsberger
National Transportation Safety Board
Washington, D.C.

Member: Dana Metz
Honeywell
Phoenix, Arizona

Member: Yoshiaki Asako
Mitsubishi Heavy Industries
America, Inc.
Dallas, Texas

Member: Kevin Bohnert
McNeely Charter Services, Inc.
West Memphis, Arkansas

C. SUMMARY

On June 7, 2020, about 0425 central daylight time, a Mitsubishi MU-2B airplane, N44MX, was destroyed when it was involved in an accident near Sioux Falls, South Dakota. The pilot was fatally injured. The airplane was operated as a Title 14 Code of Federal Regulations (CFR) Part 135 cargo flight. The flight originated at Snohomish County Airport (Paine Field) (PAE), Everett, Washington, about 2115, and was originally destined for Huron Regional Airport (HON), Huron, South Dakota, for a fuel stop. However, preliminary air traffic control information and weather data was consistent with the pilot diverting to Joe Foss Field Airport (FSD), Sioux Falls, South Dakota, due to weather at HON at the time of intended arrival. The flight landed at FSD at 0140. The destination was Kokomo Municipal Airport (OKK), Kokomo, Indiana

The Honeywell TPE331-10-511M turboprop engines were examined at the Honeywell Product Integrity Laboratory in Phoenix, Arizona with party members from Honeywell, Mitsubishi, McNeely Charter Services, and the National Transportation Safety Board (NTSB) from March 22-26, 2021.

D. DETAILS OF THE INVESTIGATION

1.0 ENGINE INFORMATION

1.1 Engine Description

The Honeywell TPE331-10-511M is a single spool turboprop engine with a two-stage centrifugal compressor, reverse flow annular combustor, three stage turbine, and hydromechnical fuel control.

According to FAA Type Certificate Data Sheet E4E3, Revision 34, dated May 22, 2014, the Honeywell TPE331-10-511M engine has a maximum continuous sea level thrust rating of 900 shaft horsepower (SHP) and a maximum takeoff sea level thrust rating of 940 SHP at international standard atmosphere conditions.

All directional references to front and rear, right and left, top and bottom, and clockwise and counterclockwise are made aft looking forward (ALF). A cutaway illustration of the engine is shown in **Figure 1**.

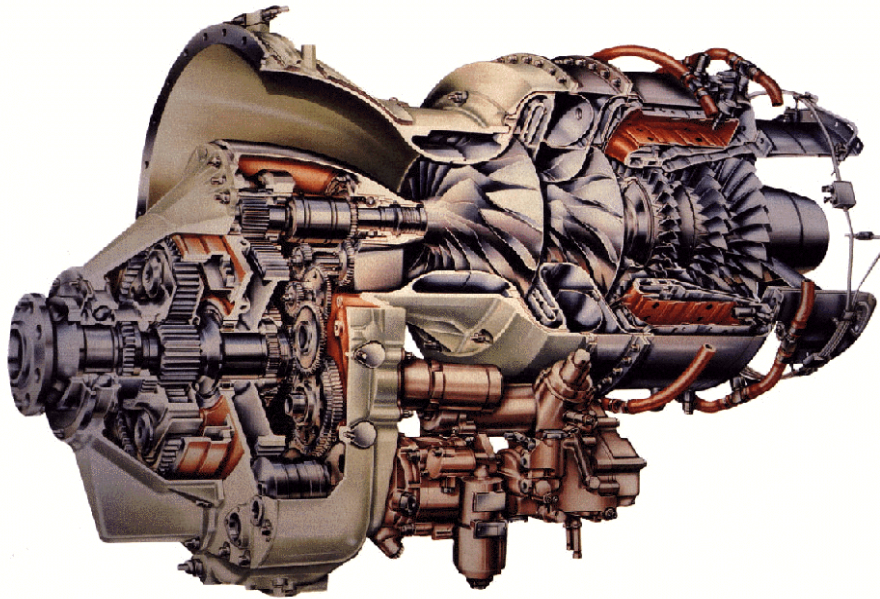


Figure 1- Honeywell TPE331

1.2 Engine History

According to the logbook records the engines had the following hours and cycles as of the last leg prior to the accident flight:

Engine	Time Since New (hours)	Time Since Overhaul (hours)
No. 1 (left)- P-36058C	12,591.1	2,381.5
No. 2 (right)- P-36235C	12,405.5	3,553.1

The last maintenance completed on both engines was a 100 hour / 1 year inspection on December 19, 2019. According to the logbook entries, the inspection was performed in accordance with Mitsubishi Maintenance Requirements Manual MR-0179.2 and all applicable inspections required per Honeywell service bulletin TPE331-72-0180¹. There were no noteworthy engine related issues identified during the inspection.

2.0 NO. 1 (LEFT) ENGINE SERIAL NUMBER (ESN) P36058C TEARDOWN EXAMINATION

2.1 Visual Inspection

The engine was secured in a cardboard box in the Honeywell Product Integrity cage when the investigation group arrived (**Photo 1**). The engine was shipped with multiple airframe components

¹ SB TPE331-72-0180, original release date April 11, 1978, current revision 40, release date July 23, 2019, provides: FAA approved life limits for certain critical components, a listing of time/cycle tracked components, instructions for determining low cycle fatigue equivalents for special-use operations, bearing assembly replacement schedules, a listing of periodic inspection and maintenance requirements, requirements for time between overhaul, and requirements for common aviation maintenance.

installed including: the engine mount horseshoe, starter generator, fire detection loops, wiring harnesses, and part of the aft firewall (**Photos 2, 3, and 4**). The beta tube and oil samples collected at Wentworth Aircraft, Inc. in Crystal, Minnesota during the wreckage layout were included in the shipping box.



Photo 1- Engine Shipping Container, as Received at Honeywell



Photo 2- ESN P36058C, Left Side, As Received



Photo 3- ESN P36058C, Right Side, As Received



Photo 4- Engine Data Plate

The airframe components were stripped from the engine and a visual inspection was performed to document the external condition. The engine did not exhibit indications of uncontainment or undercowl fire. The accessory gearbox (AGB) inlet forward lip had impact deformation along the bottom of the engine from the 5 to 7 o'clock positions and an approximately 6 inch long axial crack at the 7 o'clock position that originated 1 inch aft of the forward lip and extended aft (**Photo 5**). Five of the seven forward propeller bearing mount bolts were not present in the bolt holes. The two remaining bolts

were loose and could be removed by hand. The propeller pitch control was partially separated from the AGB mount at two of the three attachment studs (**Photo 6**). The fuel pump mounting studs were pulled out of the AGB, and the fuel pump drive spline was broken off in the AGB housing. The fuel control unit (FCU) link tree and FCU-to-fuel pump mount flange were both fractured. The propeller feather valve was disconnected/broken at the linkage connection (**Photo 7**). The propeller governor was intact and when removed, the check valve orifice was verified to be free of obstruction. The starter spline was separated, and the broken spline was recovered from the AGB case. The oil tank exhibited impact damage that was most concentrated along the forward left side (**Photo 8**). The fuel shutoff valve (FSOV) shaft indicator was at the 9 o'clock position² (**Photo 9**).

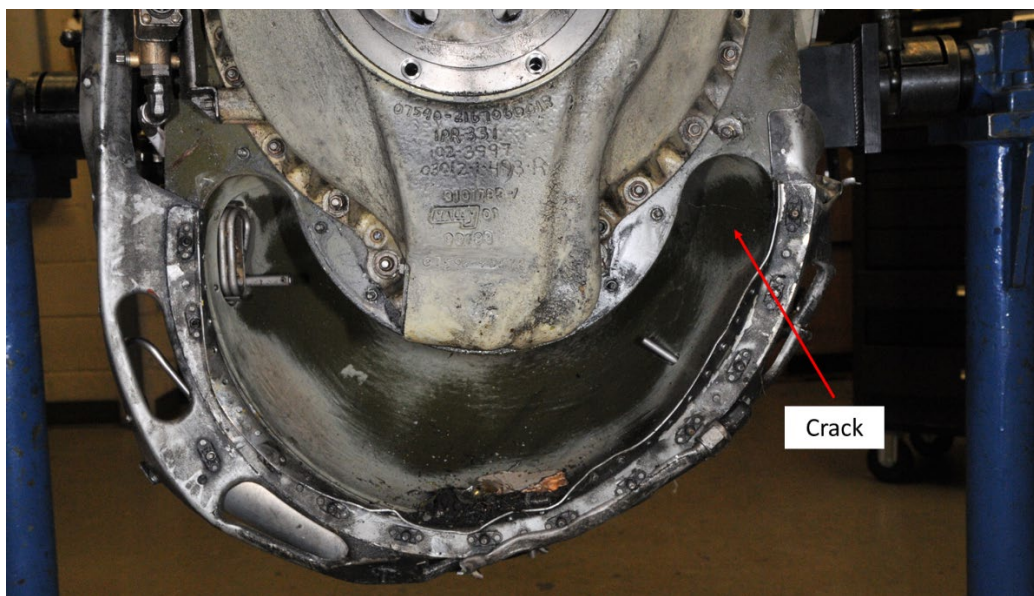


Photo 5- Accessory Gearbox Inlet Impact Damage

² The FSOV indicator is aligned with the 12 o'clock position in auto mode and rotates to the 3 o'clock position when the condition lever is retarded to the emergency shutoff position in the cockpit. According to Honeywell, the FSOV is closed when the indicator is at the 3 or 9 o'clock position, but rotation to the 9 o'clock position is consistent with FSOV/linkage damage.

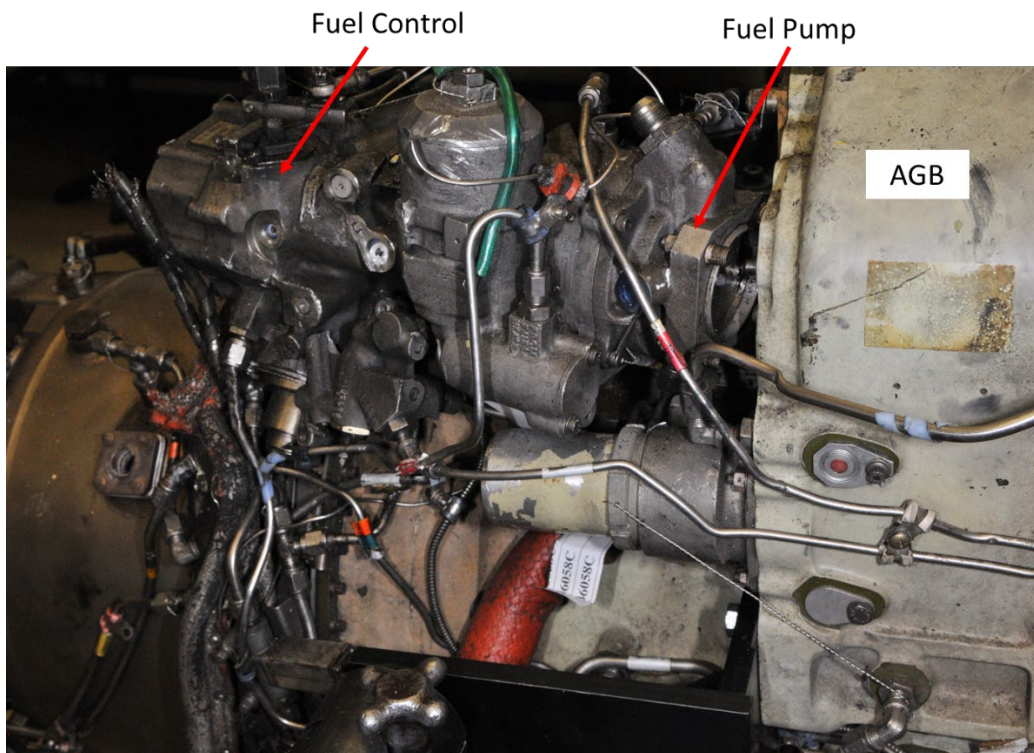


Photo 6- Fuel Pump and Fuel Control Unit Partially Separated from the AGB

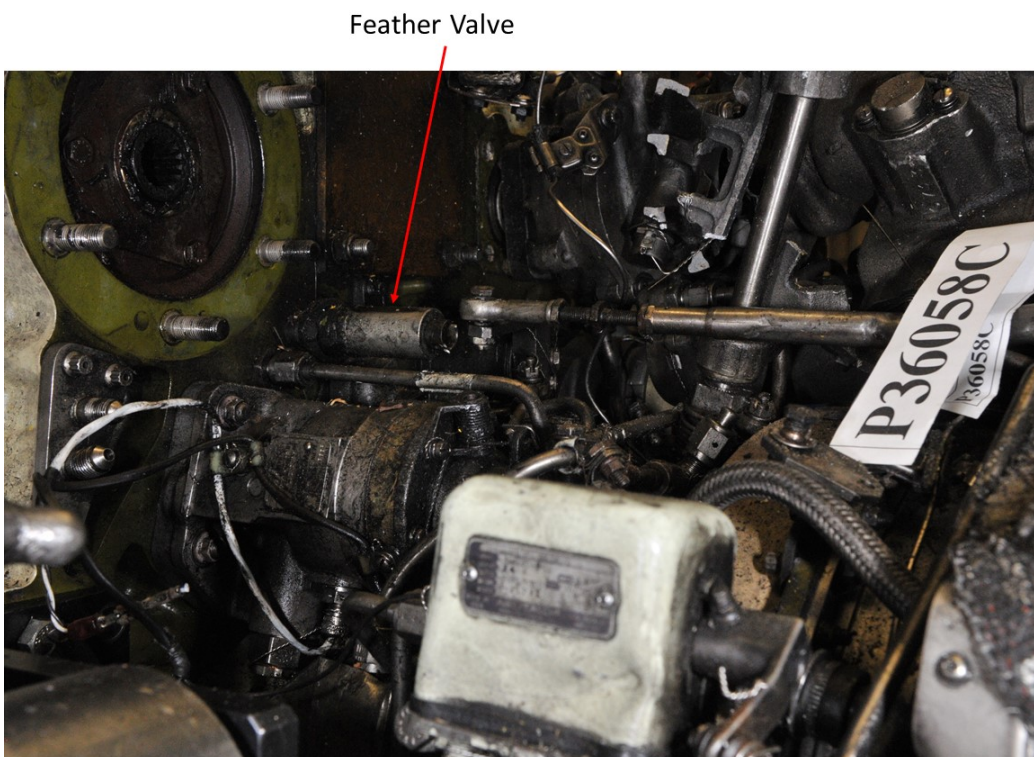


Photo 7- Feather Valve Linkage Fractured

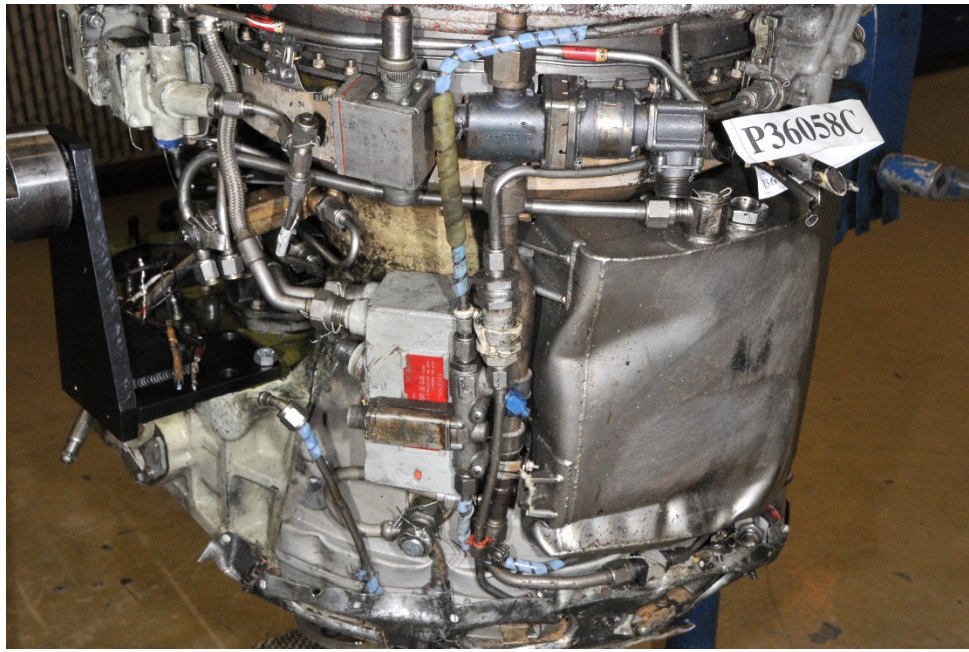


Photo 8- Oil Tank Impact Damage

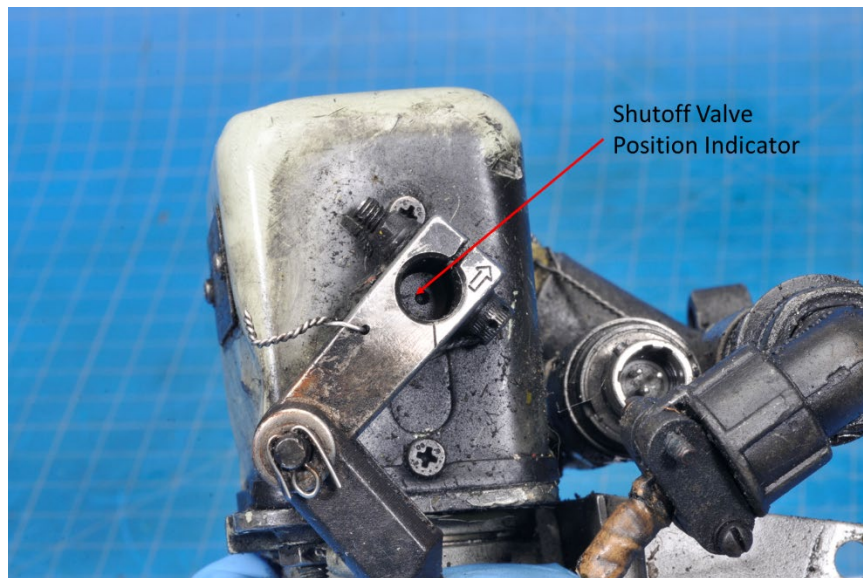


Photo 9- Fuel Shutoff Valve

The magnetic chip detector (MCD) had some debris accumulation including fine metal shavings and fuzz. The MCD housing was coated in slimy white and brown buildup and metal shavings were protruding from the housing cutouts (**Photo 10**). The oil filter bowl was difficult to unthread and required a strap wrench for removal. The oil filter pleats, and bowl were both free of debris accumulation. The fuel filter had no debris accumulation. The propeller shaft was manually spun to check for continuity and there was no concurrent rotation of the 3rd stage turbine rotor.



Photo 10- (L) Magnetic Chip Detector Housing, (R) Magnetic Chip Detector Plug

2.2 Accessory Gearbox

The mechanic notified the group that AGB nose cone attaching bolts were not torqued as expected. Breakaway torque was checked on a random sample of bolts and each had less than 5 inch-pounds (in-lbs.) of torque.³ When the nose cone was removed, the propeller thrust bearing, propeller shaft, and propeller coupling were complete. The propeller thrust bearings were oil wetted and rotated smoothly. The nose cone had white slimy residue in the lower recess and five nuts, and three fractured bolts were recovered from 6 o'clock position. The propeller shaft had a 360 degree circumferential rub at the forward radius, light localized rubs 1 inch and 1.5 inches aft of the shaft base, and non-uniform circumferential rub and gouging 5.75 inches from the shaft base that resulted in raised metal (**Photo 11**). The ring gear, sun gear and planetary gears were intact (**Photo 12**). Impact marks and rub were noted on the aft gear tooth surface of all four planet gears and there was concurrent impact and rub marks on the forward face of the ring gear support (**Photo 13**). One planetary gear bearing outer race was cracked at two locations and rotated with some resistance. The other three planetary gears rotated smoothly. Metal shavings were observed on the planetary gear carrier. The forward side of the sun gear inner diameter had 360 degree circumferential rub and raised metal slivers (**Photo 14**).

³ According to the engine maintenance manual, the nose cone bolt torque is 80 in-lbs. and the two larger bolts located at the 12 o'clock position are supposed to be torqued to 100 in-lbs.

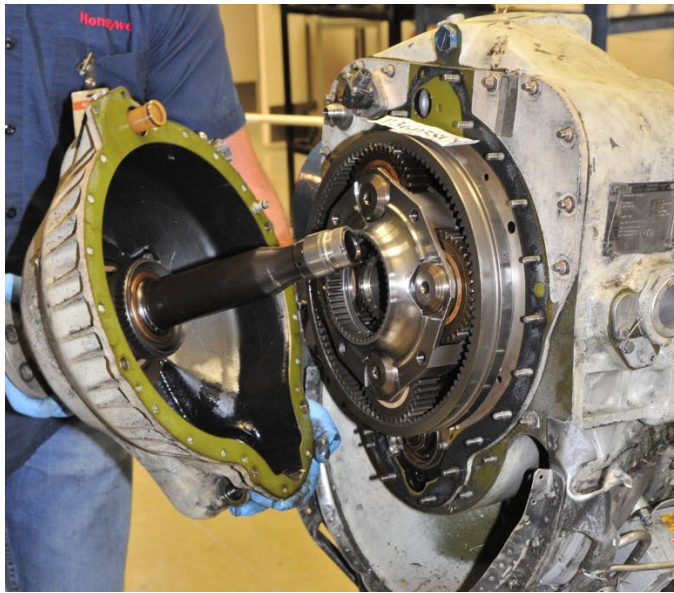


Photo 11- (L) Nose Cone Following Removal, (R) Propeller Shaft Circumferential Rub at Lower Radius

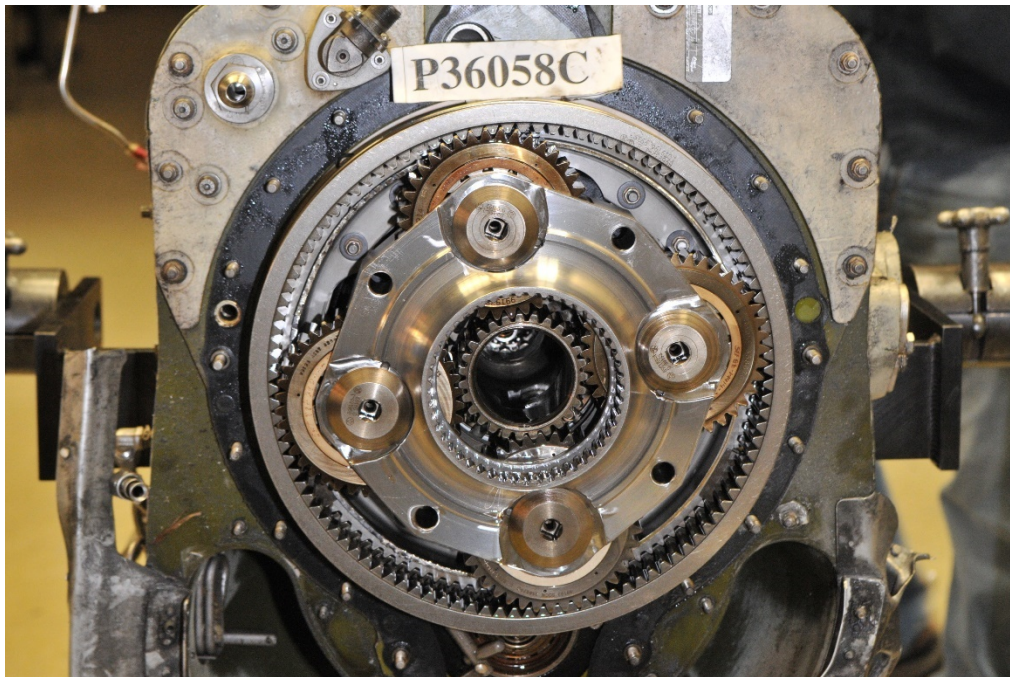


Photo 12- Ring, Sun, and Planetary Gears



Photo 13- (L) Damage on Planetary Gear Teeth Aft Face, (R) Rub/Impact Damage on the Ring Gear Support



Photo 14- Sun Gear Inner Diameter Rub Damage

The AGB diaphragm was intact and in good condition. The torque coupling shaft was removed, and the aft spline was separated. The broken spline was later recovered from the torsion shaft (**Photos 15**). The aft diaphragm gearset and mating accessory gears were intact (**Photo 16**). The torque sensor was intact, and the gear teeth were in good condition. The high speed pinion was manually rotated and the geartrain rotated smoothly. After removal of the torque sensor housing, the main shaft gear was manually rotated and there was concurrent rotation of the turbine as viewed through the exhaust. Impact marks were observed on the AGB case feather valve bore and the torque sensor housing (**Photo 17**). According to Honeywell Product Integrity, impacts in these locations are common during propeller strike events on airplanes equipped with TPE331 engines.

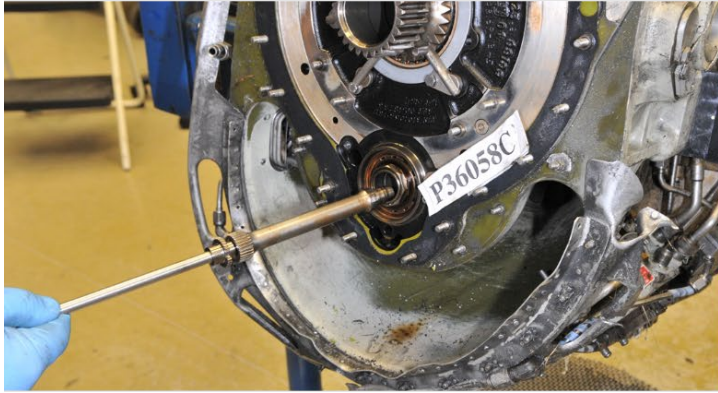


Photo 15- Separated Torque Coupling Shaft



Photo 16- Diaphragm Assembly

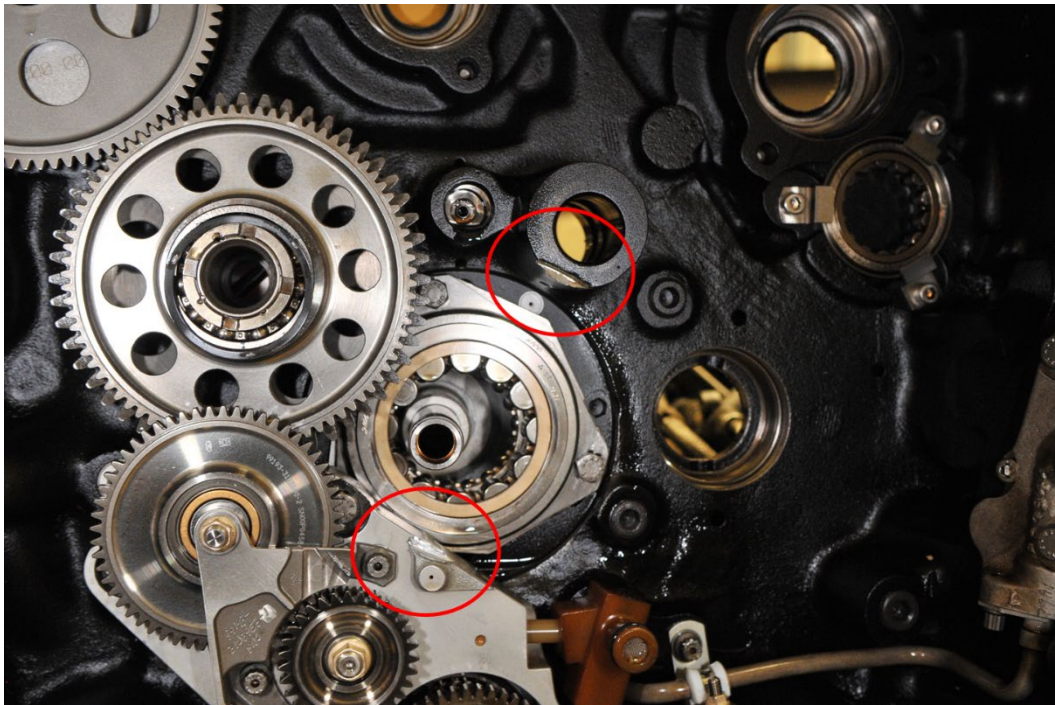


Photo 17- Impact Marks on Feather Valve Bore and Torque Sensor Housing

2.3 Turbine Section

The turbine rear frame was intact, and the rear turbine bearing was oil wetted and rotated with light resistance. All three stages of turbine rotors and stator vanes were complete (**Photos 18-23**). Metal spray and black spatter/streaking were observed on the blades and vanes of each stage. The turbine rotor shrouds were intact. There was rub/scoring on the 1st and 2nd stage turbine rotor shrouds. The 1st stage turbines vanes exhibited thermal damage and material loss on the leading edge blade tips. The curvic couplings between each stage were undamaged and properly mated. The interstage air seals were in good condition.



Photo 18- 3rd Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge



Photo 19- 3rd Stage Turbine Stator, (L) Pressure Side, (R) Suction Side



Photo 20- 2nd Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge



Photo 21- 2nd Stage Turbine Stator, (L) Pressure Side, (R) Suction Side

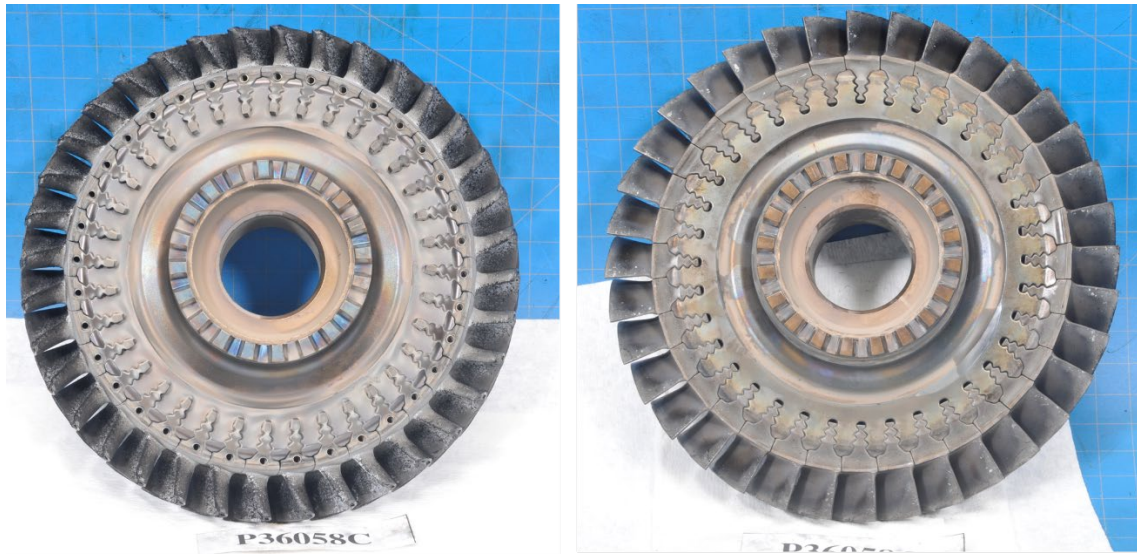


Photo 22- 1st Stage Rotor, (L) Leading Edge, (R) Trailing Edge



Photo 23- 1st Stage Turbine Stator, (L) Pressure Side, (R) Suction Side

2.4 Combustor

The combustion liner was intact and had no indications of fuel nozzle streaking or uneven thermal wear. There was minor combustion liner outer wall deformation coincident with deformation that was observed around the compressor discharge (P3) bleed bore on the plenum case. Earthen debris was accumulated in the liner cooling air holes around the liner circumference (**Photo 24**). There was light metal spray on the liner walls. All the fuel nozzles were properly seated and there was no evidence of coking. The fuel manifold plumbing was intact and in good condition.



Photo 24- Combustion Liner

2.5 Compressor Section

The 2nd stage compressor impeller was intact. The impeller vanes had light tip rub along the length of all blades and localized impact damage was observed on the leading edge of one blade. There was 360 degree rotational scoring aft of the forward 2nd stage impeller curvic coupling (**Photo 25**). The 2nd stage impeller shroud⁴ inducer had 360 degree rotational scoring, more severe from the 6 to 12 o'clock positions. The impeller shroud knee had rotational scoring from 6 to 12 o'clock positions. The impeller shroud exducer had rotational scoring from the 7 to 5 o'clock positions, more severe from the 12 to 5 o'clock positions (**Photo 26**). The 2nd stage compressor diffuser had debris between the vanes (**Photo 27**).

⁴ Honeywell refers to the forward section the impeller shroud as the inducer, the middle section as the knee, and the aft section as the exducer.



Photo 25- (L) 2nd Stage Compressor Impeller Vane Scoring, (R) Impeller Curvic Coupling Outer Diameter Scoring

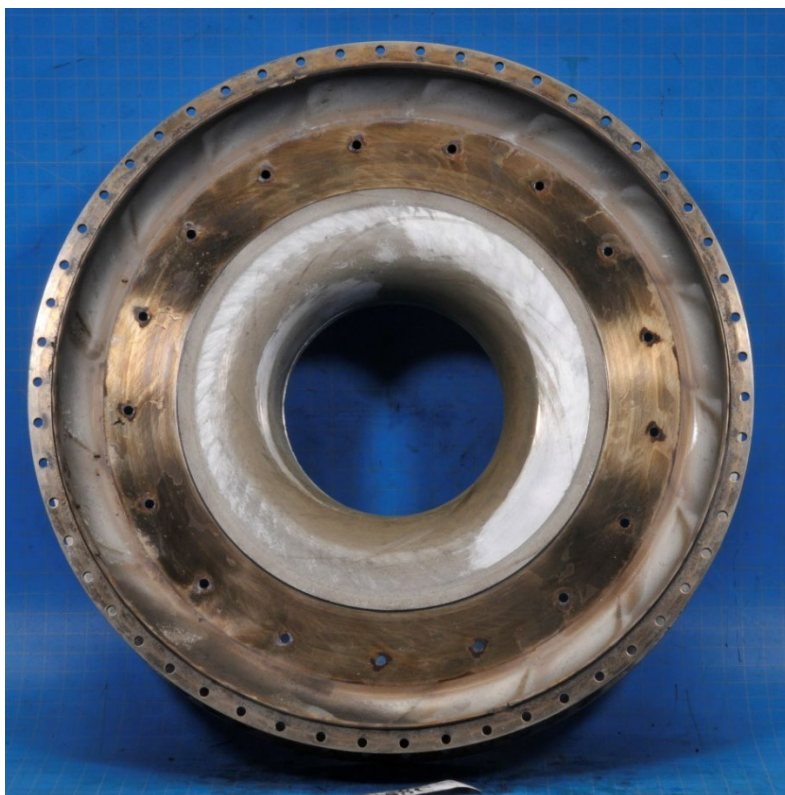


Photo 26- 2nd Stage Compressor Impeller Shroud Circumferential Scoring

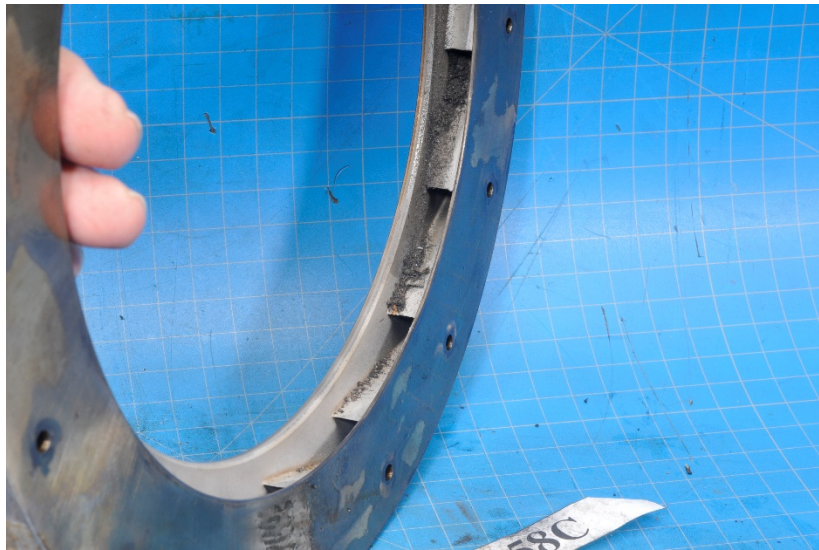


Photo 27- 2nd Stage Compressor Diffuser with Debris Accumulation Between Vanes

The 1st stage compressor impeller had blade tip rub along the length of all blades. All blade tips exhibited leading edge bending opposite the direction of rotation (**Photo 28**). The main shaft was intact and did not appear to be deformed/bent. Debris was accumulated in the forward shaft knife edge seals and the 1st stage impeller had 360 degree scoring on the outer diameter of the aft hub, forward of the curvic coupling (**Photo 29**). The 1st stage impeller shroud had rotational rub and scoring from the 1 to 11 o'clock positions of the inducer that was more severe between the 6 and 11 o'clock positions (**Photo 30**). The impeller shroud knee had rub damage from the 7 to 2 o'clock positions and the exducer had 360 degree rub damage that was more severe from the 9 to 5 o'clock positions. The crossover duct had inner diameter rub damage from the 7 to 10 o'clock position and there was impact damage and a hole in the outer surface at about the 12 o'clock position (**Photo 31**). The metal around the hole was pushed in toward the engine centerline and the damage was coincident with impact damage on the AGB housing. There was debris between the 1st stage compressor diffuser vanes.

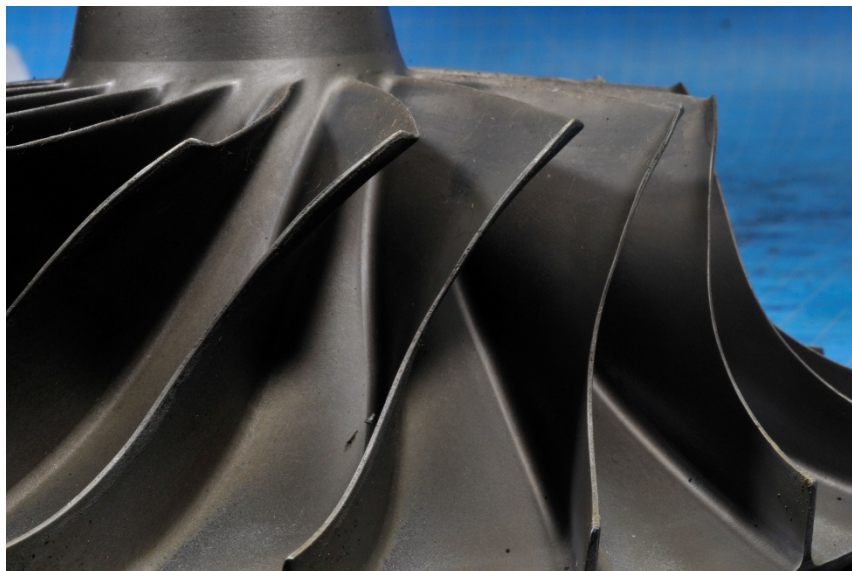


Photo 28- 1st Stage Compressor Impeller Blades



Photo 29- 1st Stage Compressor Impeller Curvic Coupling Outer Diameter Scoring



Photo 30- 1st Stage Impeller Shroud Circumferential Scoring



Photo 31- Compressor Crossover Duct Impact Damage/Hole

3.0 NO. 1 (LEFT) ESN P36058C COMPONENT TESTING

The FCU and propeller governor, removed from both the No. 1 and No. 2 engines were shipped to Woodward in Loves Park, Illinois for examination. The shipping box was accidentally opened by the Woodward receiving department. The components were not disturbed, and the box was resealed and secured in quarantine prior to the group exam. Investigation party members from Woodward, Honeywell, and the NTSB participated in the examination from July 27-28, 2021.

3.1 Fuel Control Unit and Propeller Governor

A visual examination of the FCU, part number (P/N) 807426, serial number (S/N) 1569290, removed from the No. 1 engine revealed that the input drive shaft was bent, and the input mounting flange exhibited impact damage and was missing material (**Photo 32**). The FCU could not be safely installed on a test bench due to the damage, so the FCU was fully disassembled (**Photo 33**). There was no evidence of preimpact part failure or other internal anomalies.

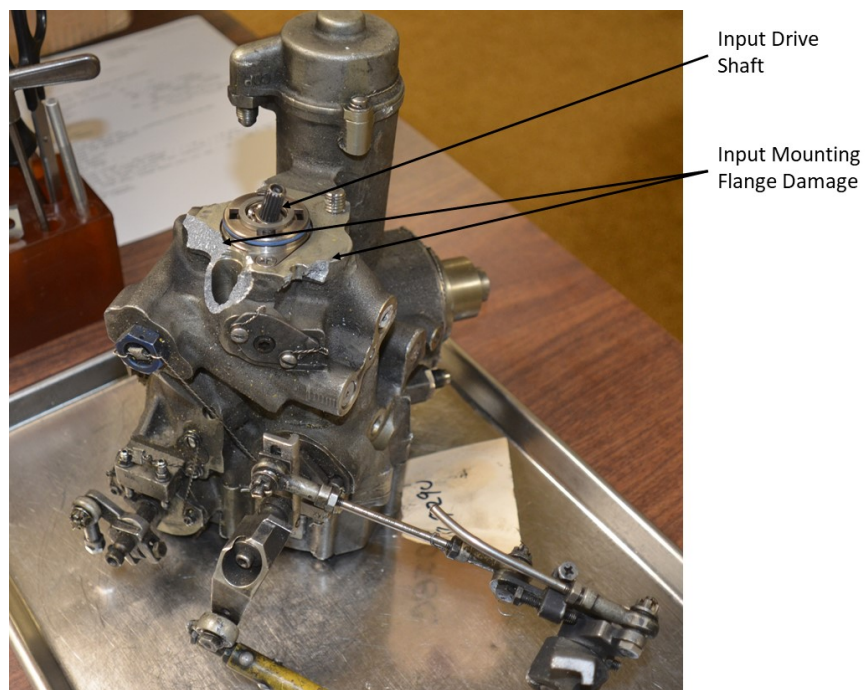


Photo 32- No. 1 Engine FCU, as Received at Woodward



Photo 33- No. 1 Engine FCU Disassembled

The propeller governor, P/N 8210-263, S/N 247721, was installed on a test bench and an acceptance test procedure (ATP) was performed in accordance with Woodward TSP-1674 Revision AD (**Photo 34**). During the examination and testing, there were no indications of internal binding. Multiple test points were recorded outside of ATP tolerance, but according to Woodward Engineering, the values were consistent with customer adjustments to the propeller governor min/max screws and were not outside of expected ranges for a typical service run component. The propeller governor test run sheet is available in the docket as Powerplants- Attachment 1- No. 1 Engine (P36058C) Propeller Governor Test Report.

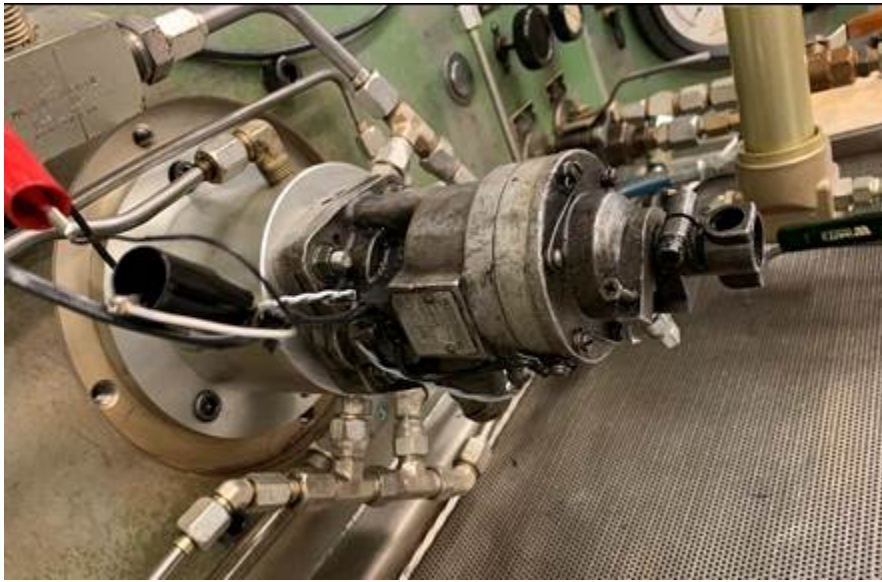


Photo 34- No. 1 Engine Propeller Governor Installed on Test Bench

3.2 Fuel Shutoff Valve

The No. 1 engine FSOV was computerized tomography (CT) scanned at the Honeywell Materials Laboratory in Phoenix, Arizona and no internal anomalies were observed. Video files of the CT scans were provided to the NTSB for review. The CT scan showed the FSOV was in the closed position, consistent with the shaft indicator. The internal Belleville washer was deflected toward the valve seat, and the valve ball was against the seat, which would have stopped fuel flow through the valve (**Photo 35**).

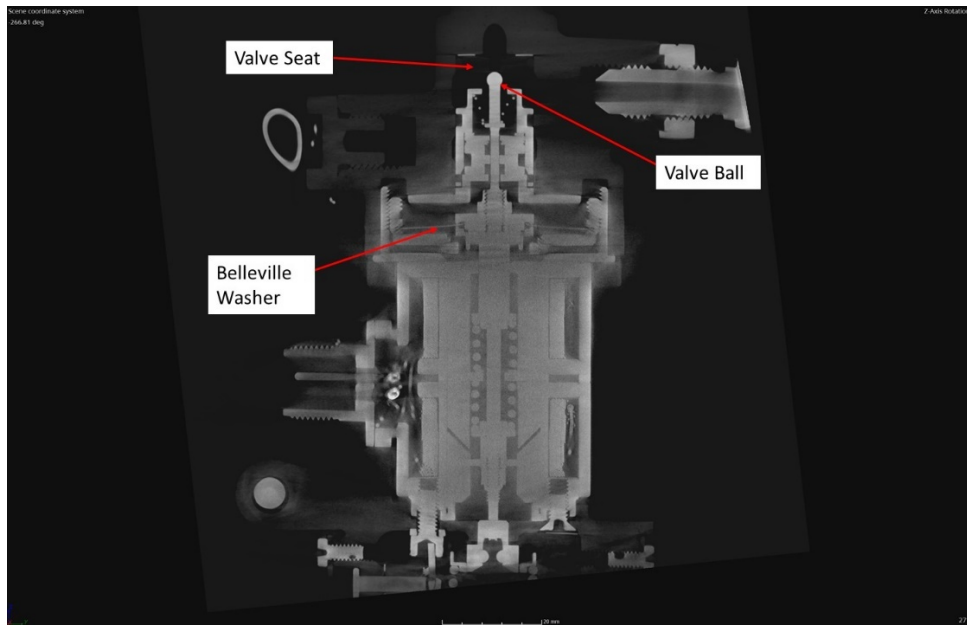


Photo 35- No. 1 Engine FSOV Computed Tomography Scan (Photo Courtesy of Honeywell)

4.0 NO. 1 (LEFT) ESN P36235C MATERIALS LABORATORY ANALYSIS

The separated No. 1 engine torque coupling shaft (**Photos 15 and 36**), separated starter shaft⁵, and the debris removed from the MCD were submitted to the Honeywell Materials Laboratory for analysis. The torque coupling shaft was separated approximately 0.582 inches from the aft end. The fracture surfaces were examined in the scanning electron microscope (SEM) which revealed that most of the fracture surfaces were obscured by smearing and secondary impact damage. Areas of overload dimples elongated in the shaft direction of rotation were identified, consistent with torsional overload. The torque coupling shaft material was analyzed using energy dispersive x-ray (EDX) and the spectrum was consistent with H11 tool steel material as called out in the part drawing.

⁵ The starter generator is not a Honeywell part, the separated starter shaft was examined by the lab to confirm overload failure.

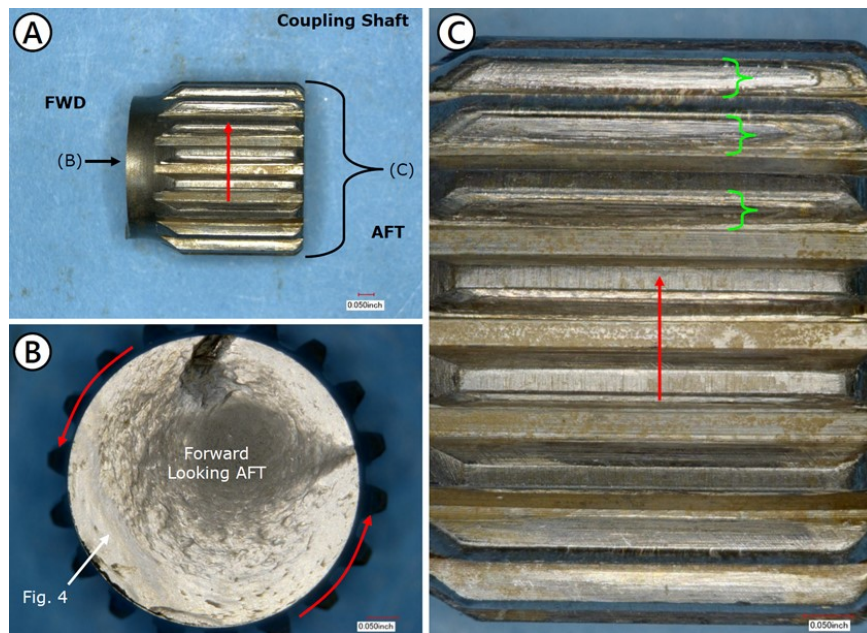


Photo 36- No. 1 Engine Torque Coupling Shaft Spline (Photos Courtesy of Honeywell)

The No. 1 engine starter shaft was separated approximately 0.689 inches from the forward end (**Photo 37**). The fracture surface was examined with a SEM and the features were too obscured by smearing and secondary damage to identify the failure mode. EDX analysis of the starter shaft produced a spectrum similar to 4140 steel.

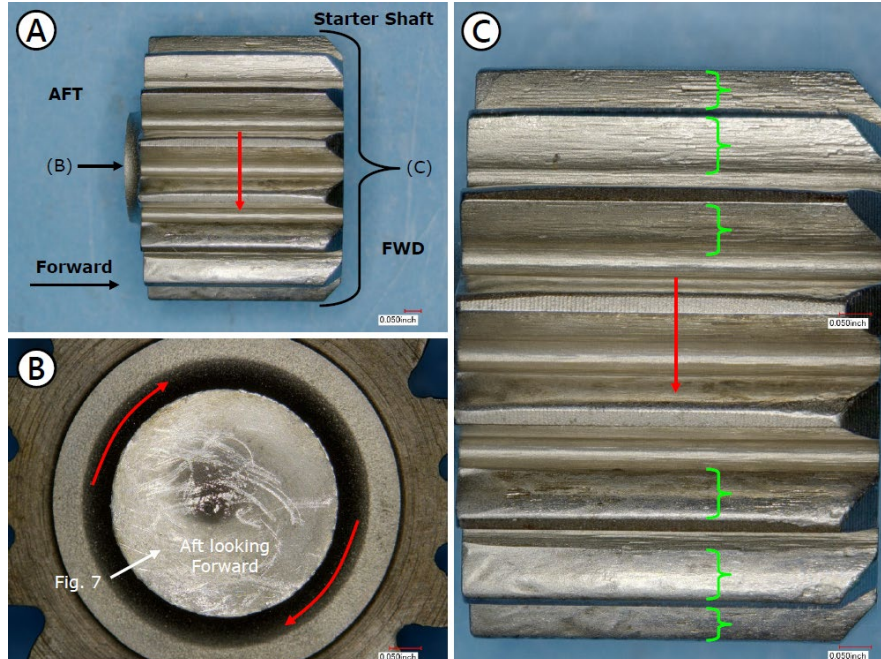


Photo 37- No. 1 Engine Starter Spline (Photos Courtesy of Honeywell)

The debris on the MCD was flushed using mineral spirits and captured onto an 8 micron filter patch. The debris was cleaned with toluene and allowed to dry. The weight of the recovered debris was 28 milligrams (mg). The larger pieces debris were viewed under SEM and analyzed using EDX and the

spectrum was consistent with 4340 or 9310 steel. The smaller particles had a spectrum similar to stainless steel and aluminum alloy. The materials laboratory report “ERS-ASYS-PENG-MA-0000800” is available in the investigation docket as Powerplants- Attachment 2- Honeywell No. 1 Engine (P36058C) Materials Laboratory Report.

Oil samples collected from the oil tank and front sump were analyzed at the Honeywell Phoenix Chemistry Laboratory in accordance with the Honeywell Spectrometric Oil Analysis Program (SOAP). High levels of silicon were detected in the oil tank sample. According to Honeywell, silicon is usually associated with dirt in the oil⁶. No other anomalies were noted. The SOAP results and TPE331-10 SOAP limits outlined in Honeywell Service Information Letter (SIL), publication number P331-97, Revision 11, July 23, 2008, are available in the docket as Powerplants- Attachment 3- No. 1 Engine (P36058C) SOAP Report.

5.0 NO. 2 (RIGHT) ESN P36235C TEARDOWN EXAMINATION

5.1 Visual Examination

The engine was secured in a cardboard box in the Honeywell Product Integrity cage when the investigation group arrived (**Photo 38**). The engine was shipped with multiple airframe components installed including: the engine mount horseshoe, starter generator, fire detection loops, wiring harnesses, and part of the aft firewall (**Photos 39, 40, and 41**). Oil samples collected at Wentworth Salvage during the wreckage layout were included in the shipping box.

⁶ Engine oil passes through a filter after leaving the tank. There was no evidence of debris accumulation in the engine oil filter or bearing wear.



Photo 38- Engine Shipping Container, as Received at Honeywell



Photo 39- ESN P36235C, Left Side, As Received

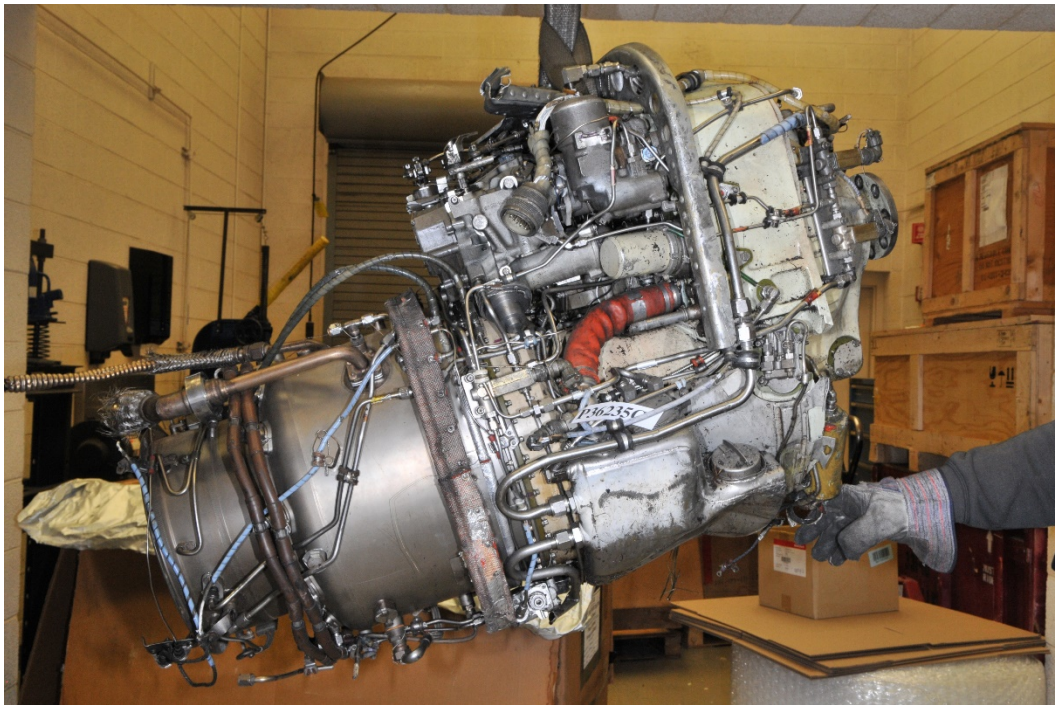


Photo 40- ESN P36235C, Right Side, As Received



Photo 41- Engine Data Plate

The airframe components were stripped from the engine and a visual inspection was performed to document the external condition. The engine did not exhibit indications of uncontainment or undercowl fire. The AGB inlet had impact damage along the bottom of the engine that separated the cowling attachment flange. The AGB case had a continuous crack from the 3 to 9 o'clock positions that extended around the boat tail over the top of the case (**Photo 42**). Five of the seven forward propeller bearing mount bolts were not present in the bolt holes. The propeller pitch control was partially separated

from the AGB mount. The FCU was pulled apart from the fuel pump at the interface flange (**Photo 43**). The FCU housing was fractured at the three fuel pump attachment studs and the attaching bolt was broken. The FCU drive spline appeared to have rust surface discoloration. The propeller feather valve plunger was separated and attached to the linkage arm (**Photo 44**). The propeller governor was intact and when removed it was verified that the check valve orifice was free of obstructions. The starter spline was separated, and the broken spline was recovered from the AGB case. The oil tank exhibited crushing damage and after removal, a small impact penetration and an indent were observed on the aft bottom side of the tank. The FSOV cover was torn open around the input shaft exposing the internal mechanism. The shaft indicator was aligned with the 3 o'clock position, consistent with the manual off position (**Photo 45**).



Photo 42- AGB Case Fracture, (L) Left Side, (R) Right Side

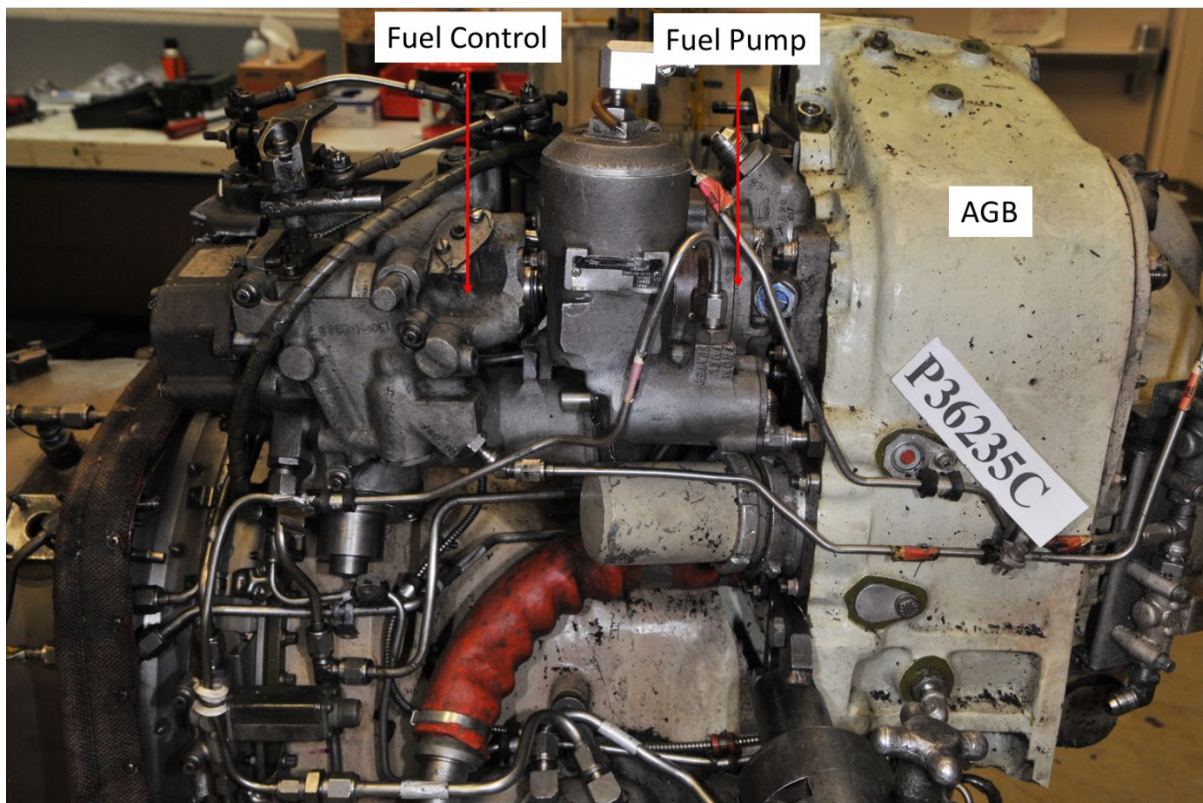


Photo 43- Fuel Control Separated from Fuel Pump

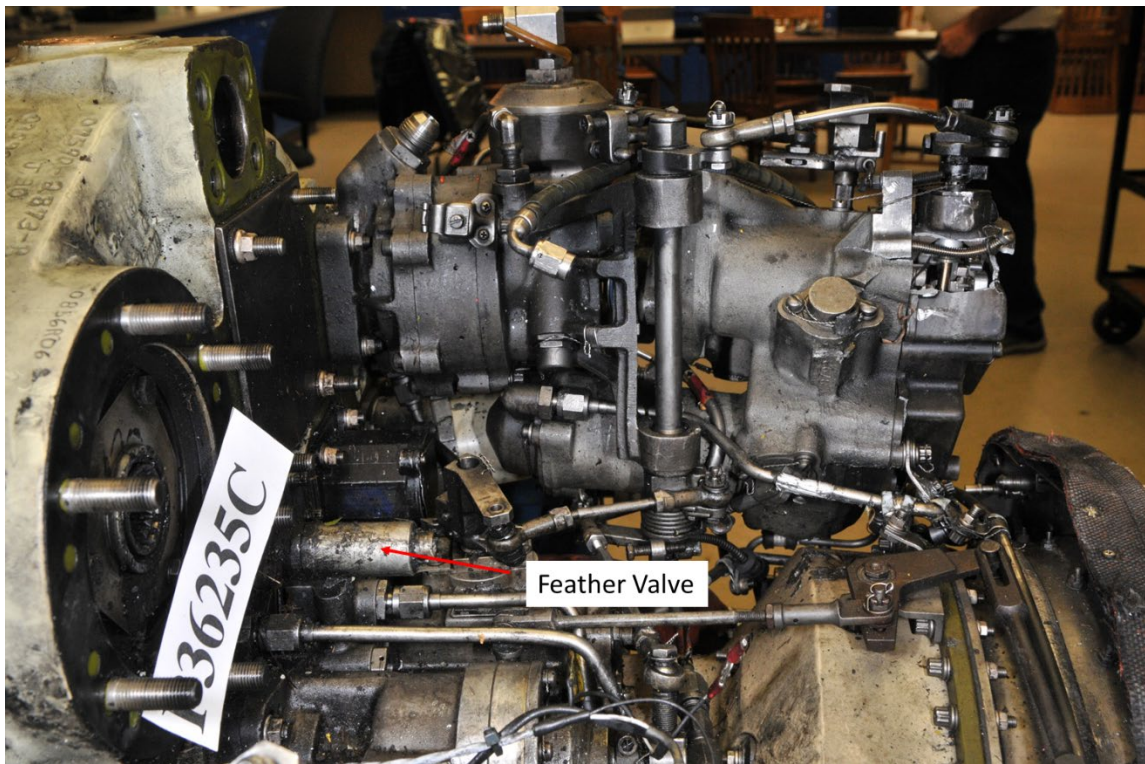


Photo 44- Feather Valve

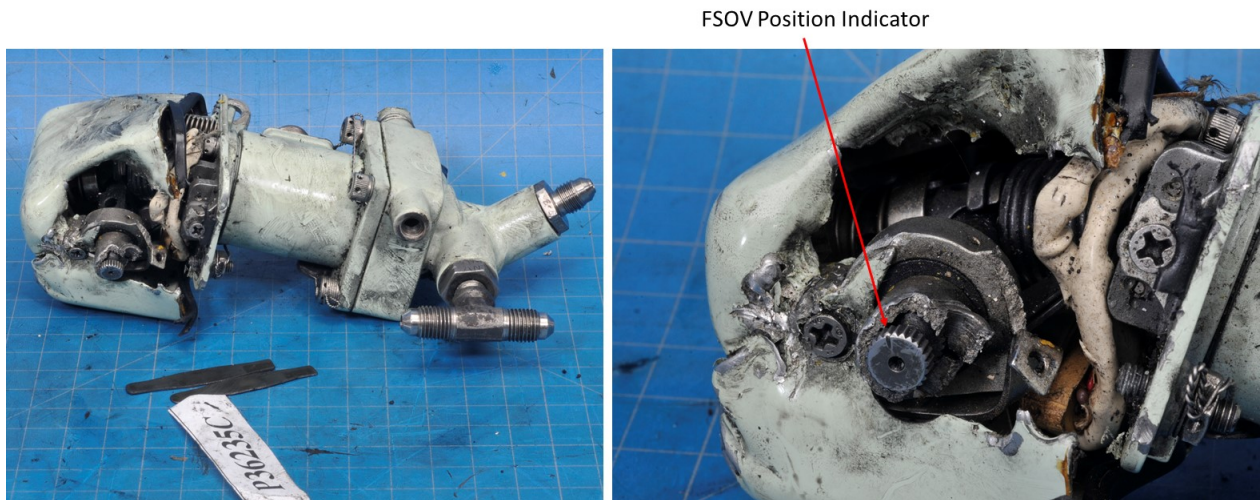


Photo 45- (L) FSOV, (R) FSOV Indicator

The MCD had some debris accumulation including fine metal shavings and fuzz. The MCD housing was in good condition (**Photo 46**). There was no debris accumulation in the fuel or oil filters. The propeller shaft was seized and could not be manually rotated. The turbine rotor was also seized and could not be rotated.

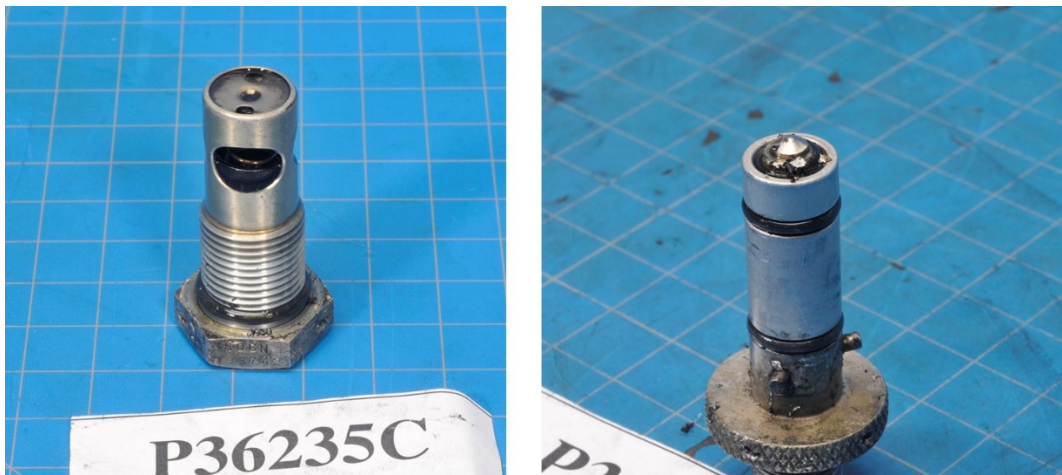


Photo 46- (L) MCD Housing, (R) MCD

5.2 Accessory Gearbox

The mechanic notified the group that AGB nose cone attaching bolts felt under torqued. Breakaway torque was checked on a random sample of bolts and all bolts were torqued to less than 10 in-lbs. When the nose cone was removed, the forward propeller thrust bearing, propeller shaft, and propeller coupling were complete (**Photo 47**). The propeller thrust bearing was oil wetted and rotated smoothly. Seven nuts were recovered from the 6 o'clock position of the nose cone. The propeller shaft had 360 degree circumferential scoring at the forward radius and a non-uniform circumferential scoring 5.75 inches from the shaft base that resulted in raised metal (**Photo 48**). The ring gear, sun gear and planetary gears were intact (**Photo 49**). Impact marks and scoring were noted on the aft gear tooth surface of all four planet gears and there were coincident impact marks and scoring on the forward face of the ring gear support (**Photo 50**). Three of the four planetary gears had bearing outer race cracks. One of the four planetary gears rotated with some resistance, the other three rotated smoothly. The sun gear forward inner diameter had 360 degree circumferential scoring (**Photo 51**). The aft propeller thrust bearing was pushed in the aft direction and the snap ring was no longer engaged in the aft side of AGB case (**Photo 52**).



Photo 47- Nose Cone and Propeller Shaft

Propeller Shaft Rubs

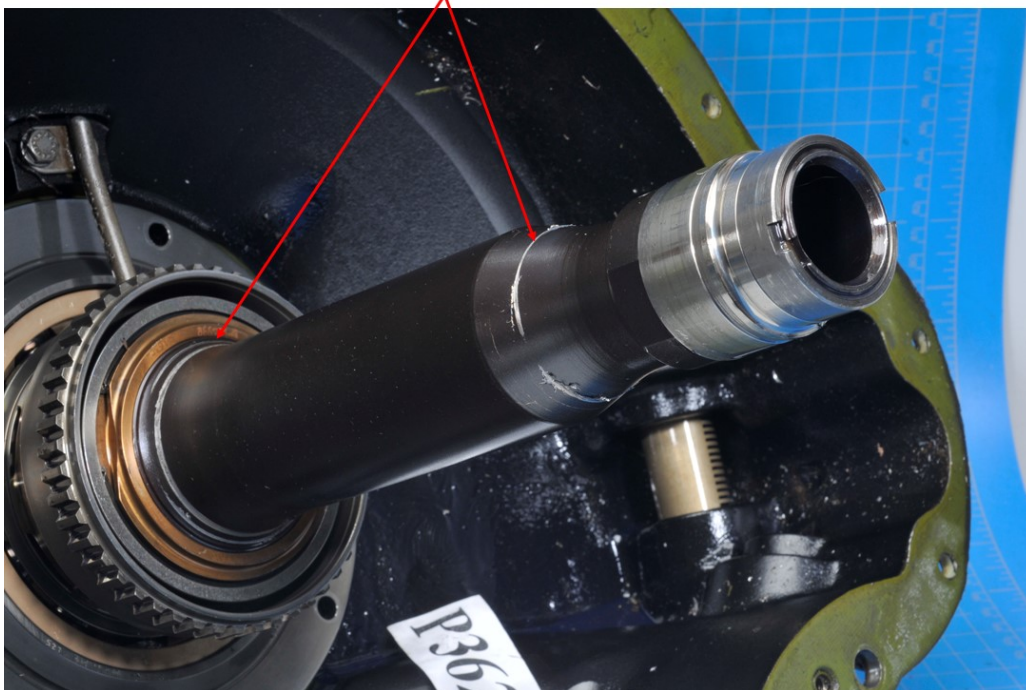


Photo 48- Propeller Shaft Rubs

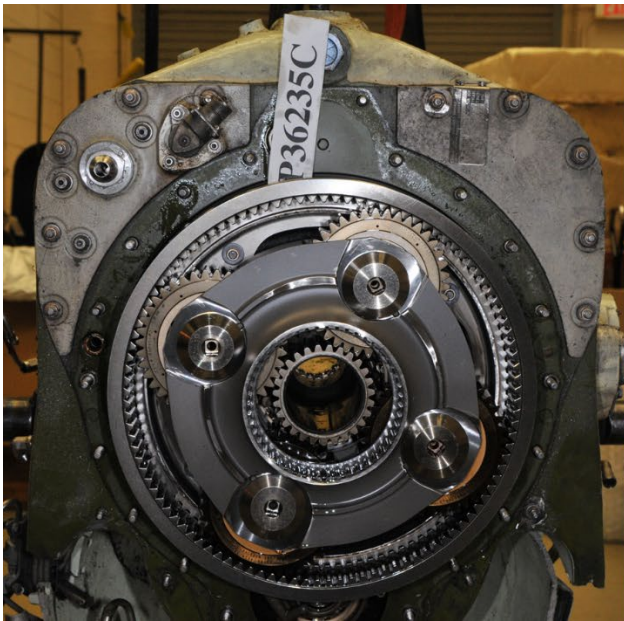


Photo 49- Sun, Planetary, and Ring Gears

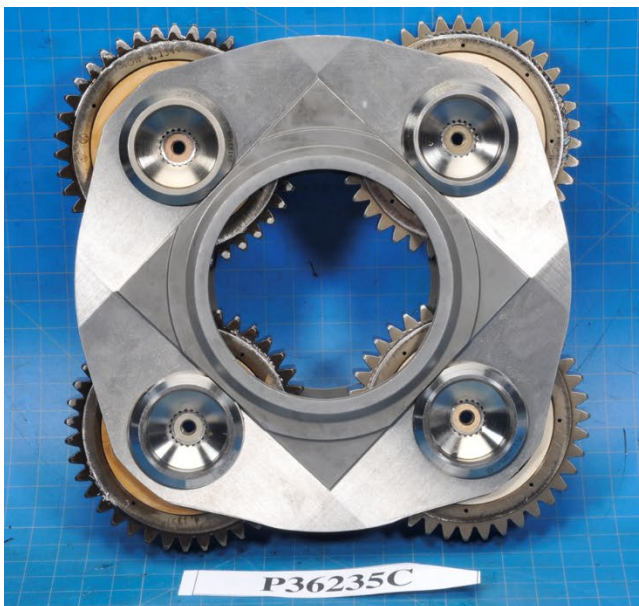


Photo 50- Planetary Gear Teeth, Aft Face Circumferential Scoring



Photo 51- Sun Gear Forward Face Circumferential Scoring

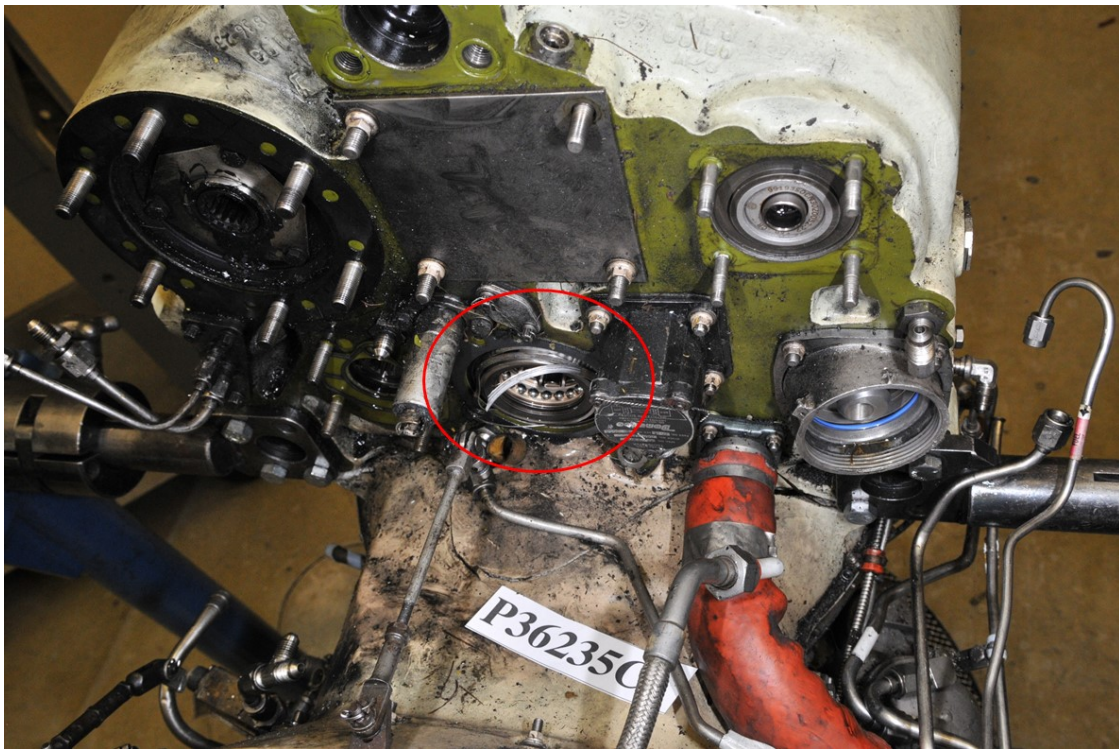


Photo 52- Aft Prop Shaft Bearing Damage

The AGB diaphragm was removed, and all components were complete (**Photo 53**). The torque coupling shaft aft spline was broken and later recovered from the torsion shaft (**Photos 54**). The aft diaphragm gearset and mating gears in the AGB were intact. The high speed pinion manually rotated smoothly, and all gears meshed properly. The torque sensor was intact. The torque sensor gears could not

be rotated by hand. The torque sensor primary gear (direct drive fuel control gear 1) had light contact marks on the loaded face of each gear tooth. The forward main shaft coupling spline had 360 scoring/deformation of the gear tooth near the forward face. Metallic debris was accumulated under the main shaft spline/compressor carrier and at the 6 o'clock position of the AGB case (**Photo 55**). Impact marks were observed on the AGB case feather valve bore and the torque sensor housing (**Photo 53**).

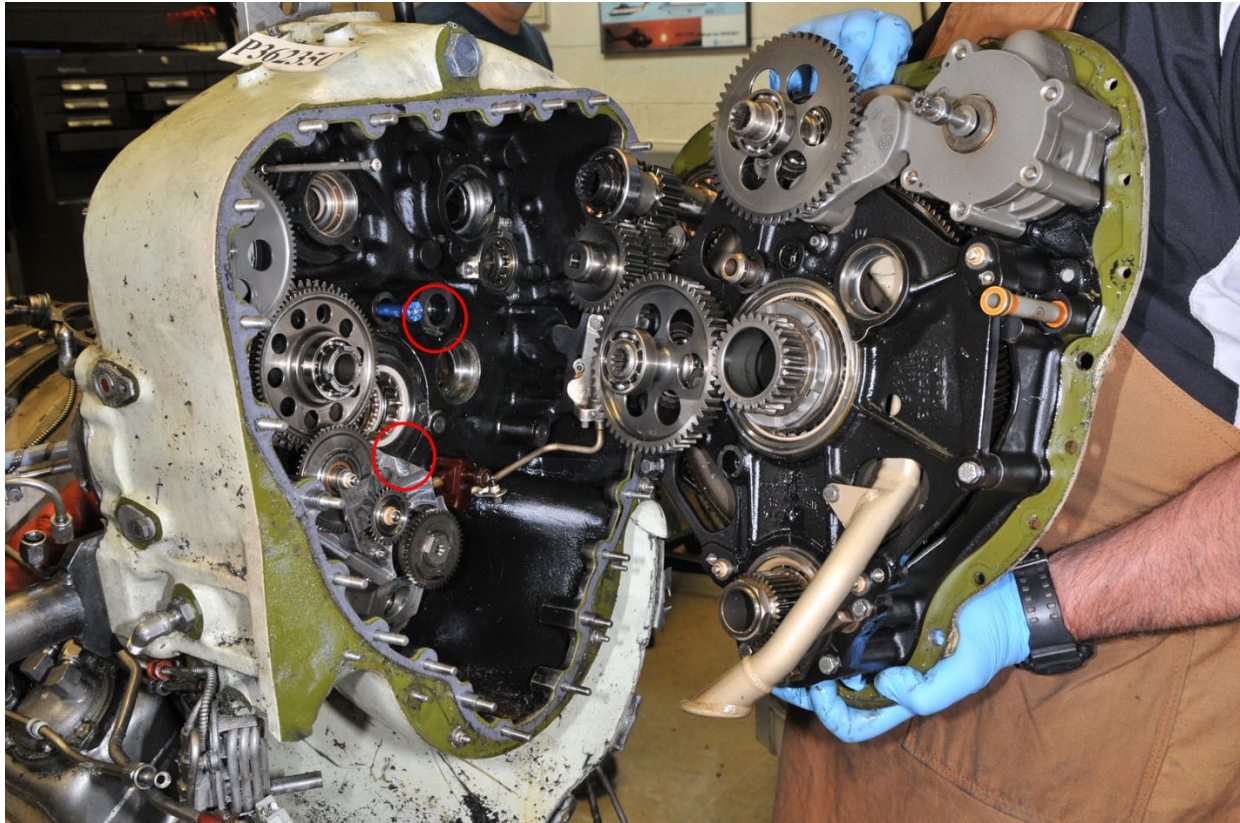


Photo 53- Diaphragm Assembly



Photo 54- Separated Torque Coupling Shaft



Photo 55- Main Shaft and AGB Debris Accumulation

The main shaft forward coupling spline damage prevented the anti-rotation tool used during removal of the main shaft nut from properly engaging the splines. Due to the spline damage and AGB crack noted earlier in this report, an alternate engine disassembly method was used. The turbine stages and plenum/combustor were removed and the AGB was then rested on its nose. The aft end of the main shaft was tapped with a mallet until a press fit between the 1st stage impeller and the shaft was

overcome and the shaft was free to be removed from the front of the engine. Any damage that may have potentially been a result of the alternate removal method is marked with an asterisk (*).

5.3 Turbine Section

The turbine rear frame was intact, and the rear turbine bearing was oil wetted and rotated smoothly. All three stages of turbine rotors and stator vanes were complete (**Photos 56-61**). The blades and vanes in all three stages had light metal spray, black spatter/streaking, and earthen debris adhered to pressure and suction surfaces of all blades. The most significant metal spray and debris coating was noted on the leading edge and pressure side of the 1st stage turbine rotor blades. The 1st stage shroud had light rub from the 11 to 12 o'clock positions. The curvic couplings between each stage were undamaged and properly mated. The interstage air seals were in good condition.

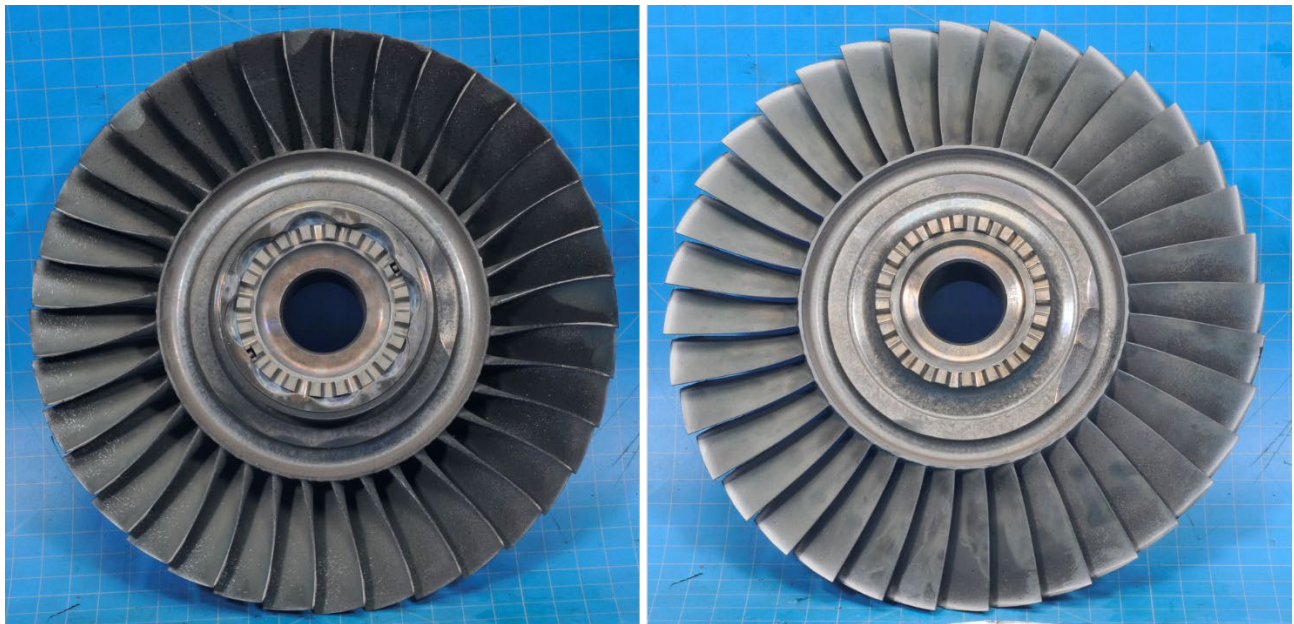


Photo 56- 3rd Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge

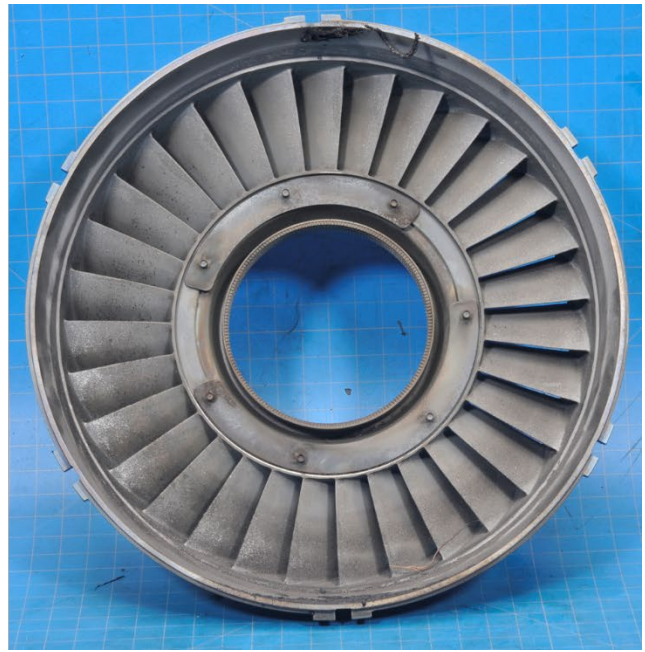


Photo 57- 3rd Stage Turbine Stator, (L) Pressure Side, (R) Suction Side



Photo 58-2nd Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge



Photo 59- 2nd Stage Turbine Stator, (L) Pressure Side, (R) Suction Side



Photo 60- 1st Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge

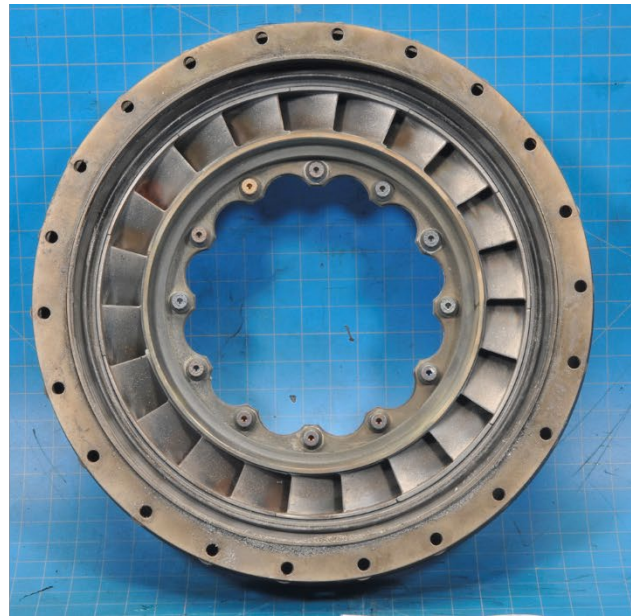
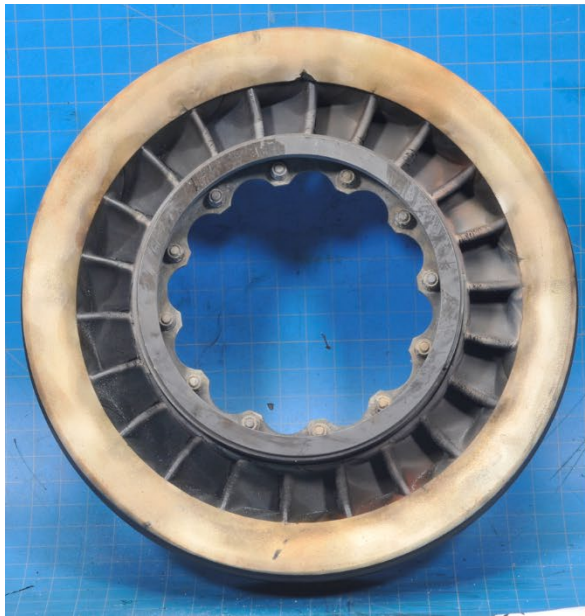


Photo 61- 1st Stage Turbine Stator, (L) Pressure Side, (R) Suction Side

5.4 Combustor

The combustion liner was intact and had no indications of fuel nozzle streaking or thermal damage (**Photo 62**). Earthen debris was accumulated between the liner and the plenum wall. There was light metal spray on the liner walls. All the fuel nozzles were properly seated and there was no evidence of coking. The fuel manifold plumbing was intact and in good condition. The igniter leads at the 5:30 and 10 o'clock positions were partially pulled from plenum case connections and the leads were deformed. The plenum case had wrinkling deformation from the 11 to 12 o'clock positions.

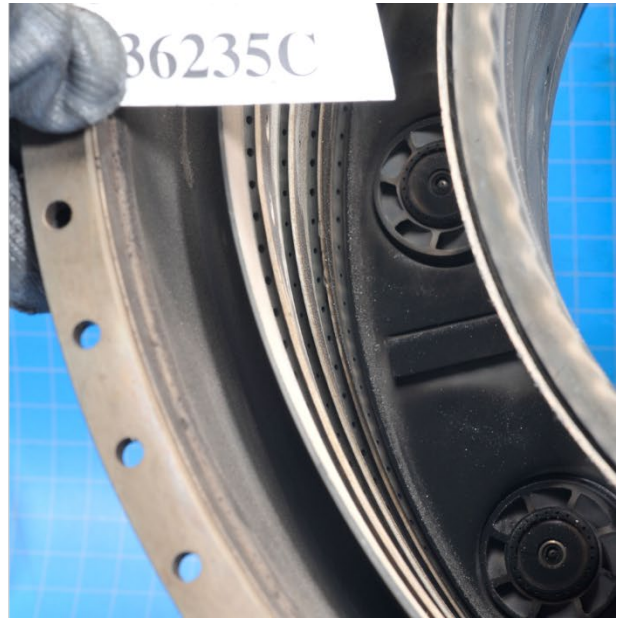


Photo 62- (L) Combustion Liner, (R) Fuel Nozzles

5.5 Compressor Section

The 2nd stage compressor impeller was intact (**Photo 63**). The impeller blades all exhibited tip rub along the blade span and there was earthen debris on the leading edges. There was 360 degree rotational scoring on the forward impeller hub. The 2nd stage impeller shroud had heavy 360 degree scoring from the forward (inducer) to aft (exducer) end (**Photo 64**). There was debris between the 2nd stage compressor diffuser vanes.



Photo 63- 2nd Stage Compressor Impeller Tip Rub

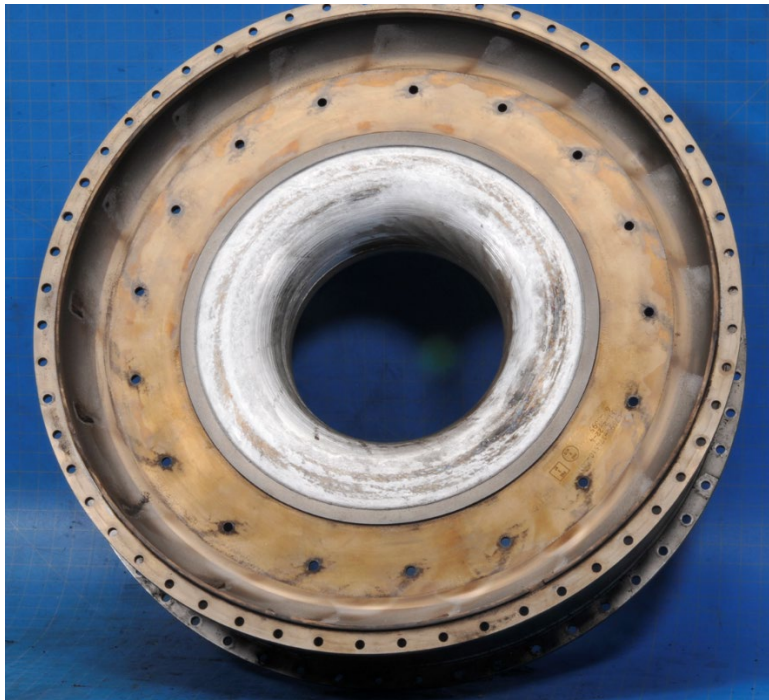


Photo 64- 2nd Stage Impeller Shroud Circumferential Scoring

The 1st stage compressor impeller had blade tip rub along the span of all blades (**Photo 65**). The impeller forward hub had 360 degree rotational scoring and the aft hub had light 360 rotational scoring. The 1st stage shroud had a crack from the 3 to 12 o'clock positions at the o-ring groove*. The six impeller shroud mount flange holes were torn, and the flange was separated*. The 1st stage impeller shroud had light 360 rotational scoring at the inducer, 360 degree rotational scoring at the knee, more severe from the 7 to 11 o'clock positions, and 360 degree scoring at the exducer, more severe from the 12 to 5 o'clock positions (**Photo 66**). The crossover duct was in a good condition. There was earthen debris between the 1st stage diffuser vanes (**Photo 67**).

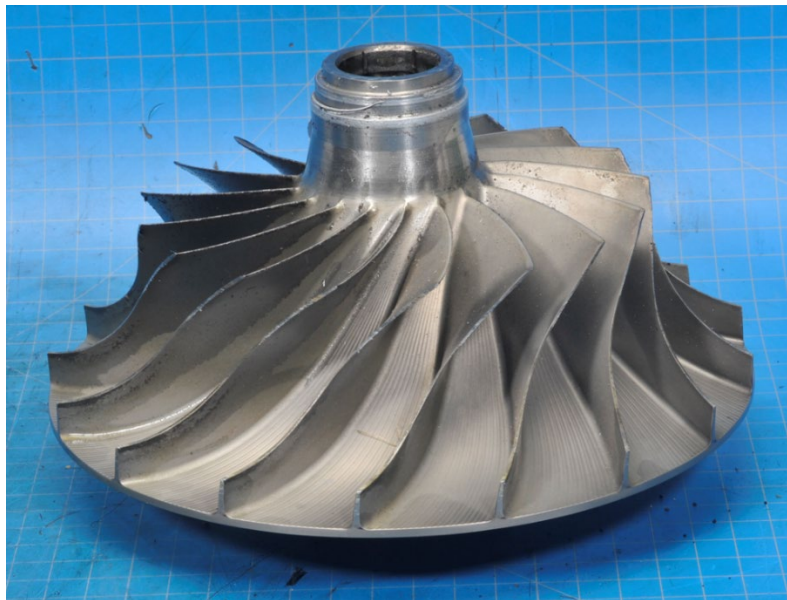


Photo 65- 1st Stage Compressor Impeller Blade Tip Rub



Photo 66- 1st Stage Impeller Shroud



Photo 67- (L) Compressor Crossover Duct, (R) 1st Stage Diffuser with Debris Accumulation

Due to the alternate disassembly method, the carrier, compressor bearing, carbon seal, carbon seal rotor, main shaft coupling gear, and main shaft nut remained on the front of the shaft when the main shaft was removed. The shaft was placed in a padded vice and an air impact gun was used to remove the nut. The bearing was removed by carefully tapping the bearing outer race. The compressor bearing was dirty and rotated roughly (**Photo 68**). Ball bearing damage was visible between the bearing races. The main shaft was not bent. The knife edge seals exhibited rub damage, had debris accumulation between the knives, and a section of one knife was separated (**Photo 69**).



Photo 68- No. 1 (Compressor) Bearing



Photo 69- Main Shaft Knife Edge Seal Damage

6.0 NO. 2 (RIGHT) ESN P36235C COMPONENT TESTING

6.1 Fuel Control and Propeller Governor

The No. 2 engine FCU, P/N 807426, S/N 1706938, and propeller governor, P/N 8210-262, S/N 1806734, were shipped to Woodward in Loves Park, Illinois for examination. A visual examination of the FCU was performed to determine if it was safe to install on a test bench. The FCU air section cover⁷ was fractured and missing material. The input mounting flange exhibited impact damage and was missing three of the four flange attaching lugs (ears) (**Photo 70**). The air section cover was replaced with a spare and the FCU was secured/clamped to the test bench with angled metal bar stock and all thread rod (**Photo 71**). The input drive speed on the test bench was slowly increased and there were no audible indications of internal damage. A steady drip leak was observed that appeared to originate from the mounting flange interface. According to Woodward engineering, the leak would not impact the test schedules. The FCU was tested in accordance with Woodward TSP-8963 Revision D. There were no anomalies noted during testing that would have precluded normal FCU operation. Multiple test points were outside of ATP limits but according to Woodward engineering were within the expected range of customer adjustments for a service run unit. The FCU test run sheet is available in the docket as Powerplants- Attachment 4- No. 2 Engine (P36235C) Fuel Control Test Report.

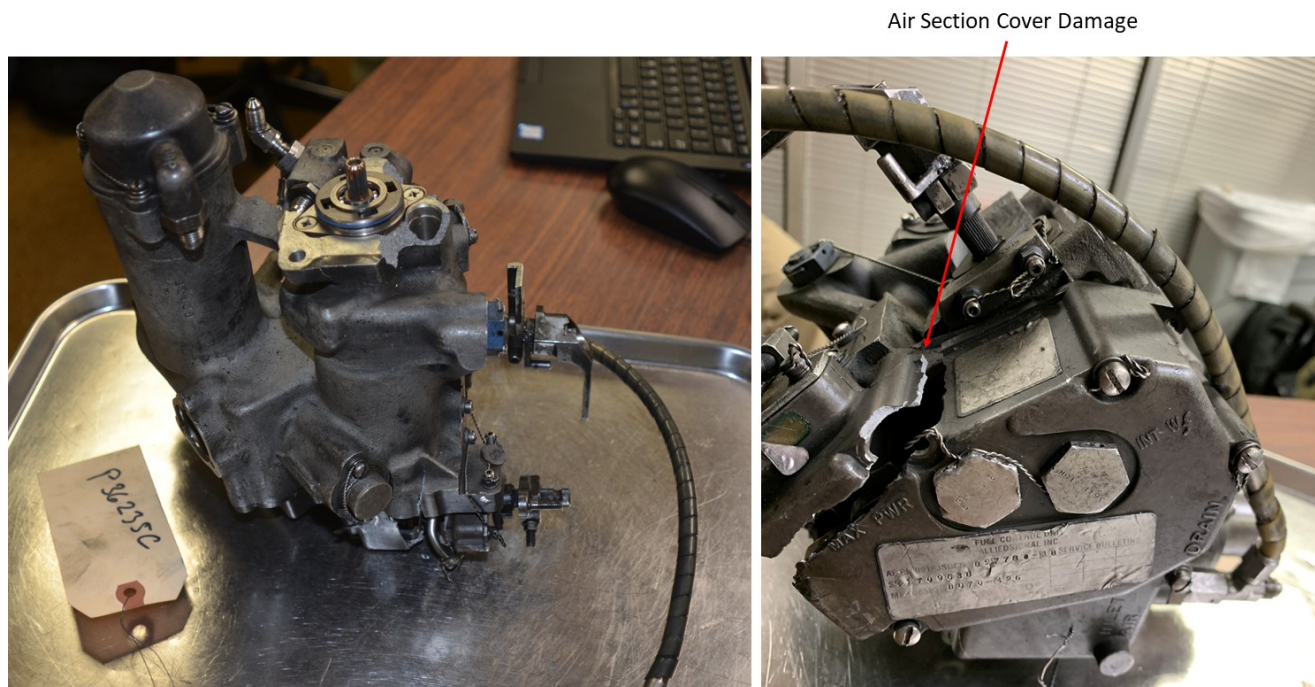


Photo 70- (L) No. 2 Engine FCU, as Received at Woodward, (R) Air Section Cover Damage

⁷ The FCU air section cover must be airtight to perform at altitude. The altitude fuel schedules could not be tested during the component exam, but other fuel schedules were not affected.

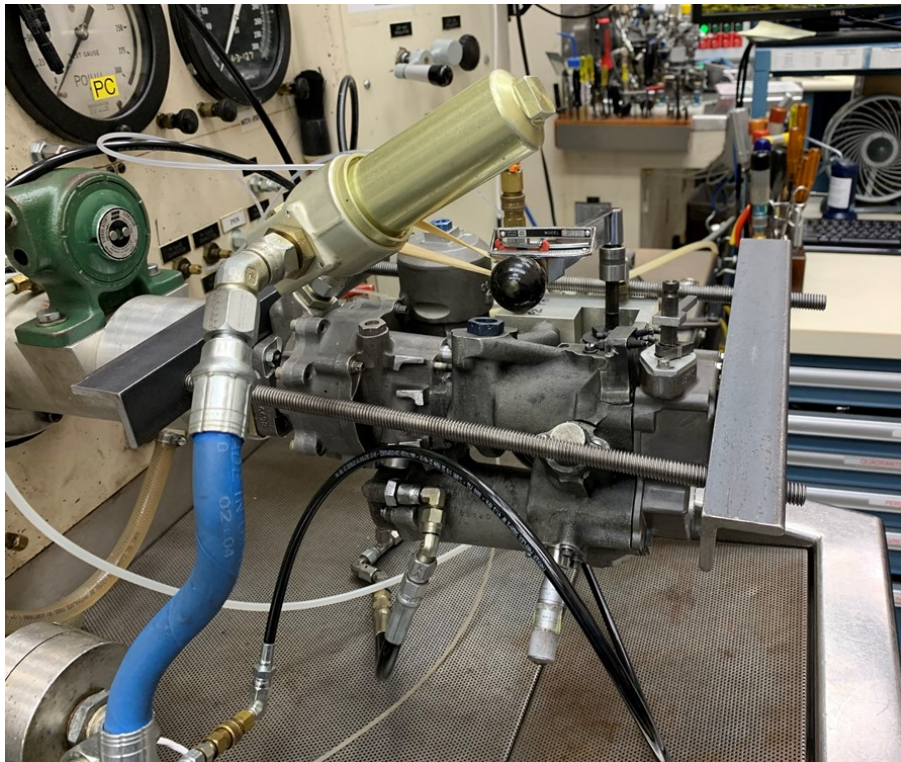


Photo 71- No. 2 Engine Fuel Control Secured to Test Bench

The propeller governor was installed on a test bench and an acceptance test procedure ATP was performed in accordance with Woodward TSP-1674 Revision AD. All test points were within the expected range of typical service run unit and no anomalies were observed that would have affected normal operation. Multiple test points were recorded outside of ATP tolerances, but according to Woodward Engineering the values were consistent with customer adjustments to the propeller governor min/max screws. The propeller governor test run sheet is available in the investigation docket as Powerplants- Attachment 5- No. 2 Engine (P36235C) Propeller Governor Test Report.

6.2 Fuel Pump

The No. 2 engine fuel pump was hand carried to the Honeywell Engineering Laboratory in Phoenix, Arizona for bench testing. The fuel pump was tested in accordance with the fuel pump ATP procedure, DS-869151-1W (**Photo 72**). All test points met specification. The fuel pump test run sheet is available in the investigation docket as Powerplants- Attachment 6- No. 2 Engine (P36235C) Fuel Pump Test Report.

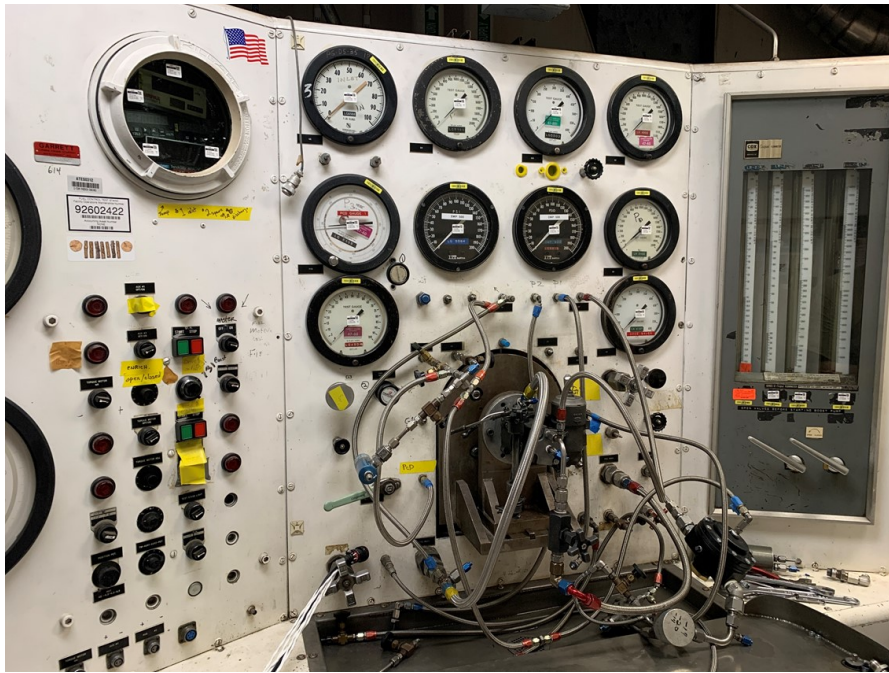


Photo 72- No. 2 Engine Fuel Pump Installed on Test Bench

6.3 Fuel Shutoff Valve

The No. 2 engine FSOV was CT scanned at the Honeywell Materials Laboratory in Phoenix, AZ and no internal anomalies were observed. Video files of the CT scans were provided to the NTSB for review. The CT scan showed the FSOV was in the closed position, consistent with the shaft indicator. The internal Belleville washer was deflected toward the valve seat, and the valve ball was against the seat, which would have stopped fuel flow through the valve (**Photo 73**).

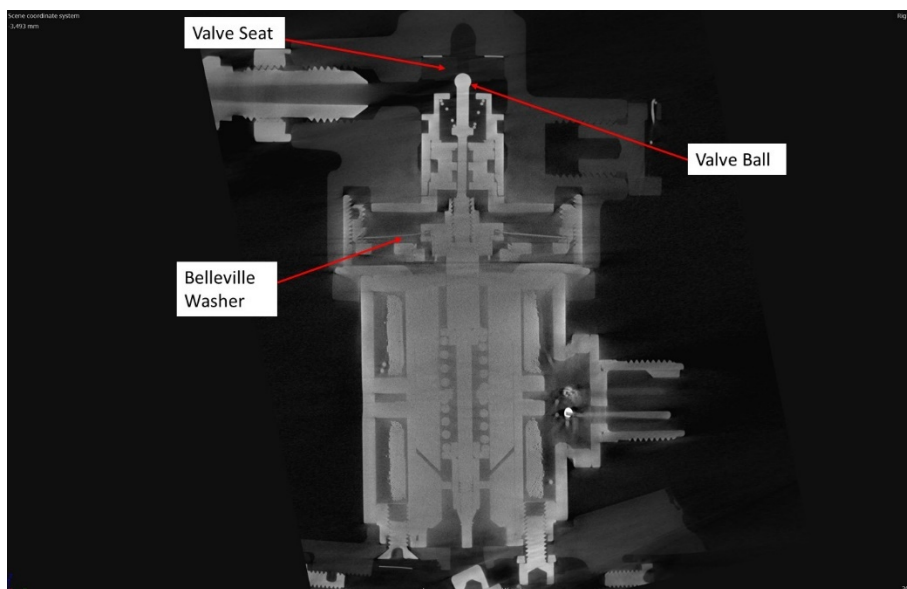


Photo 73- No. 2 Engine FSOV Computed Tomography Scan (Photo Courtesy of Honeywell)

7.0 NO. 2 (RIGHT) ESN P36235C MATERIALS LABORATORY ANALYSIS

The No. 2 engine torque coupling shaft separated starter shaft, No. 1 bearing, and the debris removed from the MCD and near the No. 1 bearing were submitted to the Honeywell Materials Laboratory for analysis. The torque coupling shaft was separated approximately 0.632 inches from the aft end (**Photos 54 and 74**). The torque coupling shaft fracture surfaces were examined with a SEM which revealed that most of the fracture surfaces were obscured by smearing and secondary impact damage. Areas of overload dimples elongated in the shaft direction of rotation were identified, consistent with torsional overload. The torque coupling shaft material was analyzed using EDX and the spectrum was consistent with H11 tool steel material in accordance with the part drawing.

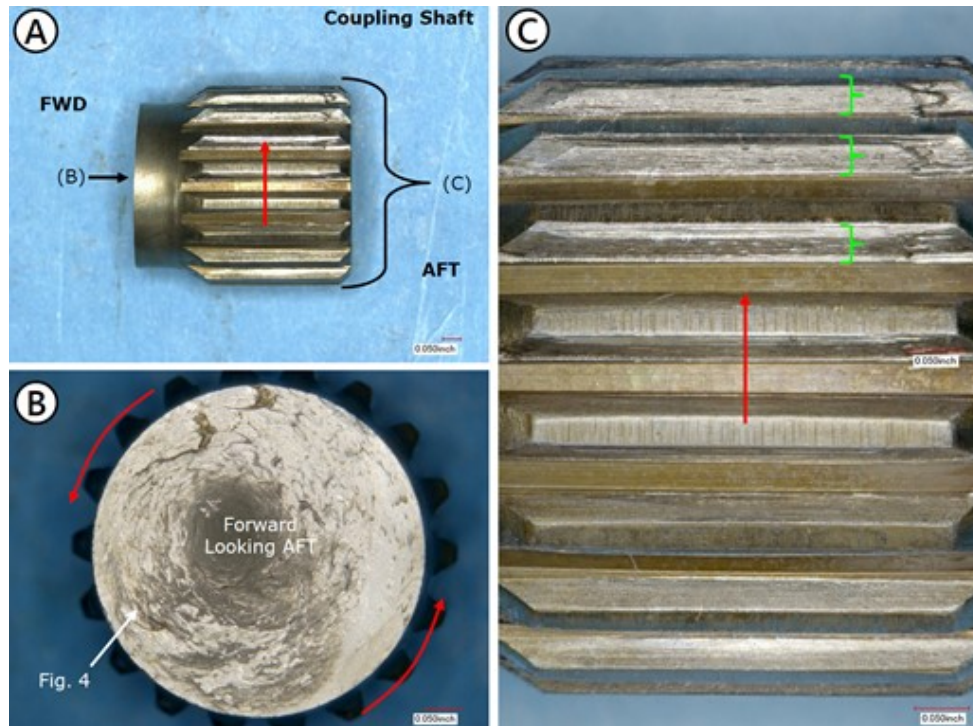


Photo 74- No. 2 Engine Torque Coupling Shaft, Separated Spline (Photos Courtesy of Honeywell)

The No. 2 engine starter shaft was separated approximately 0.690 inches from the forward end (**Photo 75**). The fracture surface was examined with a SEM and the features were too obscured by smearing and secondary damage to identify the failure mode. EDX analysis of the starter shaft produced a spectrum similar to 4340 steel.

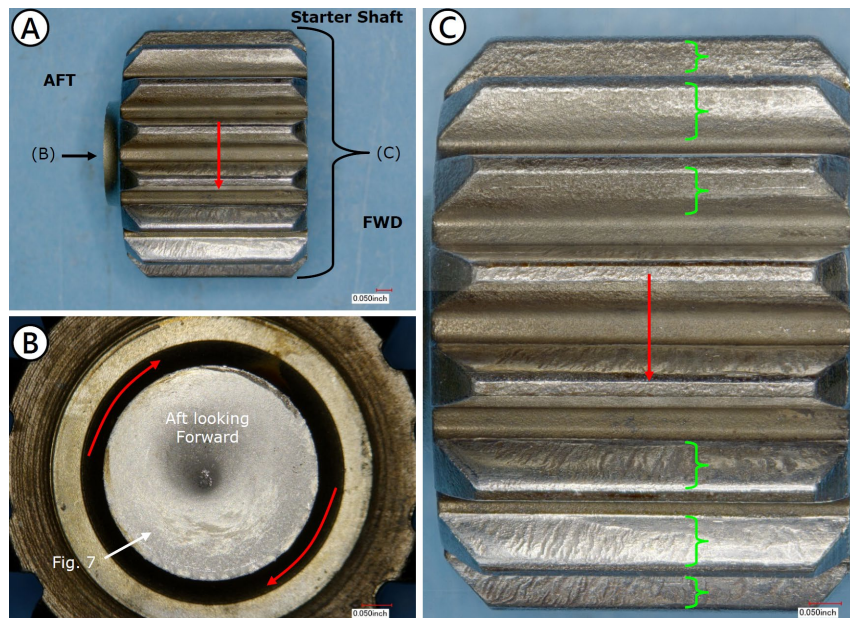


Photo 75- No. 2 Engine Starter Shaft, Separated Spline (Photos Courtesy of Honeywell)

The No. 1 bearing was disassembled for evaluation (**Photo 76**). Damage and non-uniform wear were observed on the outer race and there was deformed material from the outer race onto the aft shoulder in some locations. The split inner ring race exhibited impact damage and the forward inner ring race half had rolled over material on the outer diameter shoulder. The bearing cage had wear damage on both end rails and in the cage pockets. The aft side of the bearing cage was discolored compared to the forward side. All bearing rolling elements were damaged and discolored.



Photo 76- Disassembled No. 1 Bearing

The debris on the MCD was flushed using mineral spirits and captured onto an 8 micron filter patch. The debris was cleaned with toluene and allowed to dry. The weight of the recovered debris was 7 mg. The debris was viewed under SEM and analyzed using EDX. The EDX spectrum of the metallic particles was consistent M50 steel. M50 steel is the base material of the No. 1 bearing races and rolling elements. Other particles recovered from the MCD were also suggestive of an aluminum alloy and 4340 or 9310 steel. Debris collected from the aft side of the No. 1 compressor bearing carrier was consistent with M50 steel and aluminum alloy. Debris collected from the forward side of the compressor bearing carrier was rich in silver with concentrations of other elements consistent with aluminum alloy. Larger non-metallic particles collected near the compressor bearings were rich in carbon and smaller metallic particles in the same region were most similar to aluminum alloy. The Materials Laboratory report is available the investigation docket as Powerplants- Attachment 7- Honeywell No. 2 Engine (P36235C) Materials Laboratory Report.

Oil samples collected from the oil filter housing and AGB were analyzed at the Honeywell Phoenix Chemistry Laboratory in accordance with the Honeywell SOAP. High levels of silicon were detected in the oil tank sample. According to Honeywell, silicon is usually associated with dirt in the oil. No other elements were detected in elevated levels. The SOAP results and TPE331-10 SOAP limits outlined in Honeywell SIL, publication number P331-97, Revision 11, July 23, 2008, are available in the docket as Powerplants- Attachment 8- No. 2 Engine (P36235C) SOAP Report.

E. LIST OF ATTACHMENTS

Attachment 1- No. 1 Engine (P36058C) Propeller Governor Test Report
Attachment 2- Honeywell No. 1 Engine (P36058C) Materials Laboratory Analysis Report
Attachment 3- No. 1 Engine (P36058C) SOAP Report
Attachment 4- No. 2 Engine (P36235C) Fuel Control Test Report
Attachment 5- No. 2 Engine (P36235C) Propeller Governor Test Report
Attachment 6- No. 2 Engine (P36235C) Fuel Pump Test Report
Attachment 7- Honeywell No. 2 Engine (P36235C) Materials Laboratory Analysis Report
Attachment 8- No. 2 Engine (P36235C) SOAP Report

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