

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



ERA22FA086

POWERPLANTS

Group Chair's Factual Report

July 7, 2023

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A. ACCIDENT

Location: Bedford, New Hampshire
Date: December 10, 2021
Time: 2330 Eastern Standard Time (EST)
1230 Coordinated Universal Time (UTC)
Airplane: Swearingen SA-226AT, N54GP

B. POWERPLANTS GROUP

Group Chair Robert Hunsberger
National Transportation Safety Board
Washington, DC

Member Joseph Costa
Federal Aviation Administration
Lakewood, California

Member Ron L. Coleman
Federal Aviation Administration
Buckeye, Arizona

Member Dana Metz
Honeywell
Phoenix, Arizona

C. SUMMARY

On December 10, 2021, about 2330 eastern standard time, a Swearingen SA-226AT, N54GP, was destroyed when it was involved in an accident near Bedford, New Hampshire. The commercial pilot was fatally injured. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 135 on-demand cargo flight.

After the initial on-scene wreckage exam, the engines were separated from the wreckage and shipped to Anglin Aircraft Recovery Services in Clayton, Delaware. The engines were later crated and shipped to Honeywell in Phoenix, Arizona for teardown examination. Investigation party members from the Federal Aviation Administration (FAA), Honeywell, and the National Transportation Safety Board conducted the teardown examinations at Honeywell from February 7-11, 2022.

The No. 1 (left) engine, serial number P54128, external surfaces were discolored, sooted, and thermal damage was documented at multiple locations. One 1st stage turbine rotor blade was separated at the midspan, and the blade fracture surface appeared rough and jagged. All 1st stage turbine rotor blades exhibited leading edge tip erosion. The 2nd stage turbine stator assembly was missing vane material from the 6 to 12 o'clock positions, consistent with thermal damage. Rotational scoring was documented throughout the engine, including the propeller shaft, compressor impellers/shrouds, and turbine rotor blade tips. Sand/earthen debris was observed throughout the gaspath.

The No. 2 (right) engine, serial number P54133, external surfaces were discolored, sooted, and there was significant thermal damage, including a hole in the accessory gearbox. One 2nd stage turbine stator vane was missing material. Rotational scoring was documented at multiple locations in the engine including the propeller shaft, compressor impellers/shrouds, and turbine stages. Sand/earthen debris was observed throughout the gaspath and was found accumulated in the combustor and outer transition liner during the engine teardown.

The No. 1 engine 1st stage and 2nd stage turbine rotor blades were sent to the Honeywell Material Laboratory in Phoenix, Arizona for analysis. One 1st stage turbine blade (identified as Blade 1) separated approximately 0.38 inch from the platform as measured from the leading edge. A cross section of Blade 1 revealed oxidation and alloy depletion on the fracture surface. The microstructure near the fracture surface was consistent with exposure to temperatures near 1700°F (927°C) over a period of time between 10 and 100 hours. There was no evidence of cyclic fatigue, material defects, or other anomalies identified near the fracture surface. Energy dispersive X-ray (EDX) analysis confirmed that the blade material was consistent with IN-100 nickel alloy as specified on the part drawing. The 2nd stage turbine rotor blade microstructure analysis was consistent with exposure to temperatures near 2200°F (1204°C) over a period of time between 10 and 100 hours.

D. DETAILS OF THE INVESTIGATION

1.0 Engine Information

1.1 Engine Description

The accident airplane was powered by two Honeywell TPE331-10UA-511G turboprop engines. The TPE331-10UA-511G is a single spool turboprop engine with a two-stage centrifugal compressor, reverse flow annular combustor, three stage turbine, and hydromechanical fuel control. The TPE331-10UA model is an inlet up configuration.

According to FAA Type Certificate Data Sheet E4E3, Revision 34, dated May 22, 2014, the Honeywell TPE331-10UA engine has maximum continuous and maximum takeoff sea level thrust ratings of 840 shaft horsepower (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**.

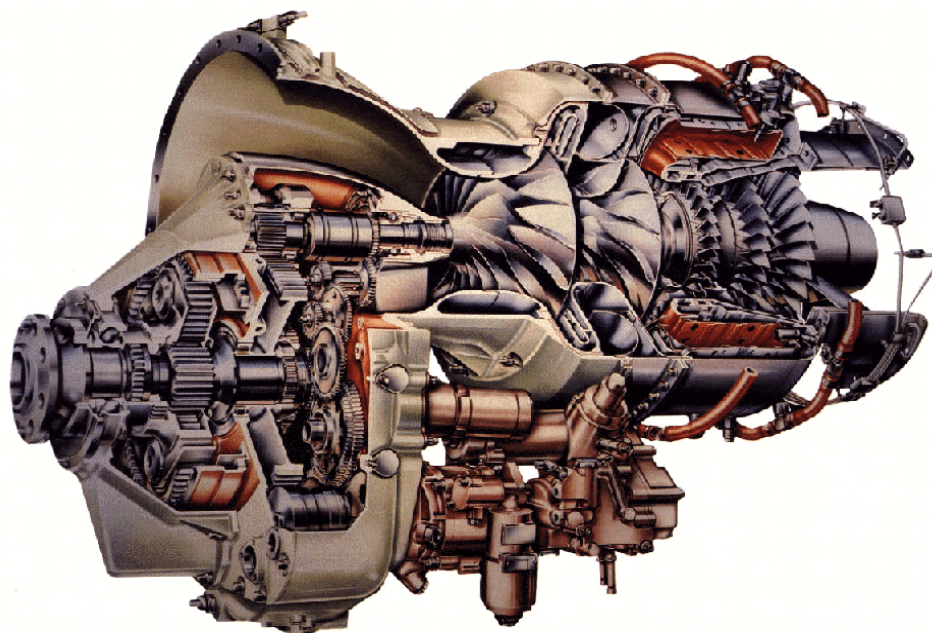


Figure 1- Honeywell TPE331 Series Engine Cutaway Diagram (Figure Courtesy of Honeywell)

1.2 Engine Operating History and Maintenance

According to the logbook records, the engines had the following accumulated the following hours and cycles as of November 30, 2021.

Engine Serial Number (ESN)	Time Since New (hours)	Total Cycles	Time Since Overhaul (hours)
No. 1 (left)- P-54128	15,419.0	17,069	3,339.7
No. 2 (right)- P-54133	12,155.5	14,800	2,871.8

1.2.1 No. 1 (Left) Engine, ESN P54128, Engine Maintenance

The last maintenance performed on the No. 1 engine were 100/150, 200 and 450 hour inspections that were completed on November 30, 2021. The engine was last removed from the airplane in February 2017, for a bird strike/propeller strike inspection, multiple components inspections, and fuel nozzle overhaul performed by Turbine Standard Ltd., Holland, Ohio (**Photo 1**). The last hot section inspection was performed in February 2010, at 2,087.7 hours TSO, approximately 1,252 hours prior to the accident by Century Turbines, Georgetown, Texas (**Photo 2**). The 1st stage turbine rotor blades were replaced with customer supplied blades as part of the hot section inspection. The 1st stage turbine blade set history prior to installation was not available¹. The fuel nozzle and manifold inspection interval on the TPE331-10UA-511G is every 350 hours. The No. 1 engine fuel nozzles were last inspected and replaced on April 2, 2019, at 2,988.9 hours TSO, approximately 350.8 hours prior to the accident.

¹ TPE331 turbine blades are not serialized and therefore individual blade history is limited.

TS **Turbine Standard, Ltd.**
10550 Industrial Rd.
Holland, OH 43030
TEL: (419) 855-0355 FAX: (419) 855-2480
FAA CRS: XZ20907K

ENGINE MODEL: TPE331-10UA-511G

ENGINE SN : P-54128 **DATE :** February 2, 2017

TSN : 14,673.6 **TSO:** 2594.3
CSN : 16,510 **CSO:** 2491

Completed Limited Repair, Bird Ingestion Inspection, Level II Prop Strike Inspection, 3600 Hr. Prop Pitch Control Cam Assy Inspection, 3700 Hr. FCU/Fuel Pump Integrity Inspection, 1000 Hour FCU/Fuel Pump Drive Spline Inspection and the Annual Magnesium Housing Corrosion Inspection in accordance with Maintenance Manual Report 72-00-45, R6 and SB 72-0180, R36 5400 Hour TBO Program. See Traceability Input Sheet on the rear of this Log Entry for Critical Life Limited Component Status. Service Bulletins and AD notes complied with are listed in the appropriate section of this logbook. Fuel Nozzles Overhauled / Flow Checked. Test Run Completed. Re-Compensation, Torque System Calibration, Vibe Survey and all required Functional/Leak Checks carried out. New DSC and Torque Data issued. Pertinent details of all work completed, on file at **Turbine Standard, Ltd.** under Work Order 63903.

*****END*****

"NOTE"

THIS ENGINE IS CONFIGURED FOR OPERATION IN ACCORDANCE WITH 5400 HOUR TBO PROGRAM AS SPECIFIED IN HONEYWELL SERVICE BULLETIN TPE331-72-0180, Rev 36.

Signature : [Redacted]
Dan M. Dunn for FAA CRS: XZ20927X

FORM: TSL10070B

SEE CHAPTER 72-06-06 OF MAINTENANCE MANUAL 72-00-45 FOR REQUIRED SYSTEM CHECKS AT ENGINE INSTALLATION

SOAP SAMPLE REQUIRED WITHIN 5 - 10 OPERATING HOURS AND AGAIN AT 20 - 30 HOURS FOLLOWING THIS REPAIR

Turbine Standard, Ltd.
10550 Industrial Rd. - Holland, OH - 43028

Photo 1- No.1 Engine, February 2017 Maintenance Logbook Entry

CENTURY TURBINES
TURBINE ENGINE SPECIALISTS

Georgetown Airport
205 Corsair Drive
Georgetown, Texas 78628
Phone: 512-863-4322
Fax: 512-864-9603

N54GP
AC SN# AT-034
DATE: 02-11-10

LH ENG SN# P-54128
LH ENG TSO: 2087.7
LH ENG CSO: 2054
AC TT: 9381.9
AC HRM: 846.7

Completed a "Hot Section Inspection and Gearbox Inspection" as recommended in Service Bulletin TPE 331-72-0180 concerning 5400 hours between engine overhaul.

A. Hot Section Inspection

1. Removed first rotor PN: 3101520-2, SN: 3-03501-1120 for repair by CRS# AP6R434N and re-installed.
2. Removed second rotor PN: 3102106-9, SN: 3-01345-5442 and installed PN: 3102106-9, SN: 9-01345-7784.
3. Removed third stage rotor PN: 3102655-2, SN: 2-01345-1430 and installed rotor PN: 3102655-2, SN: 5-01345-5414 which has 2997 cycles
4. Removed fuel nozzles for overhaul by CRS# QTFR-573L and re-installed.
5. Removed aft turbine bearing, inspected PN: 3108098-1, SN: 050633116763 and re-installed.
6. Replaced two each first stage vanes installed PN: 31038202.
7. Replaced six each first stage shroud segments, installed PN: 3103128-3
8. Removed second stage stator, removed PN: 3101515-17, SN: 9-01345-6472, installed PN: 3101513-17, SN: 00-01345-09902.
9. Removed combustion liner assembly PN: 3107053-1, SN: P-18583, and installed combustion liner assembly PN: 3103215-3, SN: 4P-16138.
10. Replaced aft main shaft nut, installed PN: 3108066-1.
11. Replaced aft scavenge pump gasket, installed PN: 3108133-5
12. Removed start pressure regulator valve PN: 894441-5, SN: P-1357 for function test by CRS# B6BR2765 and re-installed.

Accomplished a ground power performance run in accordance with the Honeywell Manual.

All the above work was accomplished in accordance with the Maintenance Manual Report Number 72-00-29.

-----END-----

RICKEY L. PETERSON
A&P 449020543
DATED: 02-11-10

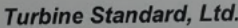
Photo 2- No. 1 Engine, February 2010 Engine Hot Section Inspection Logbook Entry

1.2.2 No. 2 (Right) Engine, ESN P-54133, Engine Maintenance

The last maintenance performed on the No. 2 engine were 100/150, 200 and 450 hour inspections that were completed on November 30, 2021, and performed by performed by Turbine Standard Ltd., Holland, Ohio. The engine was last removed from the airplane in August 2019 due to a bird ingestion and a hot section inspection and fuel nozzle overhaul/testing was completed while the engine was in the shop. The maintenance was performed when the engine had accumulated 2,613.3 hours TSO, approximately 258.5 hours prior to the accident (**Photo 3**).



TURBINE STANDARD, LTD.



Turbine Standard, Ltd.
10550 Industrial Rd.
Holland, OH 43528
TEL: (419) 865-0355 FAX: (419) 865-2460
FAA CRS: X2ZR927X



ENGINE MODEL: TPE331-10UA-511G

ENGINE SN: P-54133 **DATE:** October 18, 2019

TSN: 11,897.1	TSO: 2,613.3	TSHSI: 0.0
CSN: 14,632	CSO: 2,527	TSGBI: 0.0

Completed *Bird Ingestion Inspection, 1800 Hour Hot Section Inspection, 3600 Hour Gearbox Inspection, 3600 Hr. PPC Cam Assembly Inspection, 3700 Hr. FCU/Fuel Pump Integrity Inspection and the Annual Magnesium Housing Corrosion Inspection* in accordance with Maintenance Manual Report 72-00-45 R9 and SB 72-0180, 5400 Hour TBO Program. See Traceability Input Sheet on the rear of this Log Entry for Critical Life Limited Component Status. AD notes complied with are listed in the appropriate section of this logbook. *Fuel Nozzles Overhauled / Flow Checked.* Test Run Completed. Re-Compensation, Torque System Calibration, Vibe Survey and all required Functional/Leak Checks carried out. *New DSC and Torque Data Issued.* Pertinent details of all work completed are on file at **Turbine Standard, Ltd.** under Work Order 100128.

*****END*****

SEE CHAPTER 72-00-00 OF MAINTENANCE MANUAL 72-00-45 FOR REQUIRED SYSTEM CHECKS AT ENGINE INSTALLATION

SOAP SAMPLE REQUIRED WITHIN 5 – 10 OPERATING HOURS AND AGAIN AT 20 – 30 HOURS FOLLOWING THIS INSPECTION

Signature: 
Brandon M. Carman for FAA CRS: X2ZR927X

Turbine Standard, Ltd.
10550 Industrial Rd. – Holland, OH - 43528

FORM: TSL10070B

Photo 3- No. 2 Engine, October 2019 Maintenance Logbook Entry

2.0 No. 1 (Left) Engine, ESN P-54128, Teardown Examination

2.1 Visual Examination

The engine was secured in a cardboard shipping box in the Honeywell Product Integrity Laboratory when the investigation team arrived (**Photos 4-7**). All external engine surfaces were sooted and had an ashy appearance with localized areas of dark discoloration consistent with post-crash fire exposure. The thermal damage was most severe from the 1 to 6 o'clock positions. The discoloration pattern and the shape of resolidified molten metal indicated the engine came to rest at the 3 o'clock position. There was no evidence of radial uncontainment or penetrations through the engine cases. Approximately 70 degrees of the outer diameter of the propeller mount flange was separated, including two bolt holes and a dowel pin (**Photo 8**). The propeller shaft was seized and could not be rotated by hand. The 3rd stage turbine blades could be rotated approximately 15 degrees by hand with heavy resistance. The 1st stage compressor impeller vanes visible through the inlet and the 3rd stage turbine blades visible through the exhaust were complete.



Photo 4- Engine Shipping Box, as Received at Honeywell



Photo 5- Left Side of Engine, as Received (Upside Down Relative to Installed Orientation)

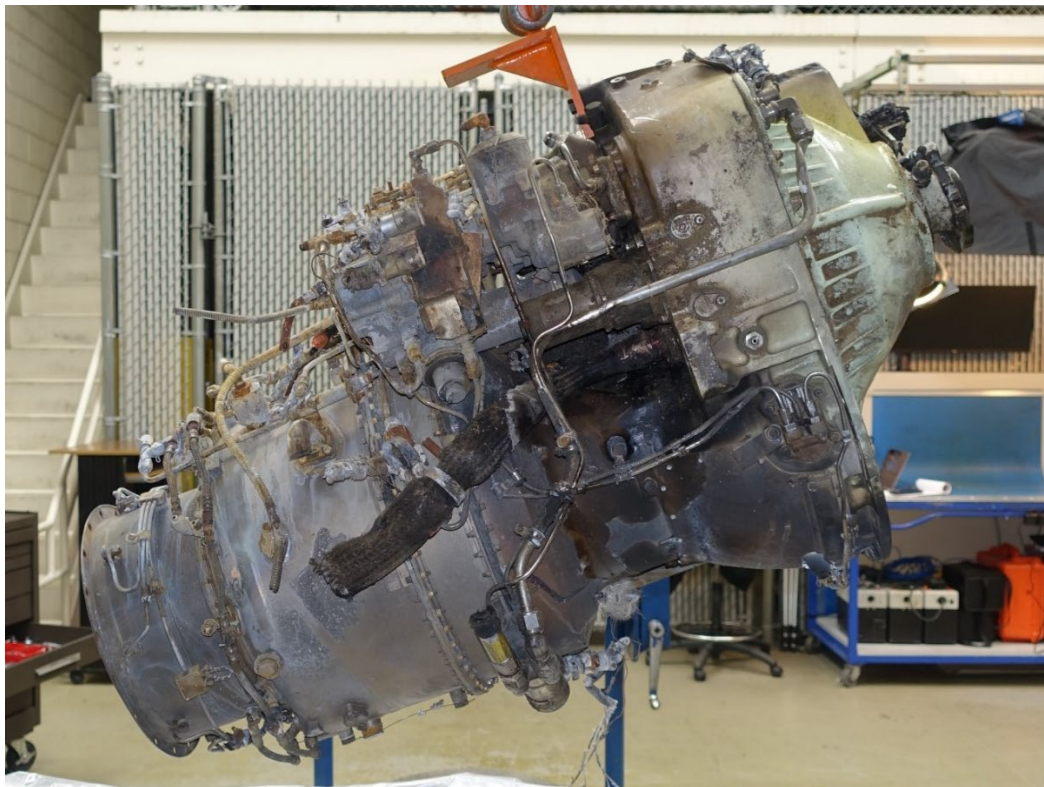


Photo 6- Right Side of Engine, as Received (Upside Relative to Installed Orientation)

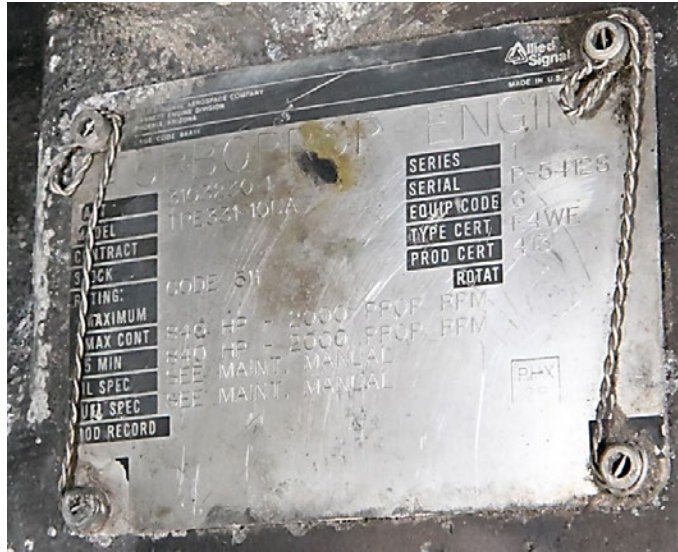


Photo 7- No. 1 Engine, ESN P-54128, Data Plate

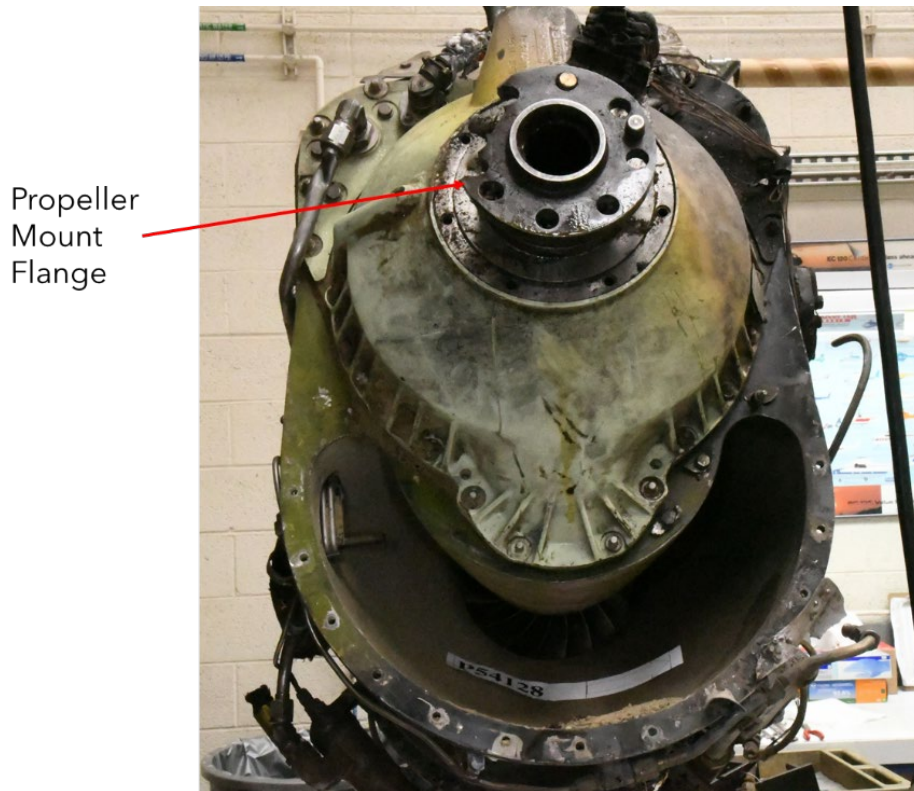


Photo 8- Propeller Mount Flange, Inlet (Upside Down Relative to Installed Orientation)

The fuel pump and fuel control unit (FCU) remained secured to the accessory gearbox (AGB). Both components appeared ashy with areas of light corrosion. The FCU power lever indicator dial was aligned with the 100 degree mark and was against the hard stop (maximum) (**Photo 9**). All three propeller pitch control (PPC) attachment lugs were broken and the PPC was pushed aft, away from the AGB. The PPC indicator dial was partially melted, but what remained of the dial was aligned

with the 90 degree mark² (**Photo 10**). The aft propeller shaft thrust bearing was pushed out of the aft side of the gearbox. The propeller feather valve was retracted (closed position). The propeller governor³ was intact with dark discoloration/sooting. The propeller governor check valve orifice on the AGB was free of obstructions. The fuel shutoff valve (FSOV) remained secured to the engine but exhibited thermal damage and case deformation. Following FSOV removal, a microscope was used to examine the scribe mark on the input shaft, and it was aligned with the 12 o'clock position⁴ (**Photo 11**). A low pressure air check was performed, and air passed through the valve, indicating it was in the open position.



Photo 9- (L) Fuel Pump and Fuel Control, (R) Fuel Control Power Lever Linkage Dial Indicator

² According to Honeywell, when the engine is rigged in accordance with the maintenance manual procedure, the PPC indicator dial and FCU power lever indicator dial should point to the same value.

³ The propeller governor is also referred to as the constant speed unit.

⁴ The fuel shutoff valve indicator is aligned with the 12 o'clock position in auto mode or the 3 o'clock position when the condition lever is retarded to the emergency shutoff position in the cockpit. According to Honeywell, the fuel shutoff valve is in the closed position at either the 3 or 9 o'clock positions.

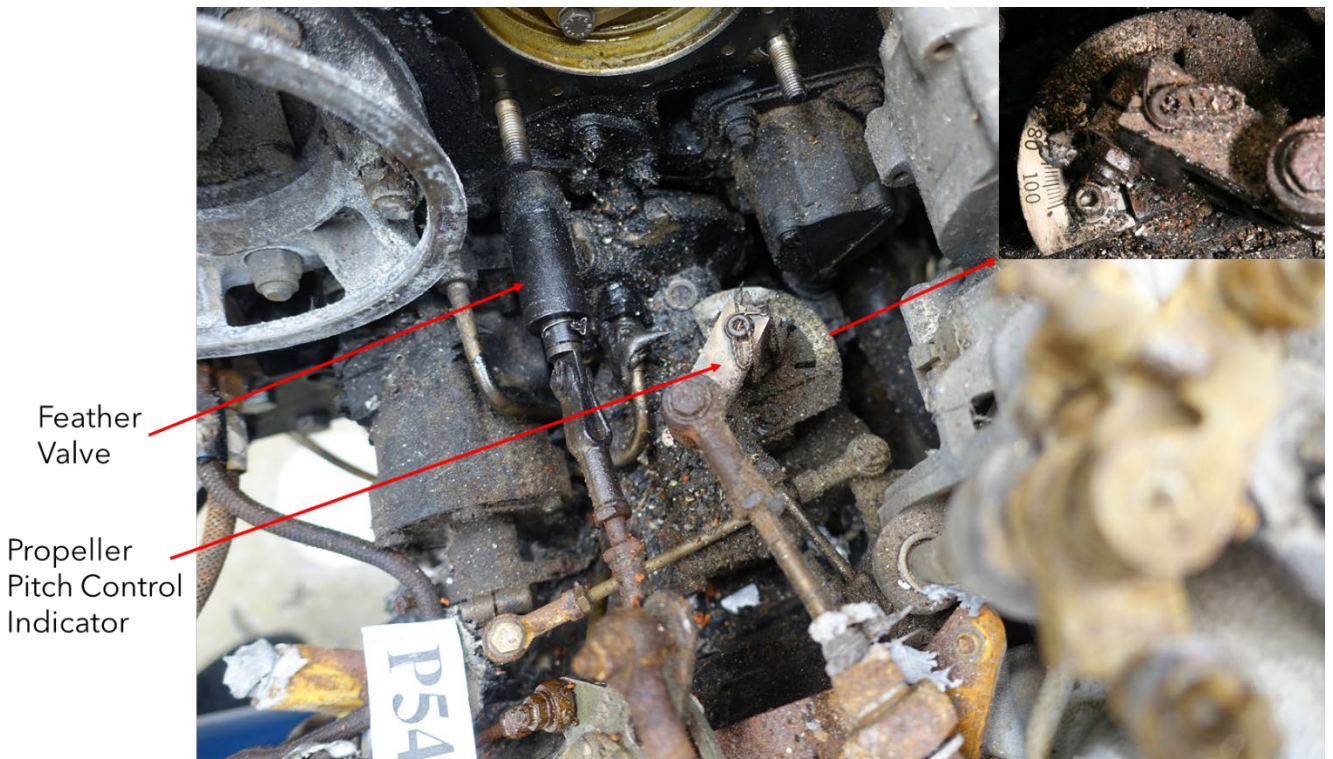


Photo 10- Propeller Pitch Control, Indicator Dial



Photo 11- Fuel Shutoff Valve, Input Shaft Scribe

The magnetic chip detector (MCD) was free of debris accumulation or metal “fuzz” (**Photo 12**). The oil filter was oil wetted and no debris was visible in the filter or the filter bowl. The fuel filter was dry with localized areas of dark discoloration. The filter and filter bowl smelled acrid, consistent with exposure to post-crash fire.



Photo 12- Magnetic Chip Detector Plug

2.2 Nose Cone Assembly and Accessory Gearbox

The AGB case and inlet were intact but exhibited discoloration and sooting. All seven forward propeller shaft bearing mount bolts were not present⁵. The nose cone could not be manually separated from the gearbox due to propeller shaft interference. The nose cone, diaphragm, and the propeller shaft were removed as an assembly (**Photo 13**) and the propeller shaft was pushed out using a custom fabricated pusher bar tool. The forward and aft propeller bearings were not exposed but rotated smoothly. The propeller shaft had a 360 degree circumferential rub at the forward radius, immediately aft of the forward retaining nut. In the same location as the circumferential rub, there was raised metal consistent with axial impact. The propeller shaft also had localized circumferential scoring ½ inch and 1¾ inches aft of the retaining nut (**Photo 14**). The ring gear, sun gear, bull gear, and planet gears were intact and rotated. Impact/contact marks were observed on the AGB case feather valve bore and the torque sensor housing with coincident impact marks on the aft sun gear retaining nut (**Photo 15**). According to Honeywell, impact/contact in these locations are

⁵ The propeller shaft bearing mount bolts were removed during removal of the airplane inlet.

common during nose down accident events on TPE331 engines. The torque sensor assembly was intact, and the gears rotated smoothly.

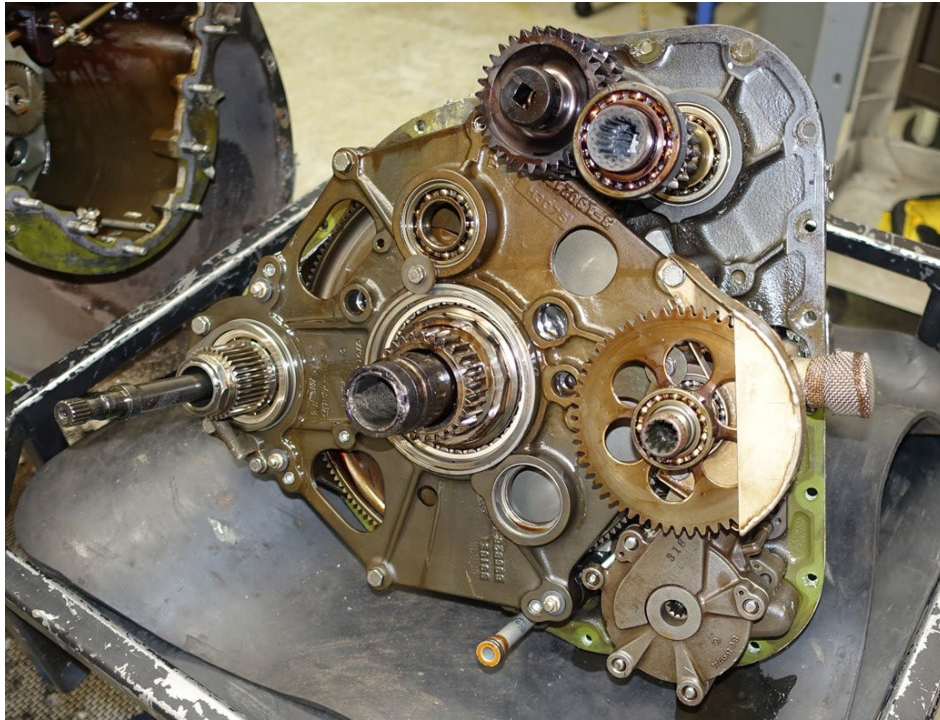


Photo 13- Diaphragm, Propeller Shaft, Nose Cone Assembly

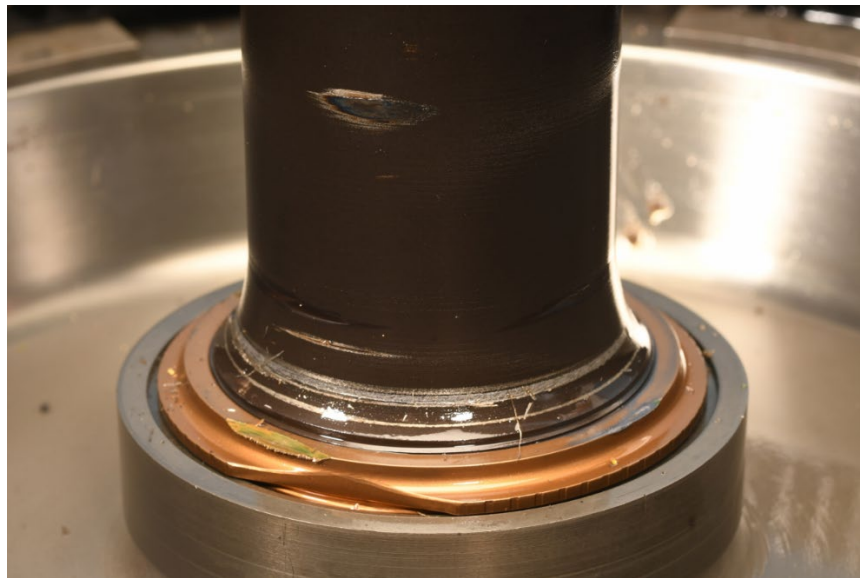


Photo 14- Propeller Shaft Circumferential Rub/Scoring

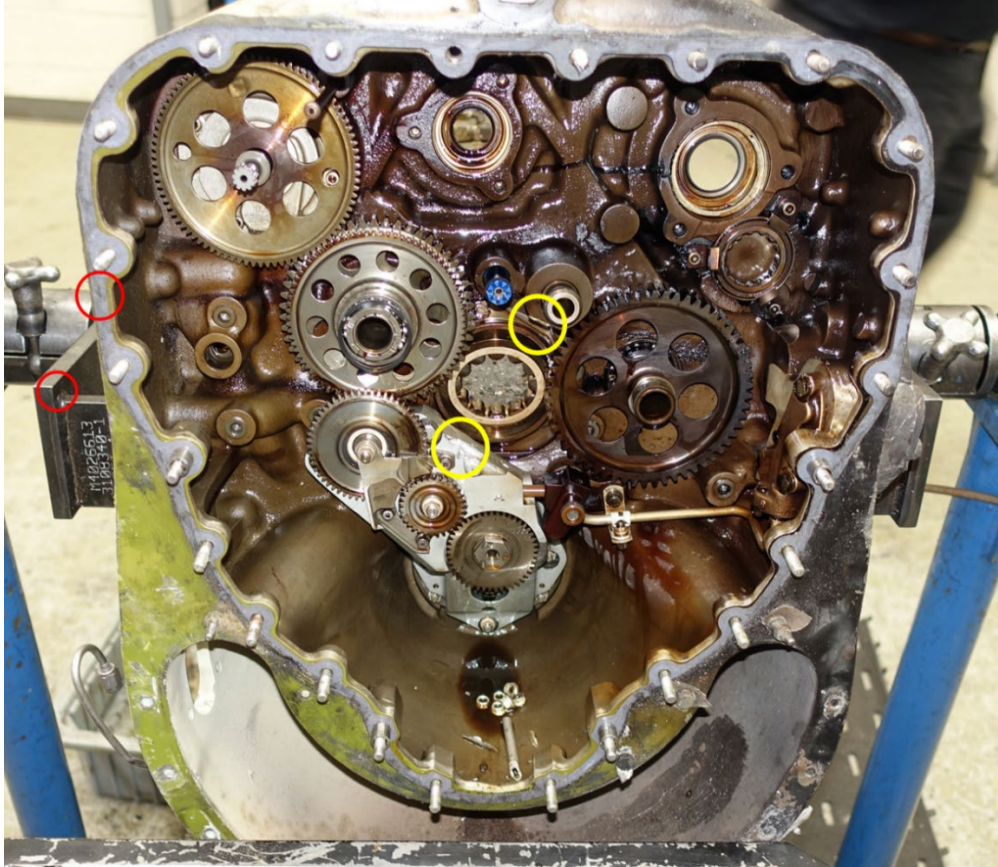


Photo 15- Accessory Gearbox, Feather Valve Bore, and Torque Sensor Impacts/Contacts

2.3 Turbine Section

The rear (turbine) bearing support was intact. The turbine bearing was oil wetted and rotated smoothly. Scoring was observed on the inner diameter of the turbine bearing retainer at the 3, 6, 9, and 12 o'clock positions. The 1st stage turbine stator was intact with light impact marks on the leading edge of all vanes (**Photo 16**). All the 1st stage turbine rotor blades were present and one blade had separated at midspan (identified as Blade 1) (**Photo 17**). The blade fracture surface appeared jagged and charred. The adjacent receding blade (blade 36) and two succeeding blades (blades 1 and 2) exhibited leading and trailing edge impact damage and material loss. The leading edge tip of all 1st stage turbine blades were missing material and appeared smooth and rolled over (**Photo 18**). The trailing edge of 1st stage turbine blades 27, 29-32, 35, and 36 had trailing edge tip material loss.

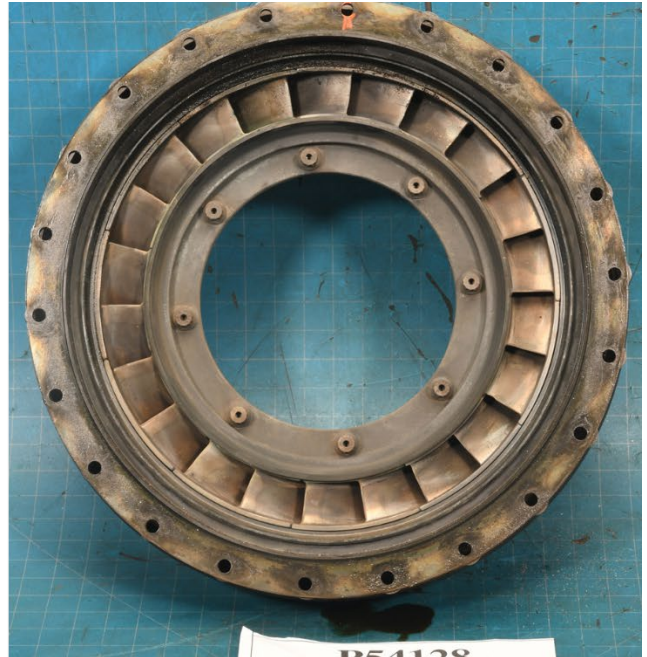
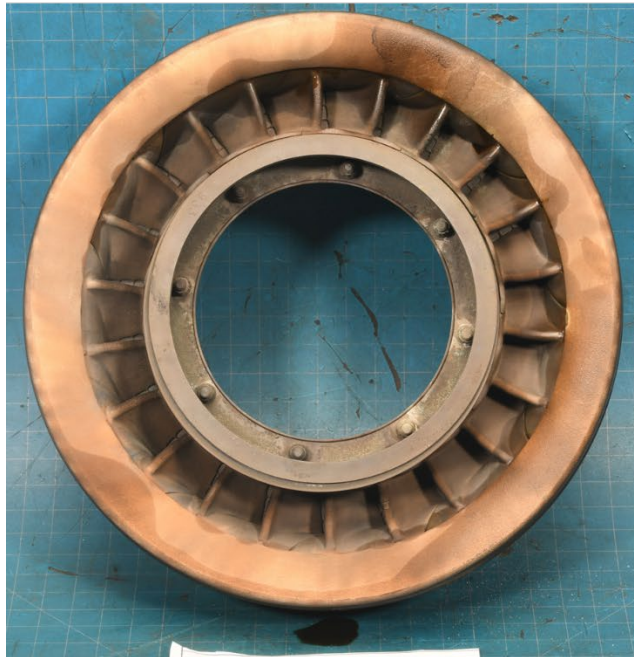


Photo 16- 1st Stage Turbine Stator, (L) Pressure Side, (R) Suction Side

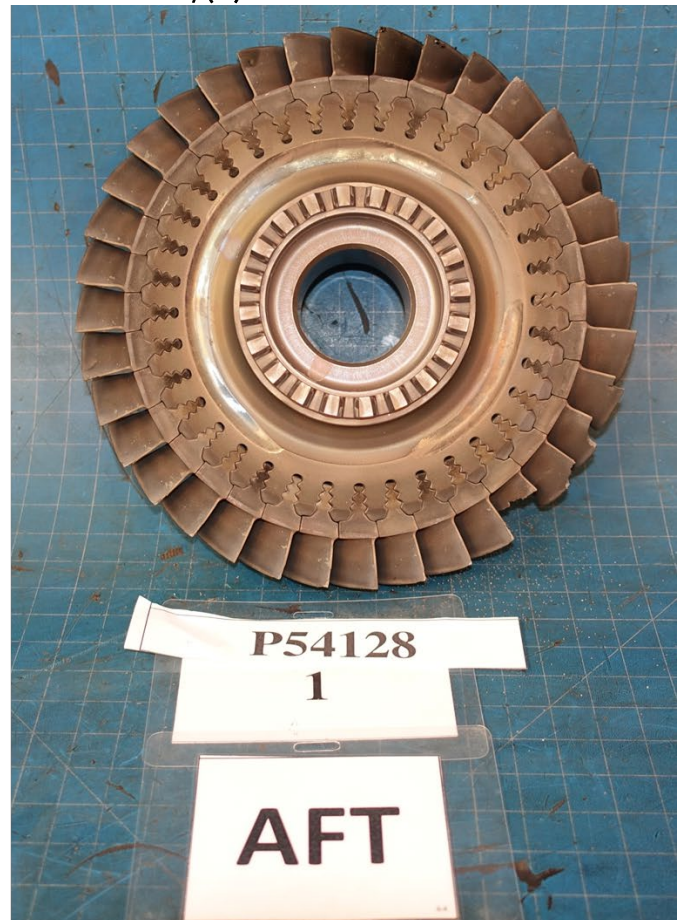


Photo 17- 1st Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge

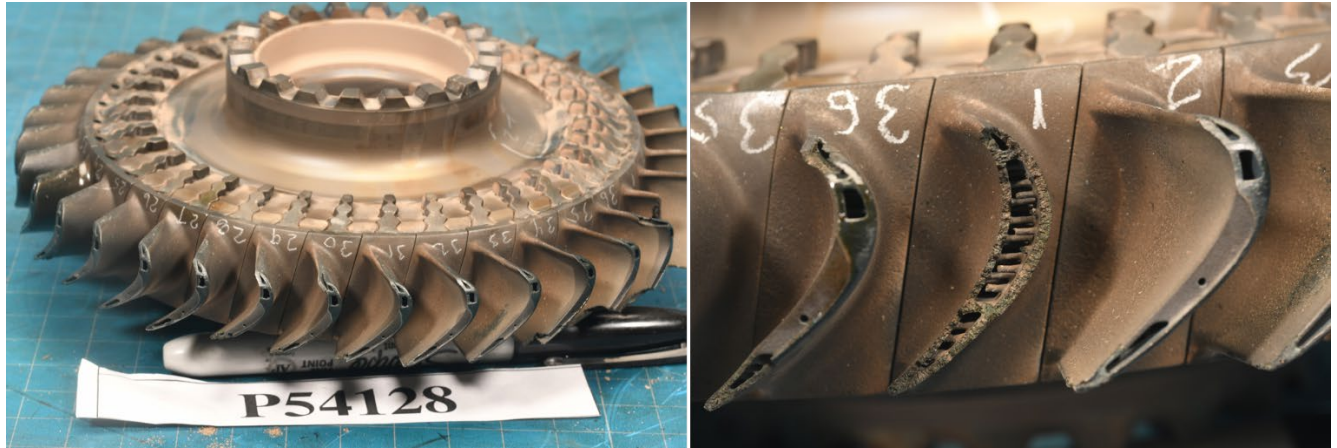


Photo 18- (L) 1st Stage Turbine Rotor Blades Tip Loss, (R) 1st Stage Rotor Blade Fracture Surface

The 2nd stage turbine stator exhibited thermal damage and vane material was missing from the 6 to 12 o'clock positions. The thermal damage was most severe from the 8 to 10 o'clock positions (**Photo 19**). All intact vanes had suction side trailing edge thermal damage and the suction side vane surfaces appeared wrinkled. Light 360 degree rotational scoring was visible on the 2nd stage turbine shroud. The 2nd stage turbine rotor blades were all intact but had light leading edge impact damage (**Photo 20**). The trailing edge along the outer third of the blade span of all 2nd stage turbine blades were rolled over opposite the direction of rotation. Tip rub was visible 360 degrees around the rotor.

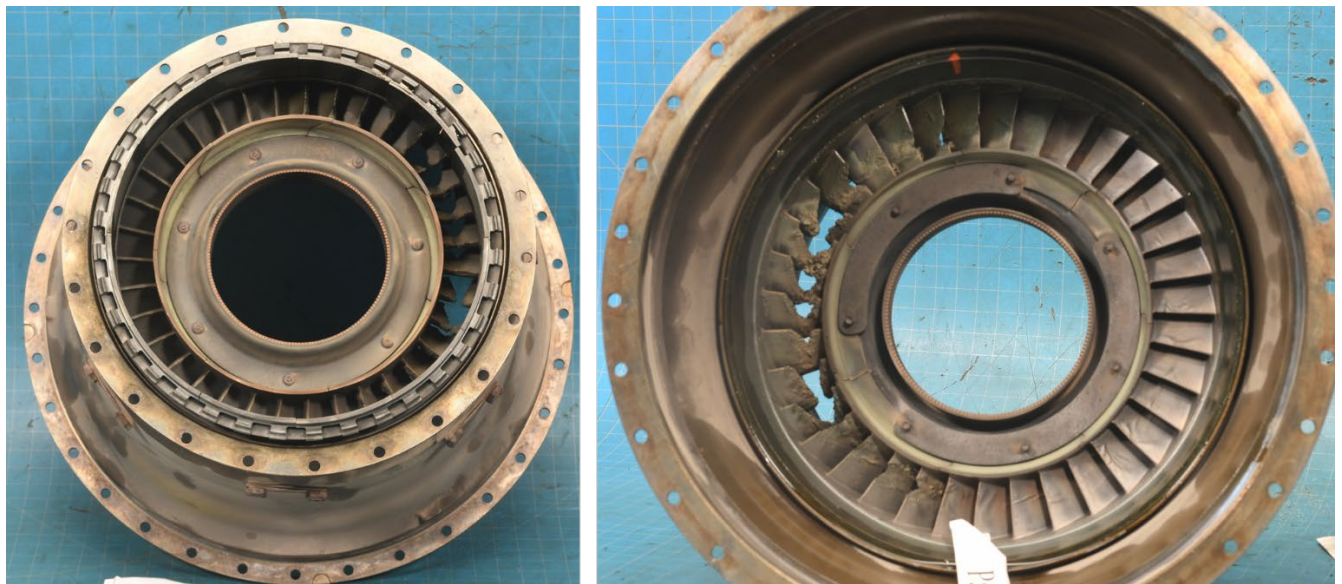


Photo 19- 2nd Stage Turbine Stator, (L) Pressure Side, (R) Suction Side

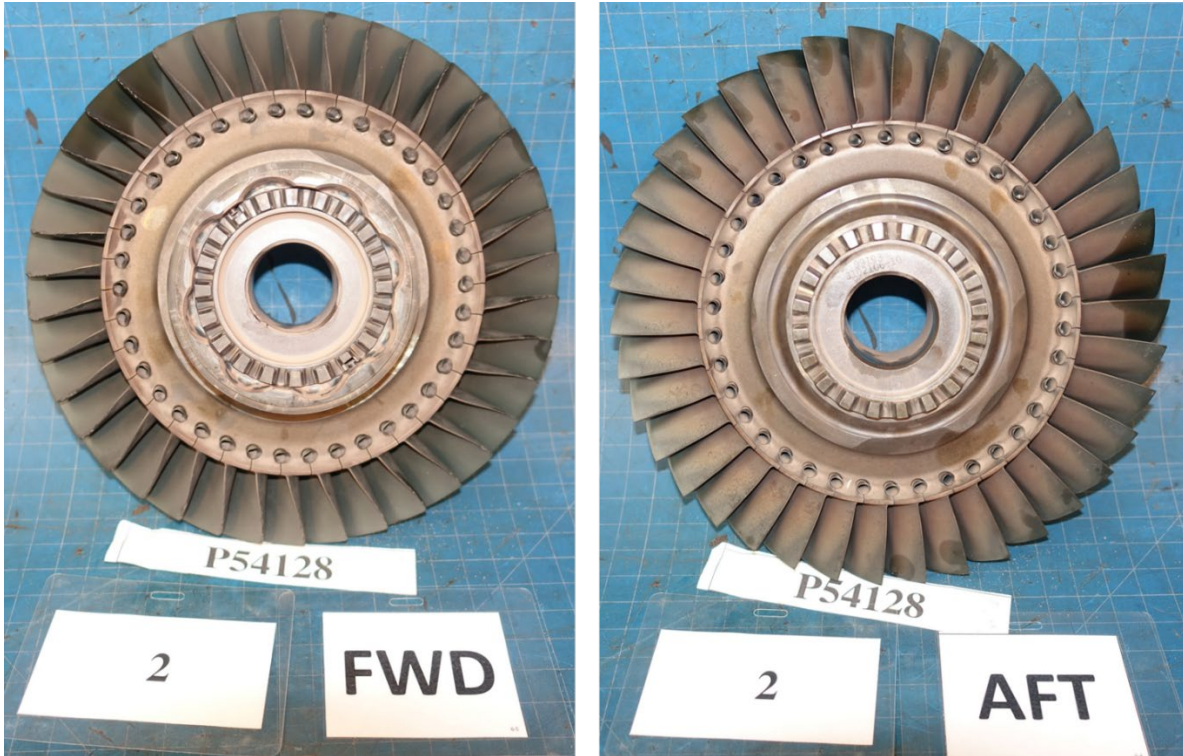


Photo 20- 2nd Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge

The 3rd stage turbine stator had four vanes with chordwise cracks at the midspan from the 9 to 10 o'clock positions (**Photo 21**). One additional vane had a small incipient crack on the leading edge at the 11 o'clock position. Trailing edge deformation was noted on three consecutive vanes at the 11 o'clock position. Light rotational scoring was visible on the 3rd stage rotor shroud at the 6 o'clock position. All the 3rd stage turbine rotor blades were intact (**Photo 22**) and exhibited tip rub and small leading edge nicks (**Photo 23**). The 3rd stage turbine shroud exhibited circumferential scoring consistent with contact from the 3rd stage blade tips (**Photo 23**).

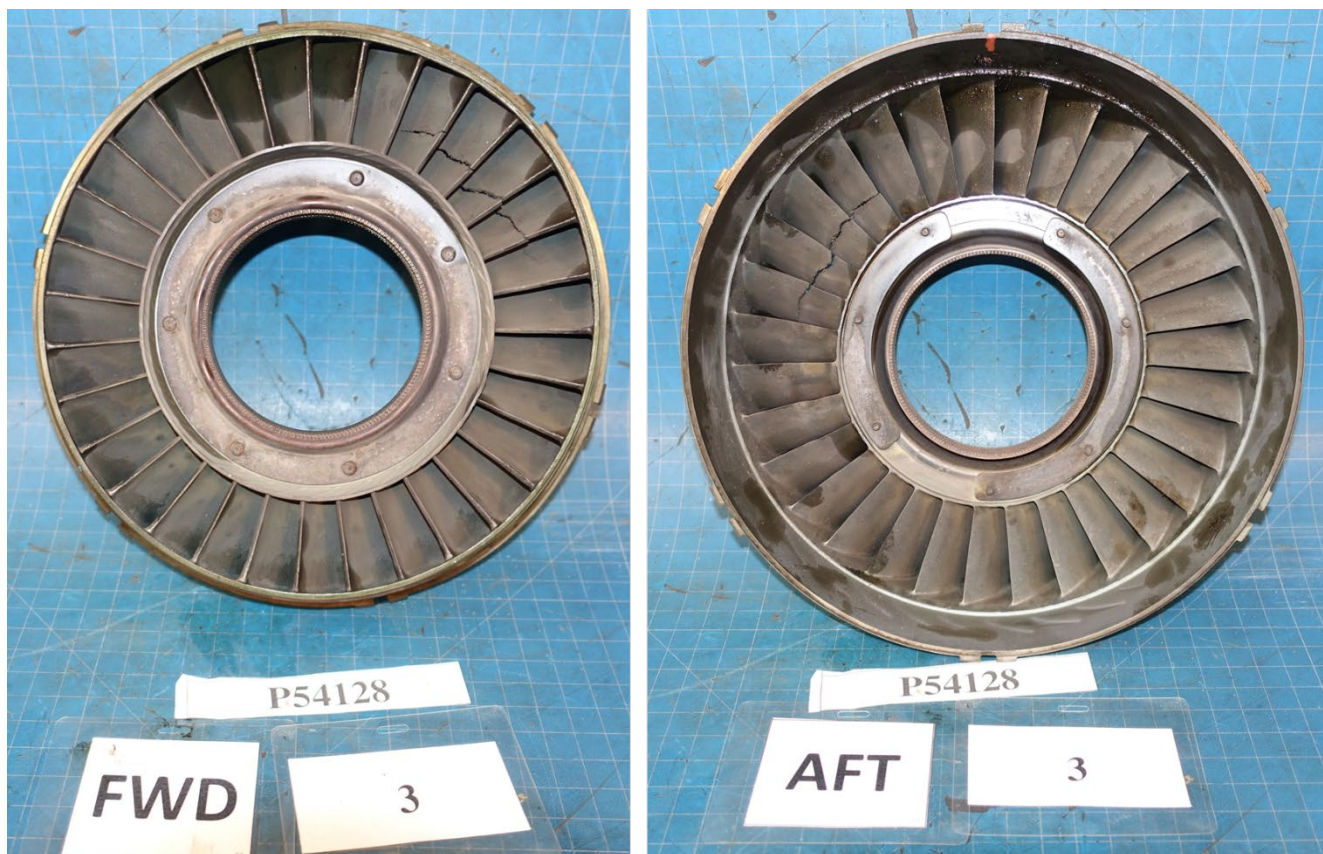


Photo 21- 3rd Stage Turbine Stator, (L) Pressure Side, (R) Suction Side

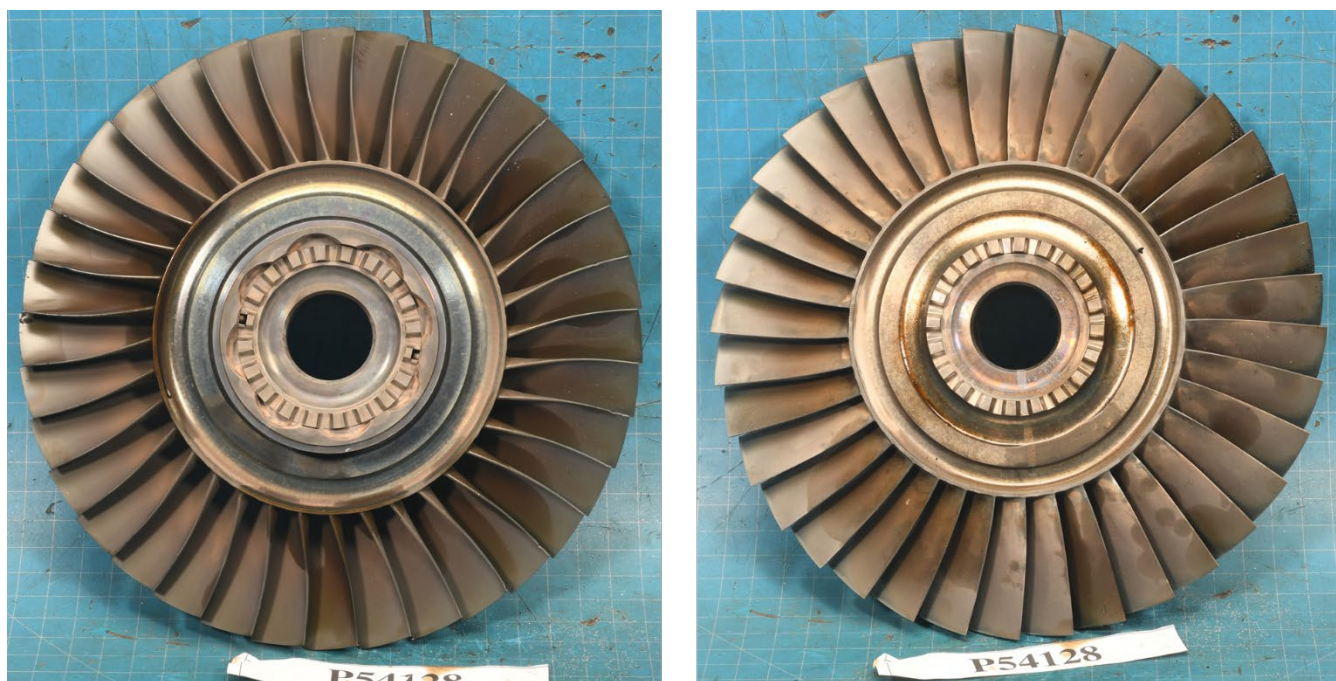


Photo 22- 3rd Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge



Photo 23- 3rd Stage Turbine Blade Tip Rub (L), 3rd Stage Shroud Rub (R)

The curvic couplings of all three turbine stages were in good condition and the contact marks were consistent with nominal assembly. There was no metal spray observed in the turbine. There was sand throughout the turbine stages on blade, vane, and shroud surfaces.

2.4 Combustor

The combustion liner was intact and had no indications of fuel nozzle streaking (**Photo 24**). All the fuel nozzles were properly seated. There was light coking/discoloration on the dome of two fuel nozzles. The primary and secondary fuel manifold was separated at the nozzle connection at multiple locations around the plenum. Most fuel nozzle manifold thermal insulation was thermally consumed. Sand was collected in the combustor, most notably in the outer transition liner. There was no metal spray visible on the combustion liner walls.

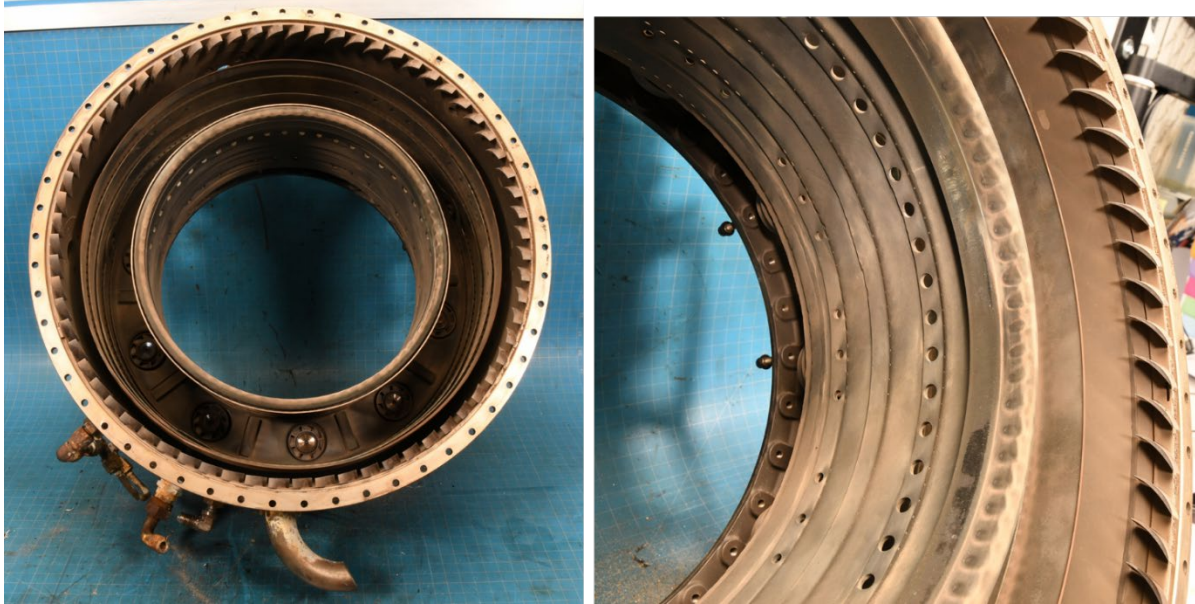


Photo 24- Combustion Liner, Plenum

2.5 Compressor Section

The 1st stage compressor impeller was intact. All impeller blades had light tip rub along the length of the blade (inducer to exducer) (**Photo 25**). There was light 360 degree rotational scoring on the hub aft of the forward curvic coupling. The 1st stage impeller shroud⁶ had light 360 degree rotational scoring from the inducer to the exducer, more visible at the exducer (**Photo 26**). The 1st stage impeller/shroud and the 1st stage diffuser vanes had fine sand accumulation on all surfaces in the flow path.

⁶ Honeywell's description of the compressor impeller shroud divides the part into three regions: inducer, knee (curved surface coincident with the impeller blade tips), and exducer.

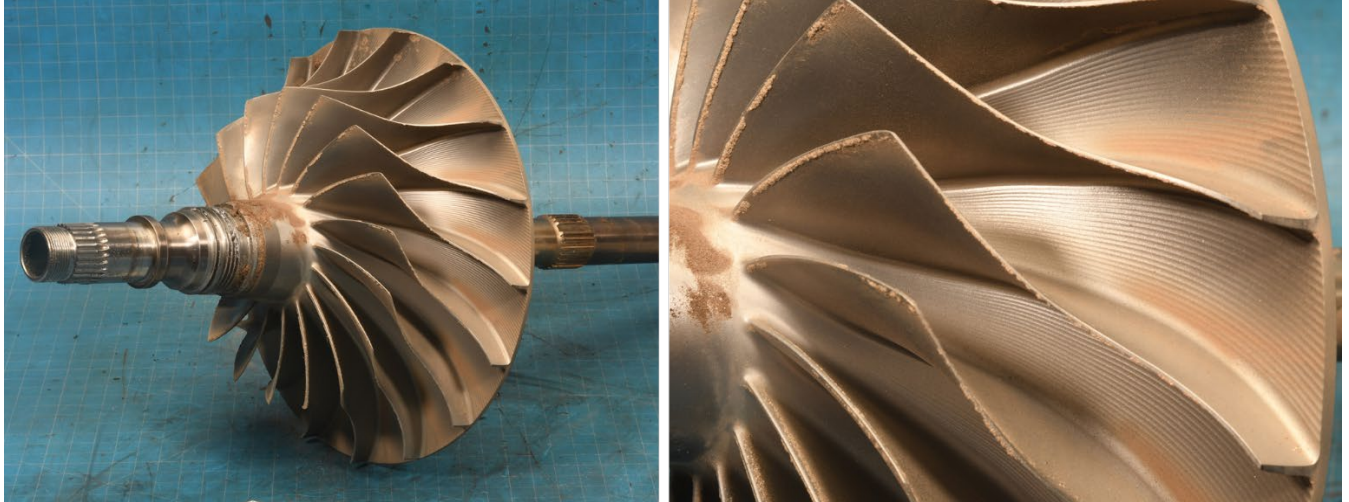


Photo 25- (L) 1st Stage Compressor Impeller, (R) Impeller Blade Tips



Photo 26- 1st Stage Compressor Shroud

The 2nd stage compressor impeller blades were all complete (Photo 27). The impeller blades tips had tip rub from the inducer to the exducer. The impeller had 360 rotational scoring on the hub aft of the forward curvic. The main shaft was intact and did not appear bent/deformed. There was light 360 degree rotational scoring on the hub aft of the curvic coupling (Photo 28). The 2nd stage impeller shroud had light 360 degree rotational scoring from the inducer to the knee (Photo 29). The 2nd stage shroud also exhibited light static impact marks from the 2 to 7 o'clock positions.

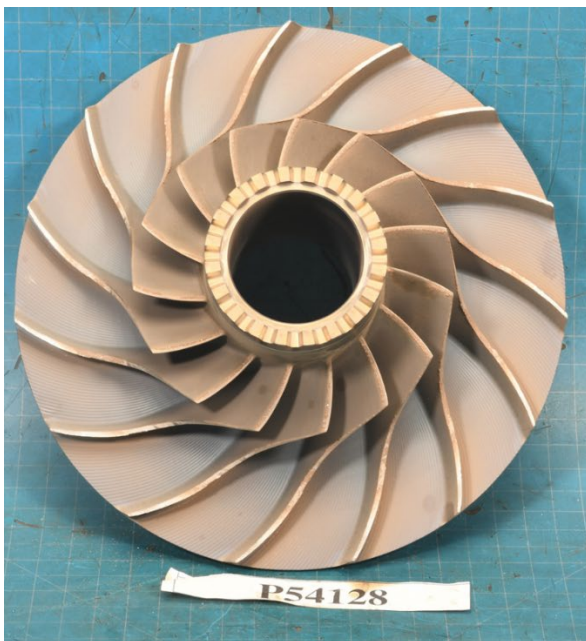


Photo 27- 2nd Stage Compressor Impeller



Photo 28- 2nd Stage Compressor Impeller Hub Curvic Scoring

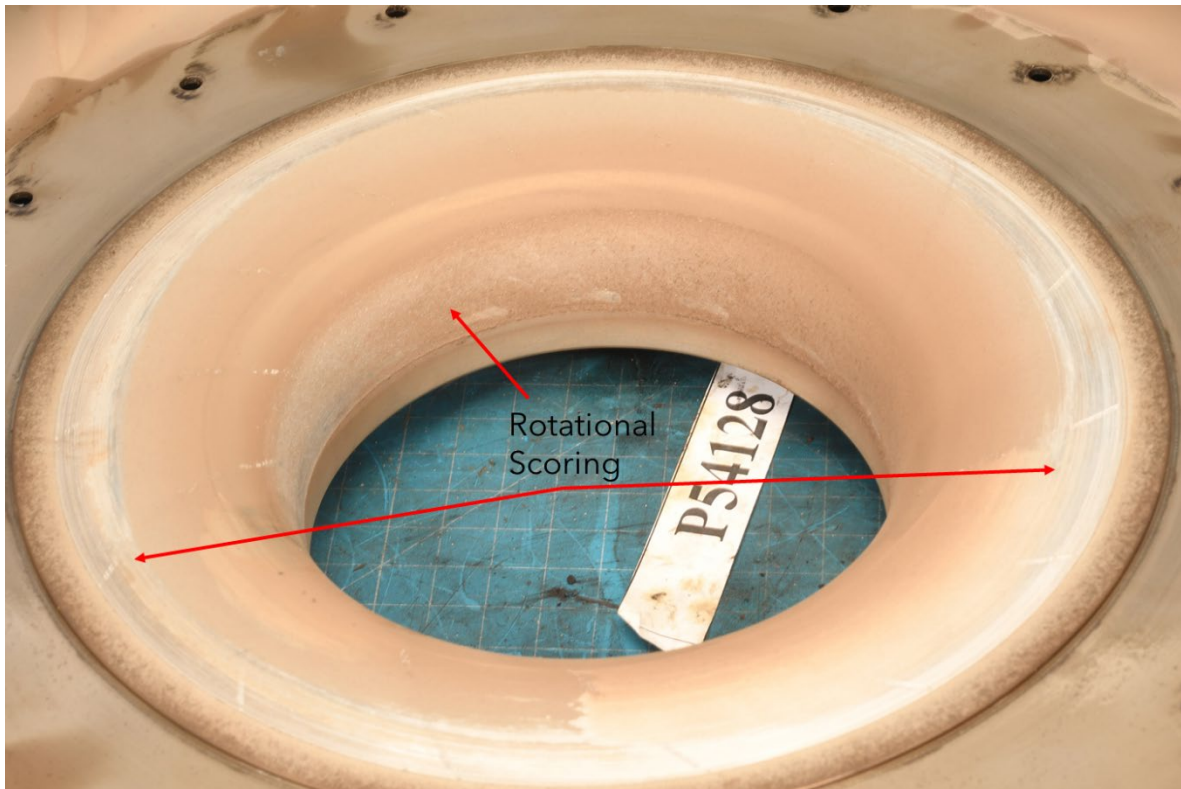


Photo 29- 2nd Stage Compressor Shroud

3.0 No. 1 (Left) Engine, ESN P-54128, Component Testing

3.1 Fuel Control Unit

The FCU was shipped to Woodard in Loves Park, Illinois for a group examination with party members from Woodward, Honeywell, and the NTSB; the exam was conducted between August 22-25, 2022. According to the engine logbook, the FCU serial number was 2007669; however, the data plate on the FCU was missing or consumed during the post-crash fire, so the FCU serial number could not be confirmed. The FCU housing case number was 7009.

Due to extensive thermal damage, the FCU could not be bench tested (**Photo 30**). The FCU was fully disassembled, and thermal damage was observed on all internal components but there was no evidence of pre-impact failure or other anomalies. The Woodward report is available in the investigation docket as "Attachment 1- Woodward Fuel Control Unit, Serial Number, 2007669, Investigation Report."

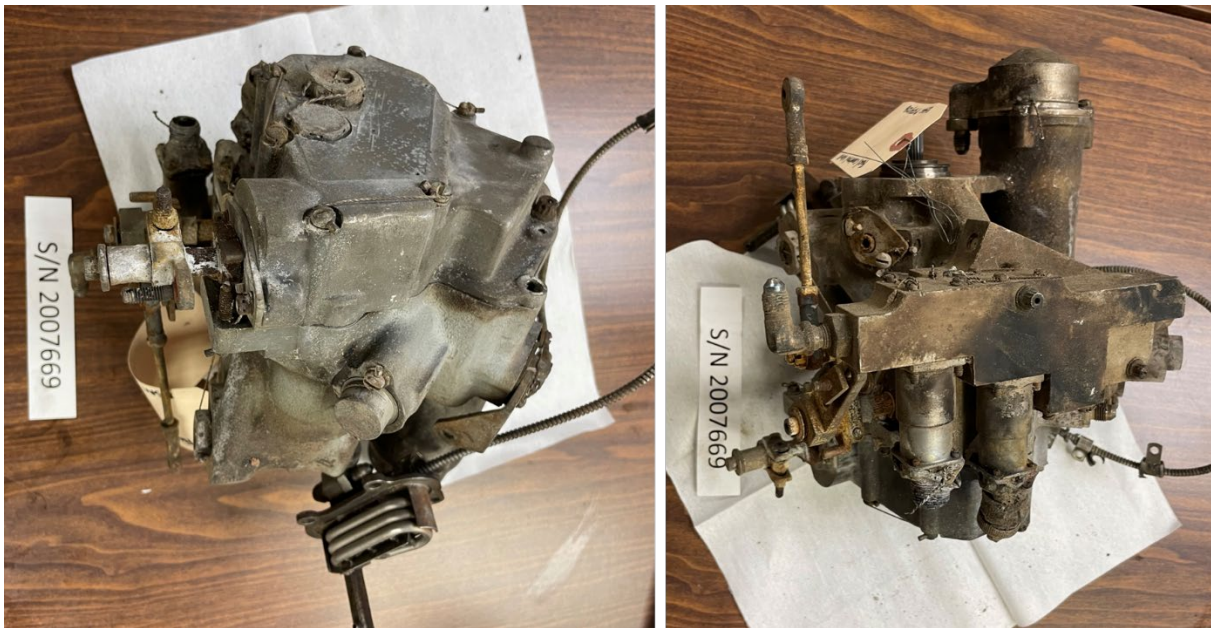


Photo 30- FCU, as Received at Woodward

3.2 Propeller Governor

Propeller governor, serial number, 1440642, was shipped to Woodard in Loves Park, Illinois for a group examination with the same group members in attendance and conducted the same time as the FCU exam. The propeller governor external surfaces were all discolored and covered with soot and debris (**Photo 31**). The governor was run on the test bench in the as received condition. During initial startup, there was significant leakage from the governor baseplate. The baseplate packing was replaced, but leakage was again observed from the governor housing and baseplate. Multiple test points were out of limits during the as received test run. The bypass valve was replaced with an engineering spare relief valve and the test procedure was run again. The test points were within the expected range of similar service run units according to Woodward.

The propeller governor was disassembled. Internal components exhibited signs of thermal exposure consistent with post-crash fire. The governor relief valve spring had a free length of 1.560 inches instead of a new spring unit length of approximately 1.760 inches. In the as-installed condition, the spring is compressed to approximately 1.500 inches. The shorter spring length on the as received unit is consistent with the spring taking a set at the working height due to post crash fire exposure. There were no other internal anomalies identified that would have precluded normal operation. The Woodward report and test run sheet are available in the investigation docket as "Attachment 2- Woodward Propeller Governor, Serial Number, 1440642, Investigation Report and Test Run Sheet."



Photo 31- Propeller Governor, as Received at Woodward

3.3 Fuel Nozzles

The No. 1 engine fuel nozzles were flow tested at Honeywell in Phoenix, Arizona on April 14, 2022, under oversight by a Federal Aviation Administration representative (Photo 32). The fuel nozzle secondary⁷ flow circuit test was performed at a pressure setting of 100 pounds per square inch (psi) in accordance with the overhaul manual, resulting in a fuel flow of 260 pounds per hour (pph). Fuel nozzles 1 and 10 had very low flow and fuel nozzle 2 had no flow. The flow observations from the remaining nozzles were recorded "ok." The primary flow circuit test was then performed at 100 psi resulting in a fuel flow of 48 pph. Fuel nozzle streaking was observed on nozzle 2, there was no flow from nozzle 8, and the flow from fuel nozzle 10 was in a jet pattern. The flow observations from the remaining nozzles were recorded "ok."

⁷ The TPE331-10UA-511G features duplex fuel nozzles with primary and secondary ports incorporated into each nozzle. The primary flow path is used during engine start and the secondary flow path opens when the engine reaches speed.



Photo 32- Fuel Nozzle Flow Test Setup (Photo Courtesy of Honeywell)

3.4 Fuel Pump

The fuel pump was examined at Honeywell in Phoenix, Arizona on November 10, 2022, under oversight by a FAA representative. The fuel pump drive spline had heavy resistance when it was rotated by hand. The fuel pump could not be bench tested due to thermal damage, so it was fully disassembled and inspected. There were indications of thermal damage throughout fuel pump internal components including discoloration and consumed/melted o-ring packings (**Photo 33**). The fuel pump relief valve was functionally tested after it was removed and opened at 1000 psi⁸. There were no indications of pre-impact failure or other anomalies that would have precluded normal operation.

⁸ Production relief valves are required is to open at 1,200 psi +/- 100psi.

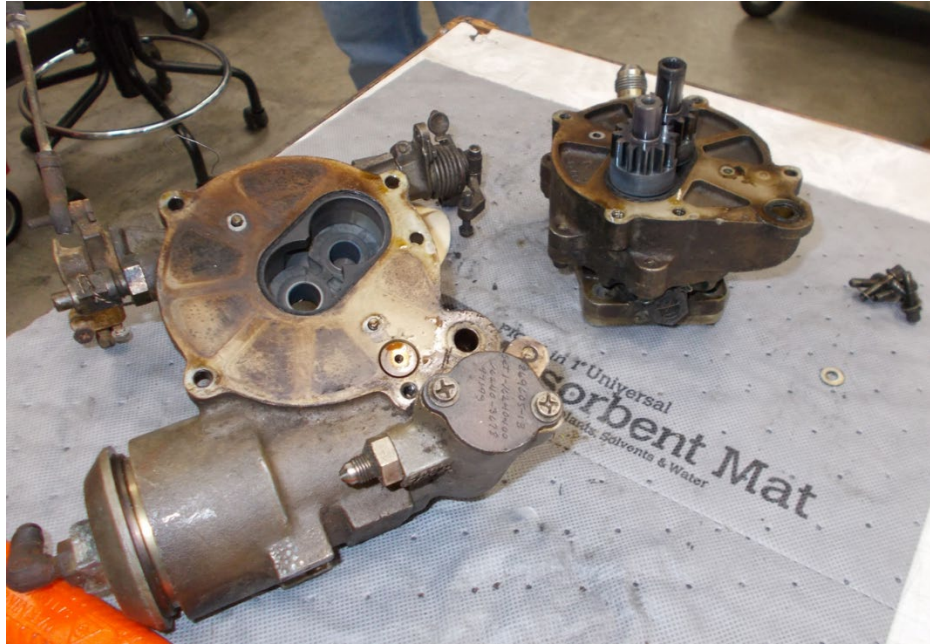


Photo 33- Fuel Pump, Partially Disassembled (Photo Courtesy of Honeywell)

3.5 Fuel Shutoff Valve

The FSOV was computed tomography (CT) scanned at Honeywell in Phoenix, Arizona and video files of the CT scans were provided to the NTSB for review. The CT scan showed the FSOV was in the open position, consistent with the low pressure test findings during the teardown examination. The Belleville washer was intact, and no internal anomalies were identified (**Photo 34**).

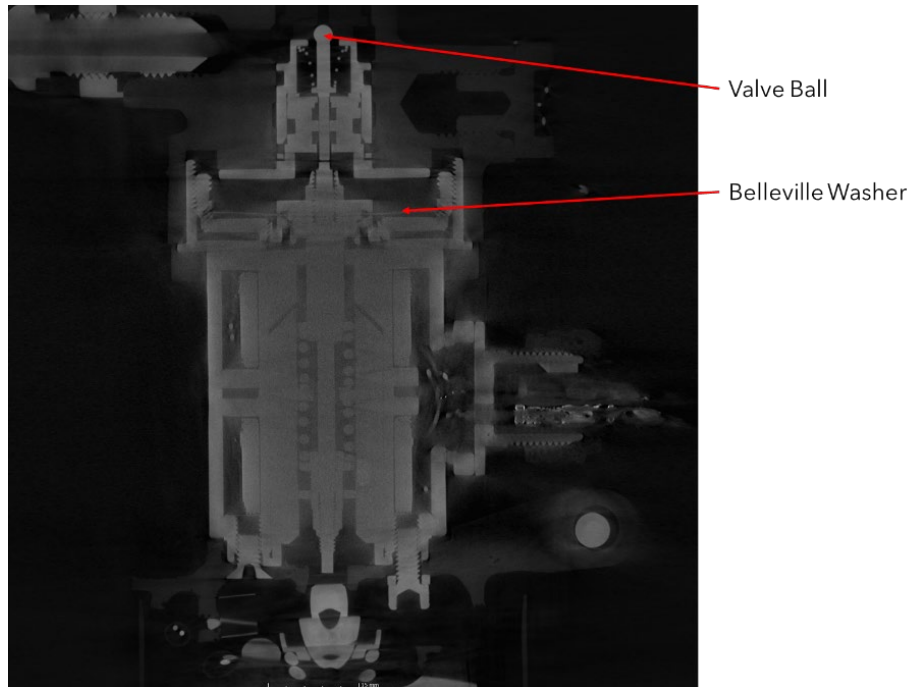


Photo 34- CT scan of the No. 1 Engine FSOV (Photo Courtesy of Honeywell)

4.0 No. 1 (Left) Engine, ESN P-54128, Materials Analysis

The 1st and 2nd stage turbine rotor blade airfoils were submitted to the Honeywell Materials Laboratory in Phoenix, Arizona for analysis.

The 1st stage turbine rotor blade that was found separated during the teardown examination was identified as Blade 1. Blade 1 separated approximately 0.38 inch from the platform as measured from the leading edge (**Photo 35**). The fracture surface had a rough oxidized appearance consistent with a stress rupture mechanism⁹.

A cross section of Blade 1 revealed oxidation and alloy depletion on the fracture surface. The microstructure near the fracture surface was consistent with exposure to temperatures near 1700°F (927°C) over a period of time between 10 and 100 hours¹⁰. There was evidence of sigma phase¹¹ along the coating/blade interface.

⁹ Stress rupture is the failure of material due to exposure to stress at elevated temperatures over an extended period that exceed material limits and eventually results in crack formation and failure.

¹⁰ Temperature exposure estimates are based on microstructure photographs compiled by Honeywell for the different materials/alloys used in the engine.

¹¹ The sigma phase in nickel alloys is a topologically closed-packed (TCP) phase that forms after extended temperature exposures. It is a tetragonal phase and is most often observed in iron-nickel and cobalt-based superalloys and has an irregular shaped globule appearance, often elongated.

There was no evidence of cyclic fatigue, material defects, or other anomalies identified near the fracture surface. Cross sections were also made through Blades 5 and 16. Grain boundary coarsening was observed at multiple locations. The leading edge cross section of Blade 16 exhibited a region of interconnected cracks and voids along the grain boundaries on the suction side of the blade. According to Honeywell, the microstructure observed along the thermal coating/blade interface, the grain boundary voids and cracks, and the coating cracks observed on Blade 1 are all consistent with stress rupture fracture mechanism (**Photo 36**). Energy dispersive X-ray (EDX) analysis confirmed that the blade material was consistent with IN-100 nickel alloy as specified on the part drawing. The IN-100 blade base material and the aluminum/silicon coating indicated that the Blade 1 part number was likely 3101512-10¹².

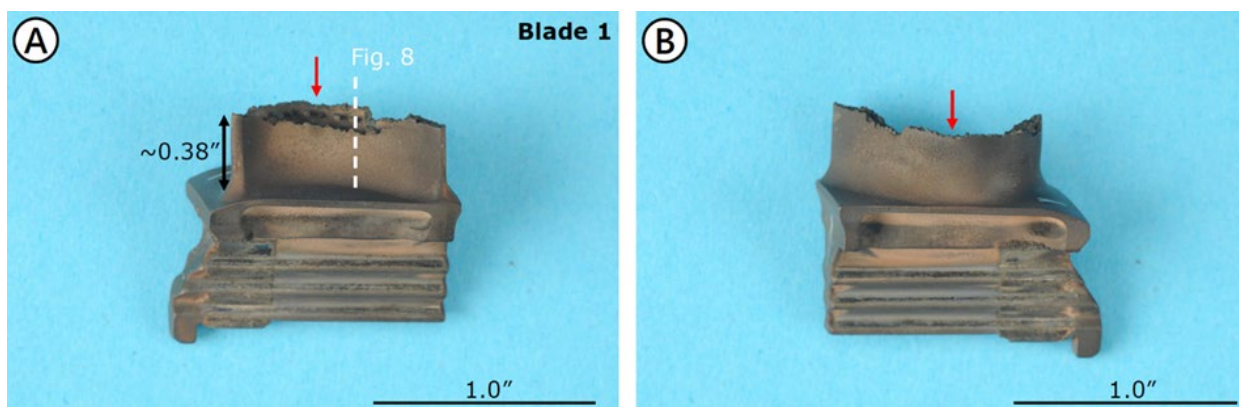


Photo 35- 1st Stage Turbine Rotor Blade, Found Separated During Teardown (Photos Courtesy of Honeywell)

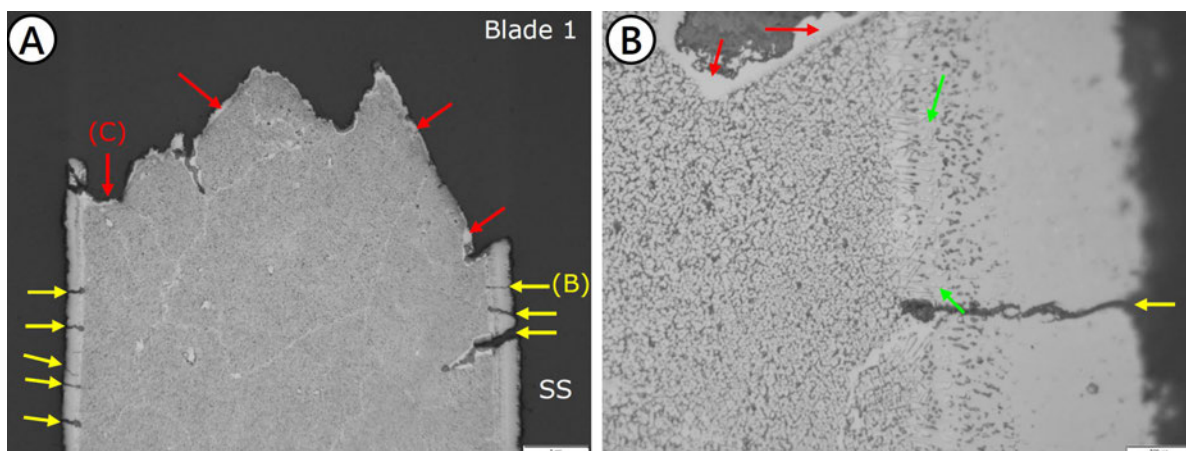


Photo 36- 1st Stage Turbine Blade Cross Section (L) Red Arrows- Alloy Depletion and Oxidation at Fracture Surface, Yellow Arrows- Blade Coating Cracks, Green Arrows- Sigma Phase Embrittlement Formation (Photos Courtesy of Honeywell)

¹² 1st stage turbine blade, part number 3101512-10 features a diffused aluminum and silicon coating. Silicon was added to the blade coating to improve hot gas corrosion resistance over previous blade part number iterations.

The 1st stage rotor blade erosion damage on the leading edge of blades 30, 35, and 36 penetrated through the surface, exposing the leading edge cooling holes. According to Honeywell, 1st stage rotor blade leading edge tip erosion has previously been attributed to carbon shedding¹³ from the combustor.

The 2nd stage rotor blades were submitted to the material laboratory for microstructure analysis to estimate the maximum temperature exposure. The microstructure analysis was consistent with temperatures near 2200°F (1204°C) over a period of time between 10 and 100 hours.

The NTSB Materials Laboratory reviewed the Honeywell Materials Laboratory report and concurred with the findings. The materials laboratory report is available in the investigation docket as "Attachment 3- Honeywell Materials Laboratory Report, Engine Serial Number, P54128."

5.0 No. 2 (Right) Engine, ESN P-54133, Teardown Examination

5.1 Visual Examination

The No. 2 engine was secured in a cardboard shipping box in the Honeywell Product Integrity Laboratory when the investigation team arrived (**Photos 37-40**). The external engine surfaces exhibited a combination of dark discoloration and ashy soot with areas of thermal damage consistent with exposure to a post-crash fire. Engine wires were thermally damaged and appeared charred and/or were missing material. There was a hole in the AGB case at the 5 o'clock position with evidence of melted magnesium around the hole circumference. The beta tube was broken at the propeller flange and remained in the engine. Resolidified molten metal was collected on the nose cone and inlet at the 6 and 12 o'clock positions (**Photo 41**). The engine was seized and could not be manually rotated at the propeller shaft or the 3rd stage turbine blades. The 1st stage impeller blades visible through the inlet were all present but one blade was bent opposite the direction of rotation at the leading edge. The 3rd stage turbine blades visible through the exhaust all appeared to be intact and in good condition.

¹³ Carbon shedding occurs when carbon accumulates near the fuel nozzles and on the combustion liner walls. When carbon pieces are liberated during engine operation, they enter the gaspath and contact downstream surfaces.



Photo 37- Engine Shipping Container, as Received at Honeywell

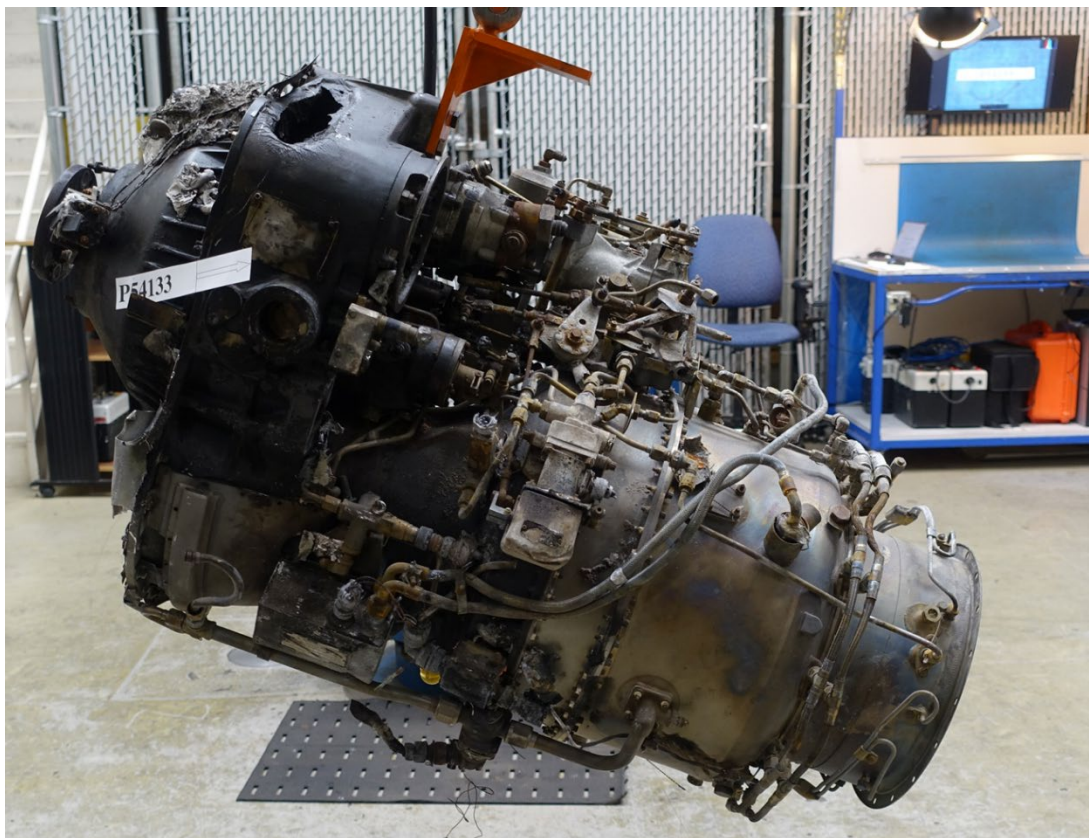


Photo 38- No. 2 Engine, Left Side, As Received (Upside Down Relative to Installed Orientation)



Photo 39- No. 2 Engine, Right Side, As Received (Upside Down Relative to Installed Orientation)



Photo 40- No. 2 Engine, ESN P-54133, Data Plate



Photo 41- (L) Nose Cone, Inlet, (R) AGB Case Hole

The fuel pump and FCU remained secured to the AGB mount and both components were thermally damaged and covered in soot. A portion of the aft side the FCU cover was thermally consumed (**Photo 42**). The FCU power lever linkage indicator dial was aligned with the 60 degree mark. All three PPC attachment mounts were broken and the PPC was pushed aft, away from the AGB. The PPC indicator dial was at the 24 degree mark (**Photo 43**). The aft propeller shaft thrust bearing was pushed out of the aft side of the gearbox. The propeller feather valve actuator end was pulled out. The propeller governor was intact with dark discoloration/sooting. After the governor was removed the mating face of the governor was discolored and the gasket was thermally damaged. The propeller governor check valve orifice was obstructed with dark carbon like debris. The FSOV was secured to the engine but exhibited thermal damage and case bulging. The input shaft scribe was pointed toward the 3 o'clock position (manually closed) (**Photo 44**). A low pressure air check was performed air did not pass through the valve, indicating it was in the closed position.

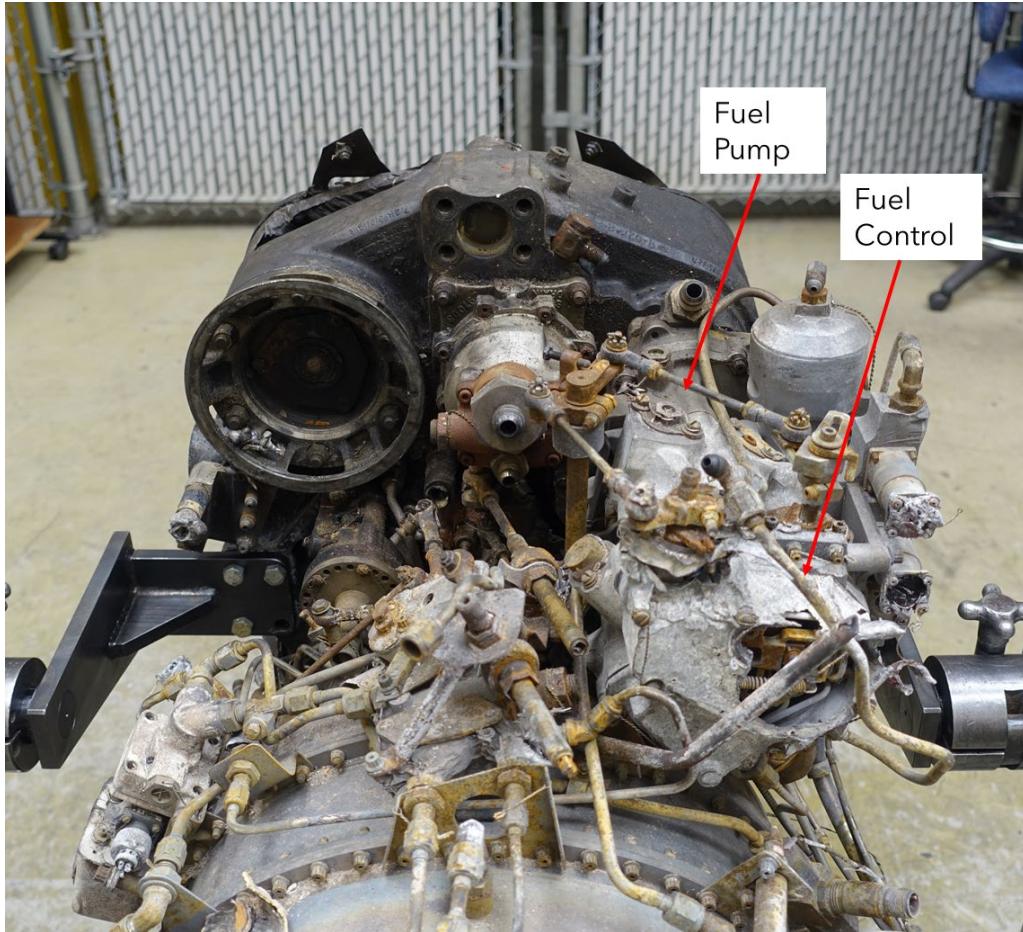


Photo 42- Fuel Pump and Fuel Control Unit

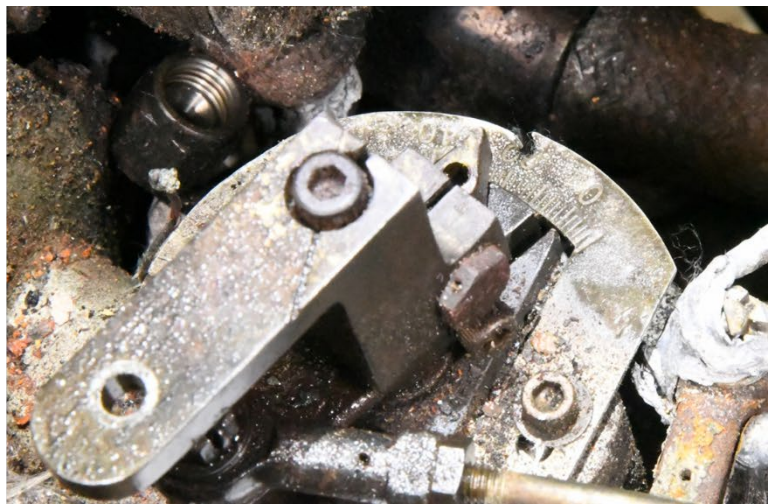


Photo 43- (L) Fuel Control Unit Power Lever Linkage Dial Indicator, (R) Propeller Pitch Control Dial Indicator.



Photo 44- (L) Fuel Shutoff Valve, (R) Input Shaft Scribe

The MCD plug was partially consumed. The MCD was removed from the gearbox and was free of “fuzz” or debris accumulation (**Photo 45**). The oil filter and filter bowl were both dry and discolored and there was no evidence of debris or other obstructions in the filter pleats. The fuel filter and filter bowl were also dry and discolored and free of debris.



Photo 45- (L) Magnetic Chip Detector Plug

5.2 Nose Cone Assembly and Accessory Gearbox

The AGB case and inlet were intact but exhibited discoloration and sooting. All seven forward propeller shaft bearing mount bolts were missing¹⁴. There

¹⁴ The propeller shaft bearing mount bolts were removed during removal of the airplane inlet.

was no residual oil in the nose cone or AGB case and the internal surfaces appeared discolored, consistent with high temperature due to fire exposure. The propeller shaft had a 360 degree circumferential rub at the forward radius, immediately aft of the forward retaining nut (**Photo 46**). The ring gear was intact and undamaged.

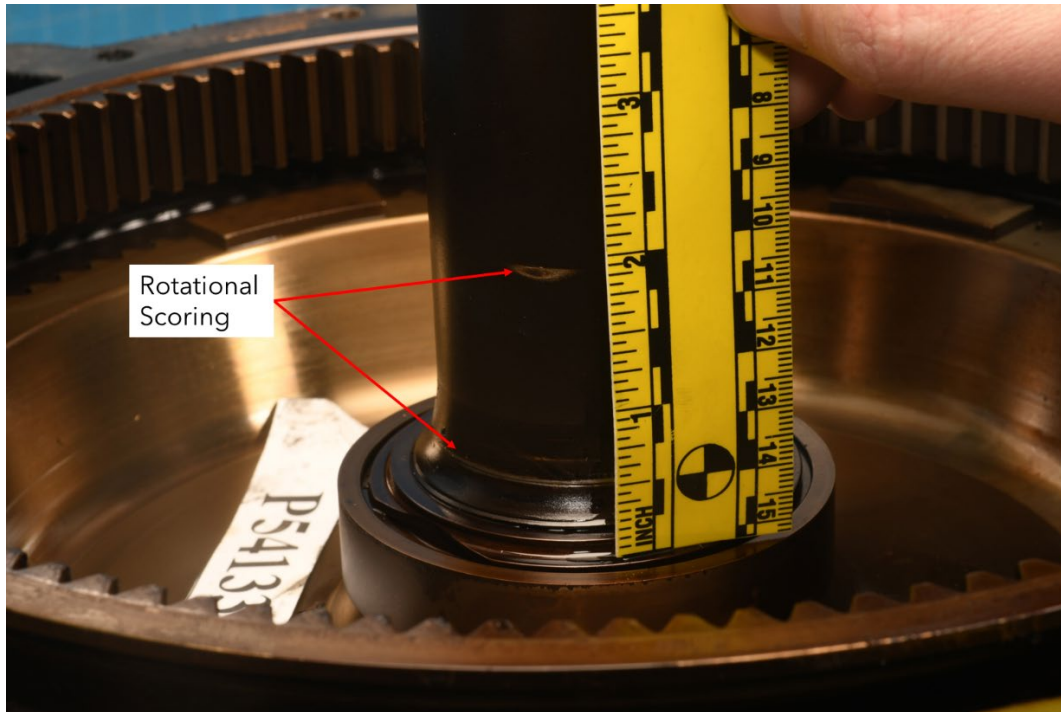


Photo 46- Nose Cone and Propeller Shaft, Rotational Scoring

The high speed pinion coupling shaft aft spline was broken and remained in the torque shaft when the shaft was removed. The negative torque sensing (NTS) quill shaft was intact and undamaged (**Photo 47**). The diaphragm was removed, and all diaphragm and AGB components were darkly discolored with no residual oil (**Photo 48**). The sun gear, bull gear, and associated accessory gears were intact, properly mated, and could be rotated by hand (**Photo 49**). Impact marks were observed on the AGB case feather valve bore and the torque sensor housing with coincident impact marks on the aft sun gear retaining nut. The torque sensor gears rotated and did not exhibit indications of pre-impact damage.



Photo 47- High Speed Pinion Power Coupling Shaft and NTS Quill Shaft



Photo 48- Diaphragm Assembly

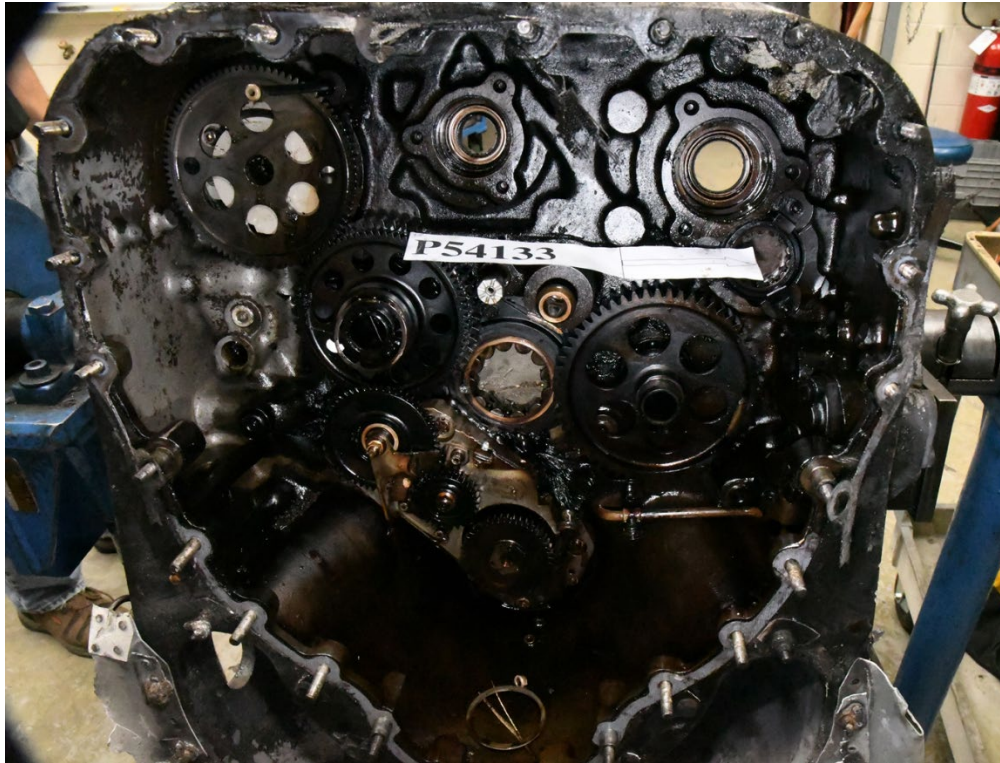


Photo 49- AGB Case

5.3 Turbine Section

The rear (turbine) bearing support was intact. The turbine bearing was oil wetted and rotated smoothly. The 1st stage turbine stator was missing part of one vane at the 9 o'clock position from the midspan to the inner diameter platform (**Photo 50**). Several vanes had small cracks midspan on the leading edge. One vane at the 10 o'clock position at trailing edge was deformed. The 1st stage turbine shroud had sand debris accumulated at the 12 o'clock position. The shroud had light localized scoring at the 10 o'clock position, coincident with the 1st stage turbine blade mid-chord. All the 1st stage turbine blades were missing material at the leading edge tip and the surface appeared smooth and rolled over (**Photos 51 and 52**).

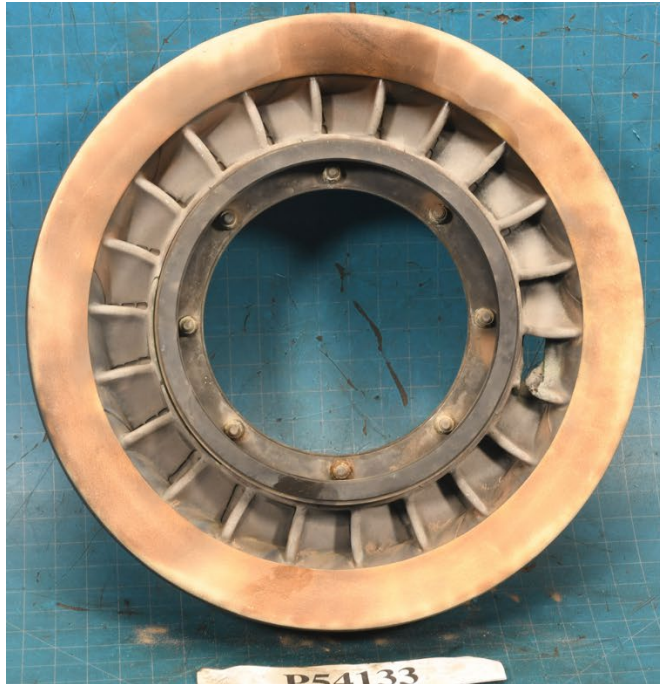


Photo 50- 1st Stage Turbine Stator, (L) Pressure Side, (R) Suction Side



Photo 51- 1st Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge

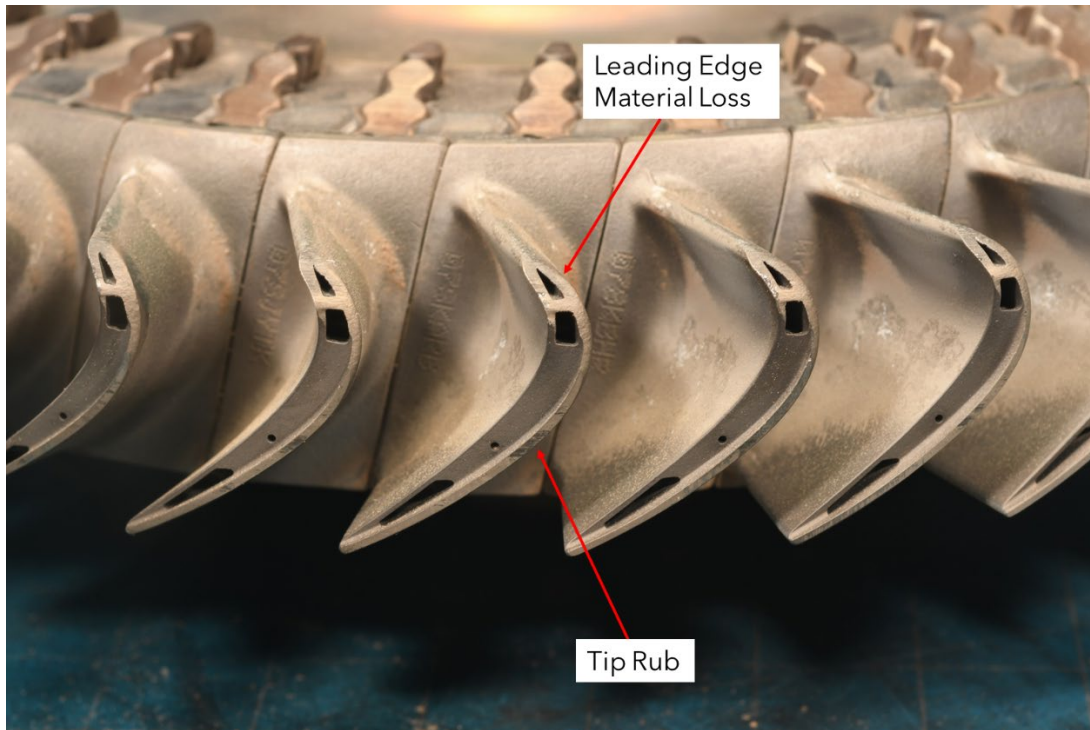


Photo 52- 1st Stage Turbine Rotor Blade Tips, Leading Edge Erosion

The 2nd stage stator vanes were all complete (Photo 53). One vane had small trailing edge cracks at the quarter span and near the inner diameter platform. The 2nd stage turbine shroud had light localized scoring at locations coincident with the 2nd stage turbine blade mid-chord. The 2nd stage turbine rotor blades were all intact and complete (Photo 54). The blades tips exhibited light tip rub from the mid-chord to the trailing edge 360 degrees around the rotor.

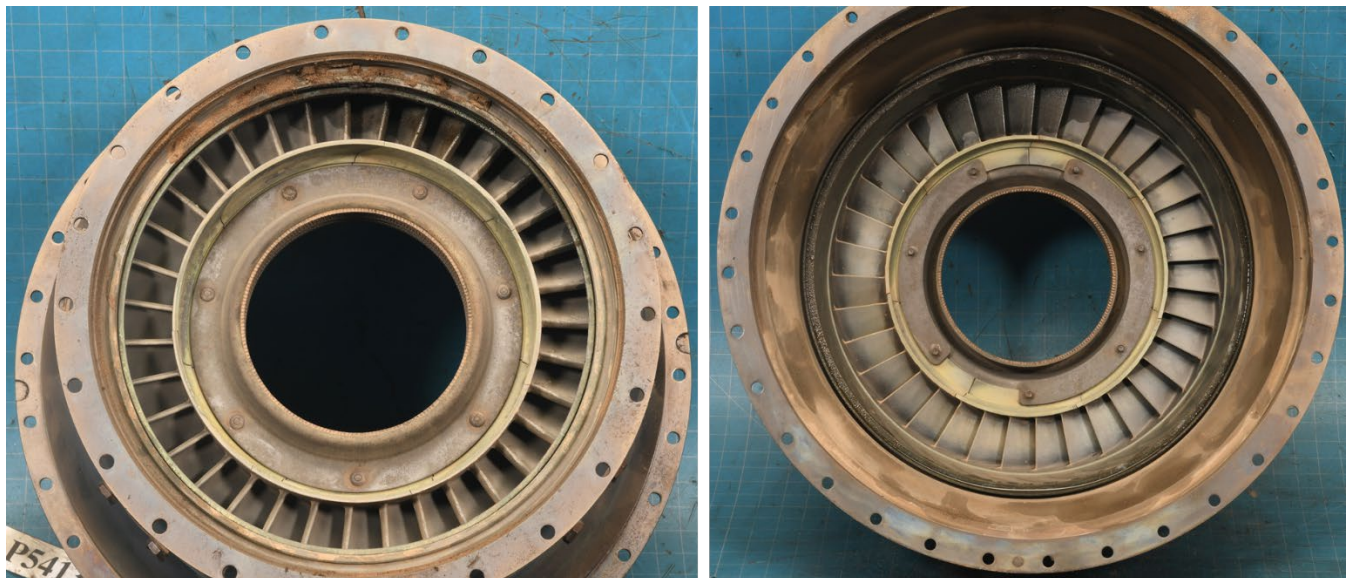


Photo 53- 2nd Stage Turbine Stator, (L) Pressure Side, (R) Suction Side



Photo 54- 2nd Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge

The 3rd stage turbine stator was intact and all vanes were undamaged (Photo 55). The 3rd stage turbine shroud had light leading edge rub from the 4 to 7 o'clock positions. The 3rd stage turbine blades were intact and undamaged (Photo 56).



Photo 55- 3rd Stage Turbine Stator, (L) Pressure Side, (R) Suction Side

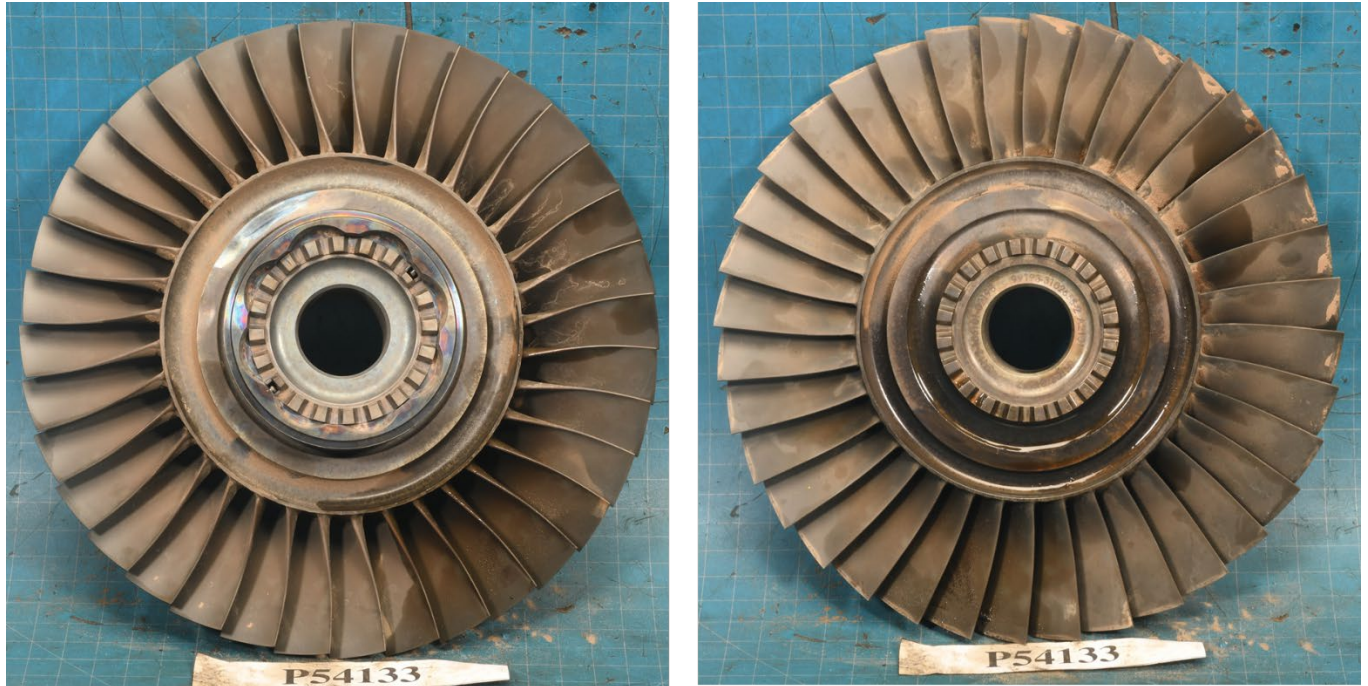


Photo 56- 3rd Stage Turbine Rotor, (L) Leading Edge, (R) Trailing Edge

The curvic couplings of all three turbine stages were in good condition and the contact marks showed nominal assembly. Fine sand debris coated all vane and blades surfaces.

5.4 Combustor

The combustion liner was intact and had no indications of fuel nozzle streaking (**Photo 57**). All the fuel nozzles were properly seated. The thermal barrier coating was eroded on the liner wall skirt adjacent to the fuel nozzle at the 2 o'clock position. The primary and secondary fuel manifold was thermally damaged, but all nozzle connections remained intact. The outer transition liner had localized thermal barrier coating missing at three locations. Sand was collected in the combustor, most notably in the outer transition liner (**Photo 58**). There was no metal spray visible on the combustion liner walls.



Photo 57- (L) Combustion Liner, (R) Fuel Nozzles

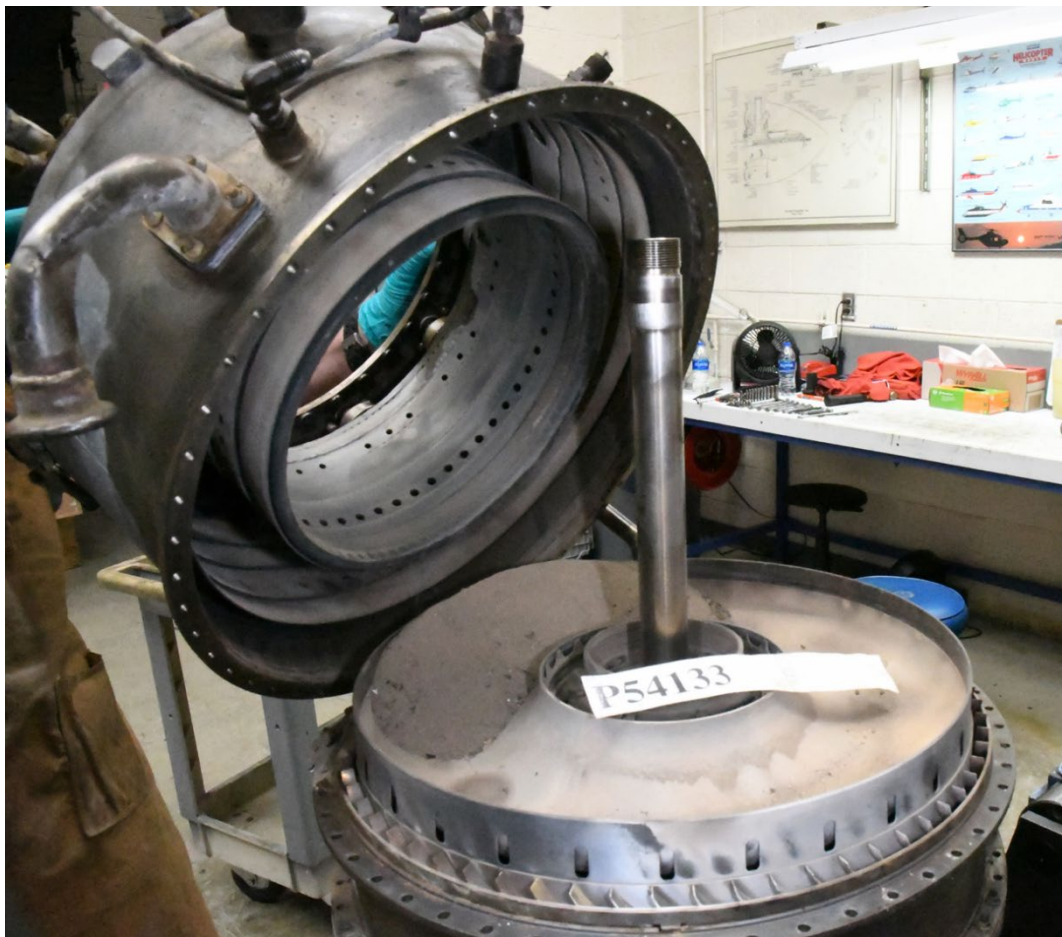


Photo 58- Outer Transition Liner

5.5 Compressor Section

The 1st stage compressor impeller was intact but exhibited thermal discoloration. One impeller blade tip was bent opposite the direction of rotation (**Photo 59**). There was light 360 degree rotational scoring on the hub forward of the aft curvic coupling. The 1st stage impeller shroud had 360-degree rotational scoring at the exducer (**Photo 60**). The 1st stage impeller, shroud and the 1st stage diffuser vanes were coated in a layer of fine sand.

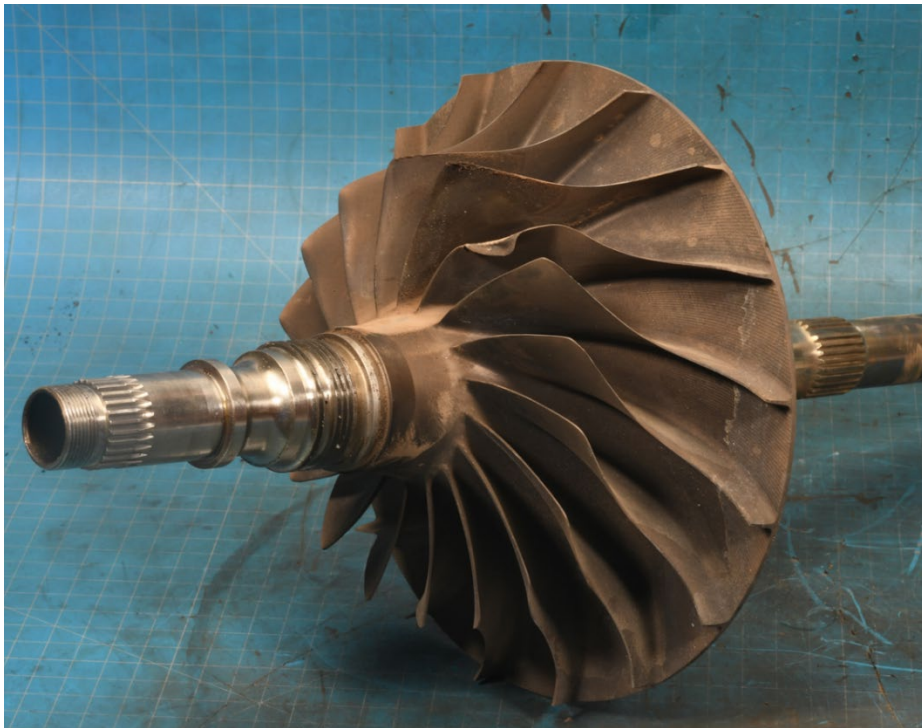


Photo 59- 1st Stage Compressor Impeller

Rotational
Scoring,
Exducer



Photo 60- 1st Stage Impeller Shroud, Rotational Scoring

The 2nd stage compressor impeller blades were all complete (**Photo 61**). The impeller blades tips had tip rub from the inducer to the knee and at the exducer. The impeller had 360 degree rotational scoring on the hub aft of the forward curvic (**Photo 62**). The main shaft was intact and did not appear bent/deformed. The 2nd stage impeller shroud had 360 degree rotational scoring at the exducer and light rotational scoring from the inducer to the knee (**Photo 63**).

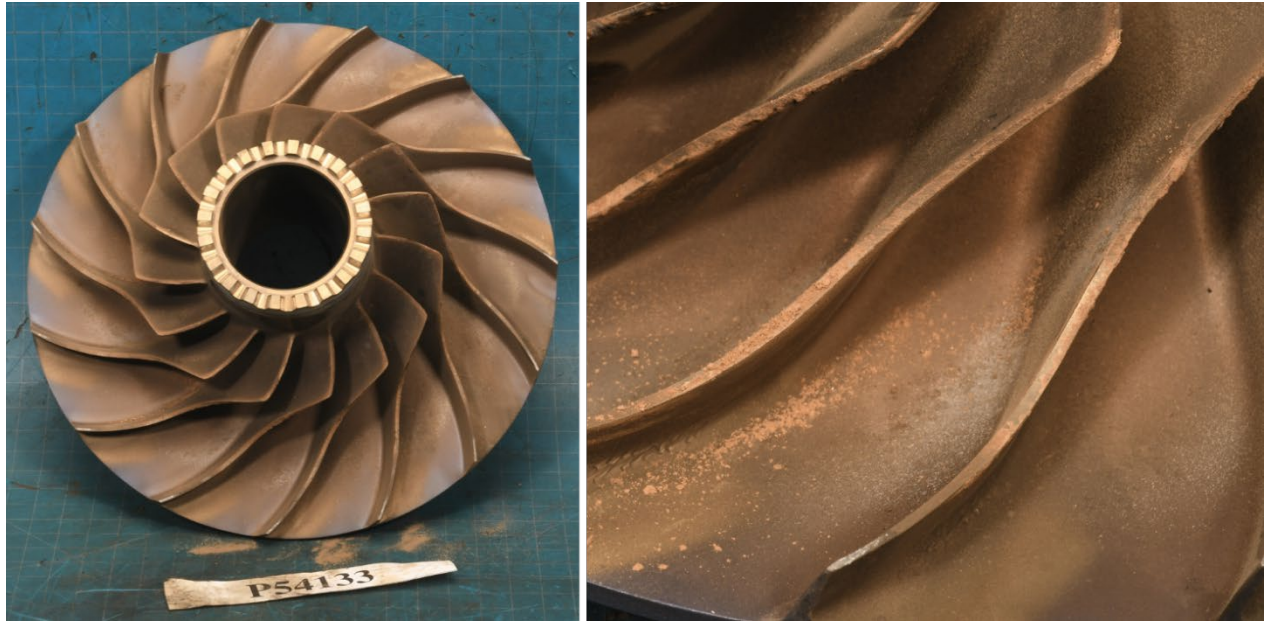


Photo 61- (L) 2nd Stage Compressor Impeller, (R) Impeller Blade Tip Rub



Photo 62- 2nd Stage Compressor Impeller Hub Rotational Scoring



Photo 63- 2nd Stage Compressor Impeller Shroud

6.0 No. 2 (Right) Engine, ESN P54133, Component Testing

6.1 Fuel Control Unit

The FCU was shipped Woodward in Loves Park, Illinois for a group examination with party members from Woodward, Honeywell, and the NTSB; the exam was conducted between August 22-25, 2022. According to the engine logbook, the FCU serial number was 905139; however, the data plate on the FCU was missing or consumed during the post-crash fire. The FCU housing case number was 1379, which matched Woodward shipping records for serial number 905139, when the unit was originally shipped in February 1969.

All external surfaces were discolored and covered in soot. A section of the FCU cover was melted and missing, exposing the internal mechanical linkages. The FCU housing was fractured next to the Pt2 (inlet total pressure) bellows assembly (**Photo 64**). The FCU driveshaft could not be rotated by hand but turned with resistance when a mating drive spline tool was used. The FCU could not be bench tested due to thermal and mechanical damage. The FCU was fully disassembled, and internal components all exhibited thermal damage but there was no evidence of pre-impact failure. The Woodward shop report is available in the investigation docket as "Attachment 4- Woodward Fuel Control Unit, Serial Number 905139, Investigation Report."



Photo 64- FCU, as Received at Woodward

6.2 Propeller Governor

Propeller governor, serial number, 1746090, was shipped to Woodard in Loves Park, Illinois for a group examination with party members from Woodward, Honeywell, and the NTSB; the exam was conducted between August 22-25, 2022.

The propeller governor external surfaces were all discolored and covered with soot and charred debris (**Photo 65**). The governor was run on the test bench in the as received condition and findings were like what was observed on the No. 1 engine propeller governor. There was significant leakage from the governor baseplate during initial startup. The baseplate packing was replaced but leakage was again observed from the governor housing and baseplate and operating pressure were below normal levels. As received testing was completed with the leak and low pressure readings and multiple test points were out of limits. The bypass valve was replaced with an engineering spare relief valve assembly and the test procedure was run again. After bypass valve replacement, test points were within the expected range of similar service run units according to Woodward. The propeller governor was fully disassembled, and internal components exhibited discoloration and thermal damage consistent with post-crash fire exposure. The relief valve assembly spring had also taken a set similar to what was observed on the No. 1 engine relief valve assembly. The Woodward shop report and test run sheet are available in the

investigation docket as "Attachment 5- Woodward Propeller Governor, Serial Number 746090, Investigation Report and Test Run Sheet."

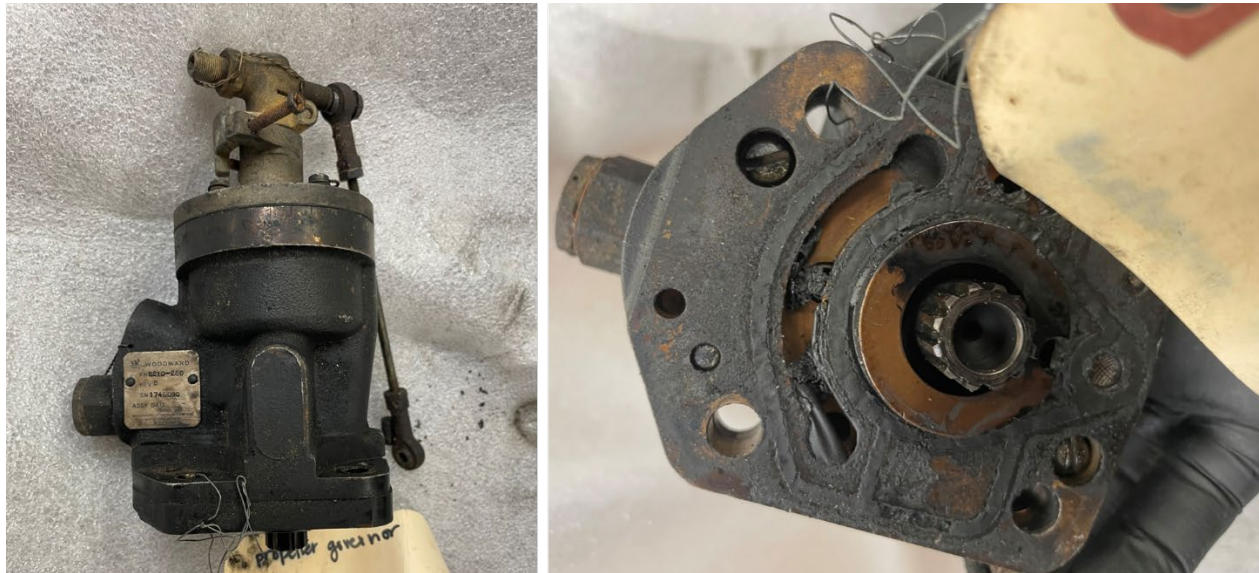


Photo 65- Propeller Governor, as Received at Woodward

6.3 Fuel Nozzles

The fuel nozzles were flow tested at Honeywell in Phoenix, Arizona on April 14, 2022, under oversight by a Federal Aviation Administration representative. Fuel nozzle 6 was cracked at the primary fitting, so nozzle No. 1 was taken from the No. 1 engine set to complete the primary flow circuit test. The primary flow circuit test was performed at a pressure setting of 100 psi in accordance with the overhaul manual procedure, resulting in a fuel flow of 48 pph. Various degrees of fuel streaking were observed on fuel nozzles Nos. 1, 3, 4, 5, 7, 9, and 10. The flow observations for the remaining nozzles was recorded "ok". The secondary flow circuit test was then performed at 100 psi resulting in a fuel flow of 313 pph. Fuel nozzles 2 and 4 were broken at the nozzle body. No fuel flow was observed from nozzle 4. The flow observations from the remaining nozzles were recorded "ok."

6.4 Fuel Shutoff Valve

The No. 2 engine FSOV was CT scanned at Honeywell in Phoenix, Arizona and video files of the CT scans were provided to the NTSB for review. The CT scan showed the FSOV was in the closed position with the Belleville washer deflected towards the valve seat, consistent with the low pressure test findings during the teardown examination. There were no internal anomalies identified during the FSOV CT scan review (**Photo 66**).

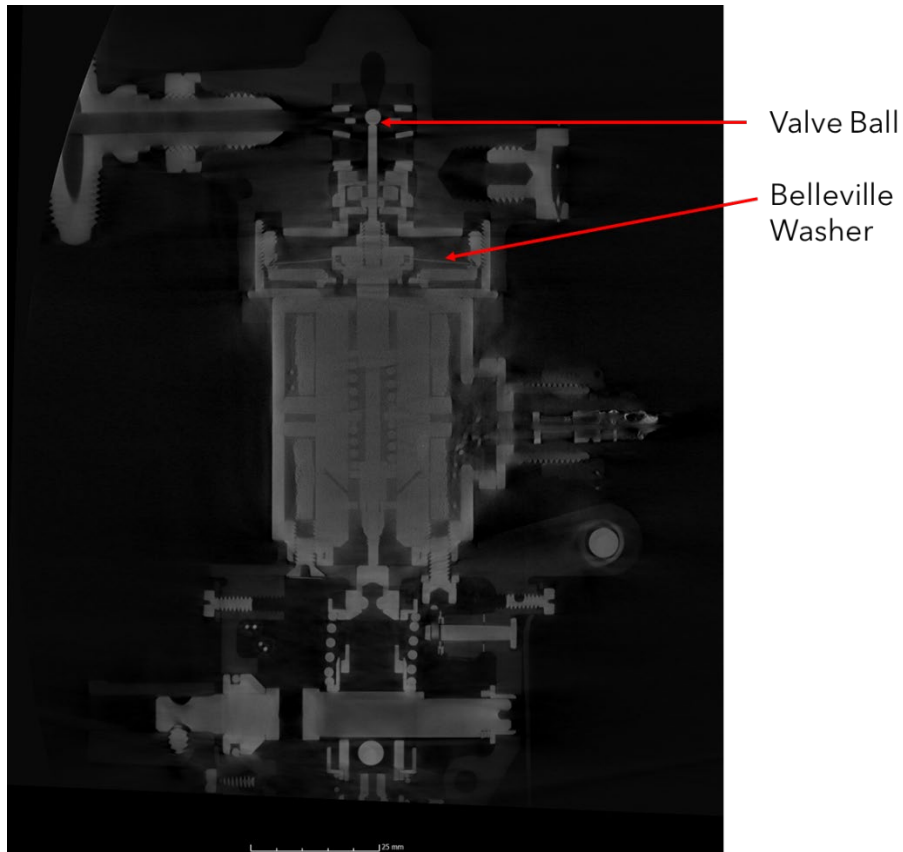


Photo 66- FSOV CT Scan

7.0 No. 2 (Right) Engine, ESN P-54133 Materials Analysis

The No. 2 engine high speed coupling shaft was submitted to the Honeywell Materials Laboratory in Phoenix, Arizona for fracture analysis. The lab concluded that the fracture surface was consistent with torsional overload (**Photo 67**). EDX analysis confirmed that the high speed coupling shaft was consistent with H11 tool steel as specified in the part drawing. The materials laboratory report is available in the docket as "Attachment 6- Honeywell Materials Laboratory Report, Engine Serial Number P54133."

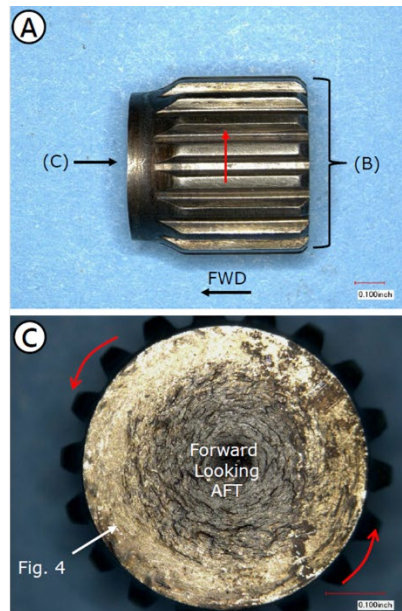
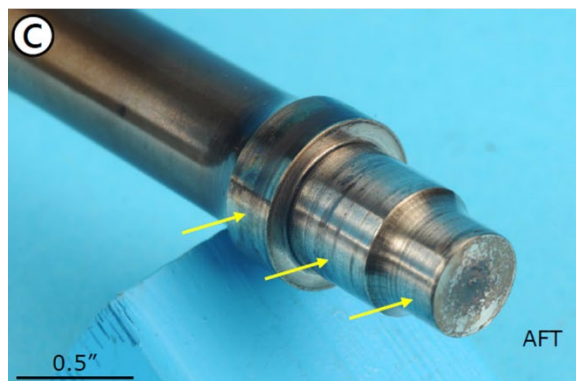


Photo 67- High Speed Coupling Shaft Fracture (Photos Courtesy of Honeywell)

Submitted by:

Robert Hunsberger
Aerospace Engineer- Powerplants