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Office of Aviation Safety

Washington, DC 20594



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POWERPLANTS

Group Chair's Factual Report

July 7, 2025

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TABEL OF ACRONYMS

°C	Degrees in Celsius	MSL	Mean Sea Level
°F	Degrees in Fahrenheit	MTS	Maintenance Terminal Software
AGL	Above Ground Level	NG/N1	Gas Producer Speed in %
ALF	Aft Looking Forward	NGT	gas generator temperature
CFR	Code of Federal Regulations	NP	Power Turbine Speed in %
CSL	Commercial Service Letter	NR	Main Rotor Speed in %
CSN	Cycle Since New	NTSB	National Transportation Safety Board
CSO	Cycle Since Overhaul	NVG	Night Vision Goggles
DC	Direct Current	P1	Ambient Pressure
ECU	Engine Control Unit	PLA	Power Lever Angle
EDS	Energy Dispersive X-ray Spectroscopy	PMA	Part Manufacturing Approval
EEPROM	Electrically Erasable Programmable Read Only Memory	PN	Part Number
FAA	Federal Aviation Administration	PT	Power Turbine
FADEC	Full-Authority Digital Electronic Control	Q	Engine Torque
GP	Gas Producer	rpm	revolutions per minute
GPT	gas producer turbine	RR	Rolls-Royce Corporation
HMU	Hydromechanical Unit	SEM	Scanning Electron Microscopy
HTS	High Thermal Stability	SHP	shaft horsepower
In Hg	Inches of Mercury	SN	Serial Number
in.	Inch/inches	TCDS	Type Certificate Data Sheet
lbs.	pounds	TSLSV	Time Since Last Shop Visit
MGT	Measured Gas Turbine Temperature	TSN	Time Since New
MIL-PRF	Military Performance	TSO	Time Since Overhaul

A ACCIDENT

Location: Raft River, Idaho
Date: August 2, 2024
Time: 21:10 Local Time (Mountain Daylight Time)
Helicopter: Bell 407, Registration Number N20BH

B POWERPLANTS GROUP

Group Chair	Jean-Pierre Scarfo National Transportation Safety Board Washington DC
Group Member	Jack Johnson Rolls-Royce Air Safety Investigator Indianapolis, Indiana
Group Member	Jeff McDermott Brainerd Helicopters - Owner Jefferson, Wisconsin
Group Member	Jason Hunt Brainerd Helicopters - Director of Maintenance Brainerd, Minnesota

C SUMMARY

On August 2, 2024, at 21:10 Mountain Daylight Time, a Chemair helicopters Inc. Bell 407 helicopter, powered by one Rolls-Royce Corporation model M250-C47B turboshaft engine, experienced an engine failure while enroute transporting persons from Gerlach, Nevada, to the helicopter's base at Pocatello, Idaho, with intermediate stops at Winnemucca, and Elko, Nevada. The pilot reported that the first two legs were uneventful, and that the accident occurred on the final leg.

About 55 minutes after departure from Elko, the pilot observed the barrier inlet air filter light starting to flicker. The filter had been changed the week prior, so he thought such an activation was premature. The light then transitioned from flickering to ON, and the pilot activated the filter bypass system, by pressing the "FILTER" light switch. Due to arrival time restraints, the crew then discussed the option of diverting to land in Burley, Idaho for the night but ultimately decided to continue to Pocatello, and a few minutes later the pilot stated that he noticed the engine measured gas temperature gauge on his instrument panel started to show a rise into the yellow (caution) band. In response, the pilot stated that he reduced power and began to

descend; however, the measured gas temperature continued to rise, and at an altitude between 1,000 and 1,500 feet above ground level, it went past the gauge redline of 779°C and continued rising. The pilot decided to make a precautionary power-on landing and began looking for a suitable landing area. As he was maneuvering the helicopter towards a grass field, the engine began to indicate an overspeed condition. The pilot raised the collective control twice to try to arrest the overspeed, but the engine did not respond so he decided to commit to a full down autorotation into an adjacent corn field. Due to the unknown height of the corn, the pilot was unable to judge the best time to initiate the final pitch pull, and the helicopter landed hard after dropping from about five feet. The main rotor transmission assembly separated from the helicopter during the ground impact and dropped down into the cabin compartment.

All occupants were able to egress by themselves. The pilot sustained serious injuries, and the three passenger's sustained minor injuries. At the time of the accident, the helicopter was operated as a Title 14 *Code of Federal Regulations (CFR)* as a public aircraft.

The accident helicopter was recovered and transported to a salvage facility for initial examination and storage; NTSB did not travel for the initial on-scene examination of the airframe and engine nor for the follow-on examination at the salvage facility. Persons from the FAA and Rolls-Royce provide an initial assessment of the airframe and engine. Looking through the engine inlet, all the impeller inducer blades exhibited hard body impact damage, tears/rips, missing material, and distortion while the exducer blades exhibited shiny contact wear consistent with contact with the compressor shroud housing. The engine exhaust duct, which is an airframe supplied part and is mounted to the engine exhaust collector support, was pot-marked outwards while the engine's exhaust collector support was pot-marked outwards and exhibited a large exit penetration through-hole. Both the right and left compressor discharge tubes exhibited exit penetration holes. The horizontal firewall shield assembly exhibited a hole at the bottom of the shield near the drain port; the shield did not exhibit any signs of thermal distress or fire damage. The engine's right compressor discharge tube was pot-marked outwards and exhibited a small exit penetration through-hole. Looking through the exit hole in the exhaust collector support, the stage 4 turbine wheel was observed, and all the blades were fractured transversely across the platform.

The engine was shipped to the Rolls-Royce facility in Indianapolis, Indiana for examination and disassembly by the Powerplant Group lead by the NTSB. The freewheeling clutch (an airframe supplied component) was removed, and it rotated smoothly in both directions, and the clutch mechanism was engaged correctly consistent with a properly functioning freewheeling clutch. Turning of the compressor by hand, the gas producer turbine did not rotate along with it; however, the accessory gearbox did, thus continuity was confirmed between the compressor and accessory

gearbox but not with the gas producer turbine. The gas producer had decoupled from the compressor.

The tie bolt, which secures the gas producer stages 1 and 2 wheels together, was found fractured as was the turbine-to-compressor coupling shaft that connects the gas producer turbine to the accessory gearbox. The No. 6 roller bearing inner race and PT coupling shaft, which connects to the power turbine-to-pinion gear shaft, was also fractured. The turbine shaft-to-pinion gear coupling was fractured and no longer coupled to the inside spur teeth of the helical gear but remained seized within the helical gear bore. All the blades on stages 1, 2, and 3 turbine wheels were present and fractured transversely across the airfoil; the stage 4 turbine wheel blades were fractured at the platform. In general, both the gas producer and power turbine exhibited extensive rotational damage throughout consistent with stationary and rotating parts/components circumferential and longitudinally contacting one another.

Gas producer turbine and power turbine parts were submitted to the Roll-Royce material engineering department in Indianapolis, Indiana for further destructive analysis. Parts were subjected to combination of visual binocular examination and backscattered electron scanning electron microscopy (SEM) imaging to study the fracture features (fractography) and energy dispersive X-ray spectroscopy to identify the material composition of the part. No parts were found with any pre-existing anomalies or fatigue fractures; Rolls-Royce considered the damage to the turbine section as secondary damage following loss of axial and radial control of the components during the crash sequence.

D DETAILS OF THE INVESTIGATION

1.0 General Engine Information

1.1 Engine Description

The Rolls-Royce Corporation (RR)¹, model 250 series turboshaft engine is a reverse-flow internal combustion gas turbine engine featuring a free power turbine (**FIGURES 1** and **2** and **PHOTOS 1** and **2**). The gas generator (sometime referred to as the gas producer (GP)) is composed of a single-stage, single entry centrifugal flow compressor directly coupled to a two-stage gas producer turbine (GPT). The power turbine (PT) is a two-stage free turbine, which is gas coupled to the GPT. The engine has an accessory gearbox which incorporates a gas producer gear train and a power turbine gear train with an integral reduction gearbox that has a front and rear drive flanges to mate with the aircraft drives. The engine has a single combustion chamber with a single ignition. The output shaft center line is located below the center line of the engine rotor, and the single exhaust outlet is directed upward. The engine incorporates a Full-Authority Digital Electronic Control (FADEC) system. The engine is comprised of four major assemblies as follows: compressor assembly, combustion assembly, turbine assembly, and accessory gearbox assembly. The cold section of the engine consists of the compressor and accessory gearbox assemblies while the hot section of the engine consists of the combustion and turbine assemblies.

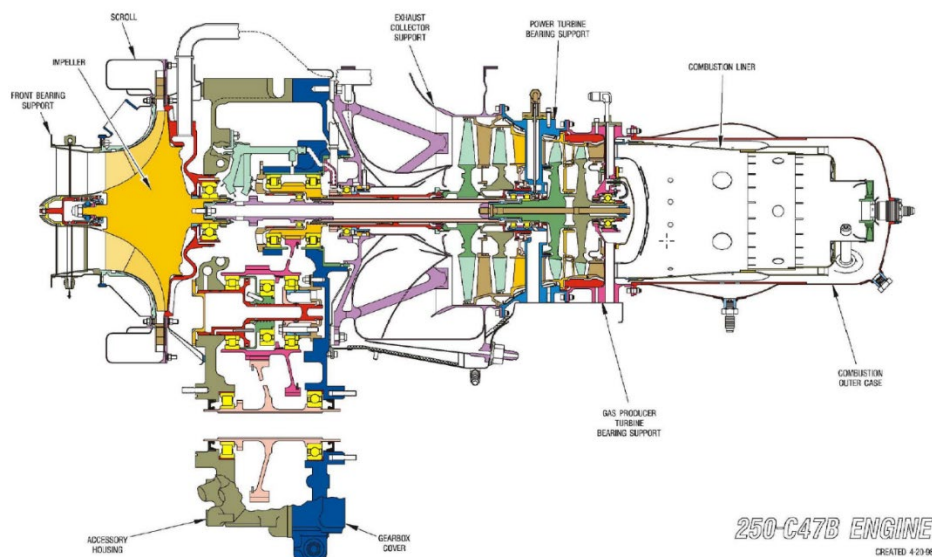


FIGURE 1: ROLLS-ROYCE MODEL 250-C47B CROSS-SECTION

Figure Courtesy of Rolls-Royce

¹ Rolls-Royce Corporation originally was Detroit Diesel Allison and subsequently Allison Gas Turbine Division and Allison Engine Company before Rolls-Royce took over the type certificate for the model 250 in September 2000.

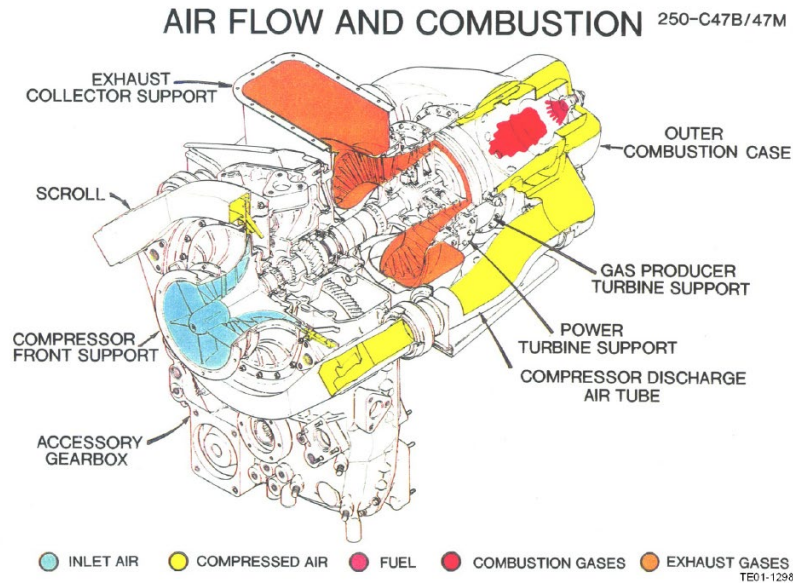


FIGURE 2: ROLLS-ROYCE MODEL 250-C47 Air Flow

Figure Courtesy of Rolls-Royce

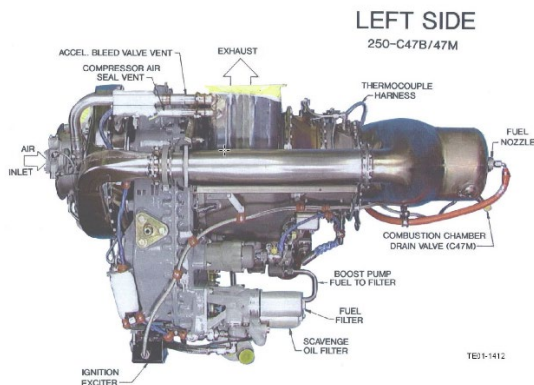


PHOTO 1: LEFT SIDE OF EXEMPLAR 250-C47B

Photo Courtesy of Rolls-Royce

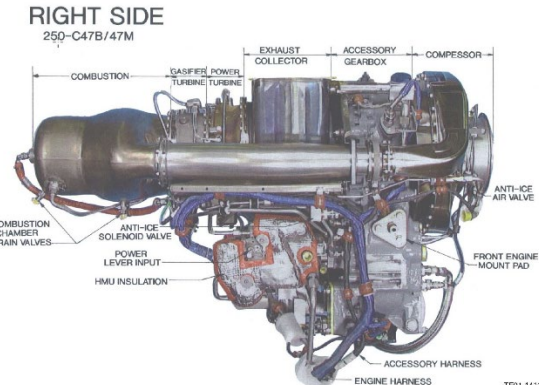


PHOTO 2: RIGHT SIDE OF EXEMPLAR 250-C47B

Photo Courtesy of Rolls-Royce

According to the engine's FAA Type Certificate Data Sheet (TCDS) E1GL, Revision 32, dated November 1, 2019, the RR model 250-C47B turboshaft was issued a FAA type certificate on January 19, 1996. Its principal dimensions are as follows: length 43.198 inches (in.), width 21.996 inches, and height of 25.130 inches with a dry weight of 278.5 pounds (lbs.). The engine has a maximum takeoff (5 minutes) at sea level static shaft horsepower (SHP) rating of 650 lbs.at an estimated gas producer speed (revolutions per minute (rpm)) of 48,863 rpm and output shaft speed of 6,317 rpm². For maximum continuous, the engine has a seal level static SHP rating of 600

² The engine ratings, unless otherwise specified elsewhere, are based on static sea level standard conditions. Compressor inlet air (dry) 59°F, 29.92 in Hg (inches of mercury). Compressor inlet bell attached (250-C28, -C28C, -C30, -C40 and -C47 Series) to provide suitable air approach conditions. No external accessory loads, anti-ice and no bleed air offtake. Measured rated gas temperature is indicated by the average of the 4 gas temperature thermocouples.

lbs. at an estimated gas producer speed of 48,258 rpm and output shaft speed of 6,317 rpm. The maximum transient (up to 15 seconds) and maximum sustained output shaft speed is 113.3% (7,159 rpm) and 102.1% (6,449 rpm) respectively. The maximum transient (up to 10 seconds) and maximum sustained gas producer speed is 106.5% and 105%, respectively. 100% speed for the output shaft is 6,317 rpm and for the gas producer is 51,000rpm. The engine does produce some amount of thrust from the exhaust gases.

All directional references to front and rear; right and left; top and bottom; and clockwise and counterclockwise are made aft looking forward (ALF) as is the convention. All numbering is in the circumferential direction starting with the No. 1 position at the 12:00 o'clock position or immediately clockwise from the 12:00 o'clock position and progressing sequentially clockwise ALF. The front of the engine is the compressor end, the rear is the combustion section, top is where the exhaust gases exit, and the bottom is where the scavenge oil outlet fitting and burner drain plug are located. The gas producer turbine and power turbine rotors rotate in a clockwise direction ALF.

1.2 Turbine Section Description

The turbine section of the engine incorporates a two-stage GPT and a two-stage PT. Power to drive the compressor rotor and gas producer gear train is provided by the GPT rotor while the PT rotor drives the PT gear train and the helicopter rotor system. The two turbine rotor assemblies are not mechanically coupled, but they are gas coupled (See **FIGURE 3**).

The GPT rotor consists of the stage 1 and stage 2 wheels, tie bolt, and tie bolt nut (**FIGURE 4**). Both wheels are investment castings of stainless steel, and the blades are cast integral with the wheels. The stage 1 wheel has a bearing shaft which extends rearward and is supported by the No. 8 ball bearing (thrust bearing). The front of the stage 1 wheel has face-type (curvic coupling) splines which mate with similar splines on the rear face of the stage 2 wheel. The No. 7 roller bearing, housed in the power turbine support, provides radial support for the forward end of the GPT rotor (**FIGURE 5**).

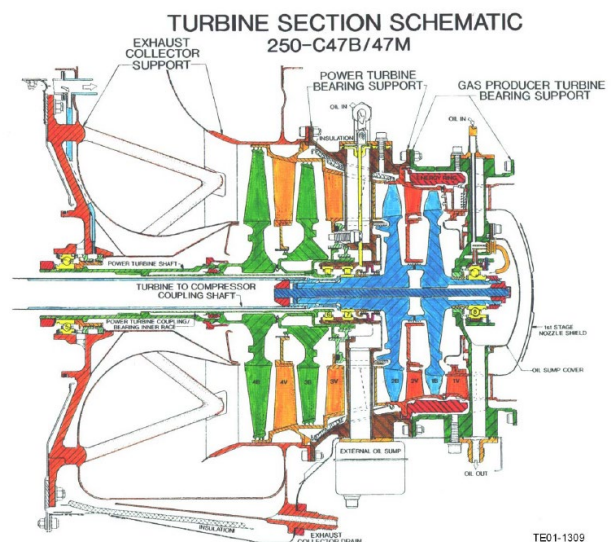


FIGURE 3: TURBINE SECTION SCHEMATIC

Figure Courtesy of Rolls-Royce

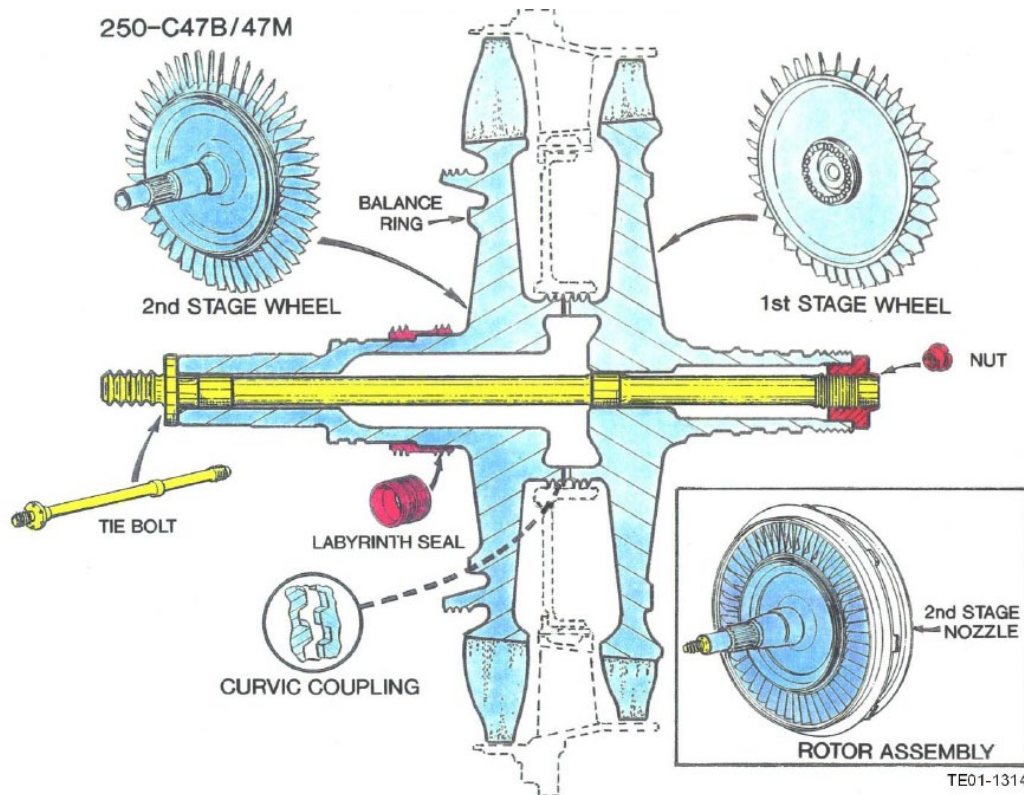


FIGURE 4: GPT ROTOR SCHEMATIC

Figure Courtesy of Rolls-Royce

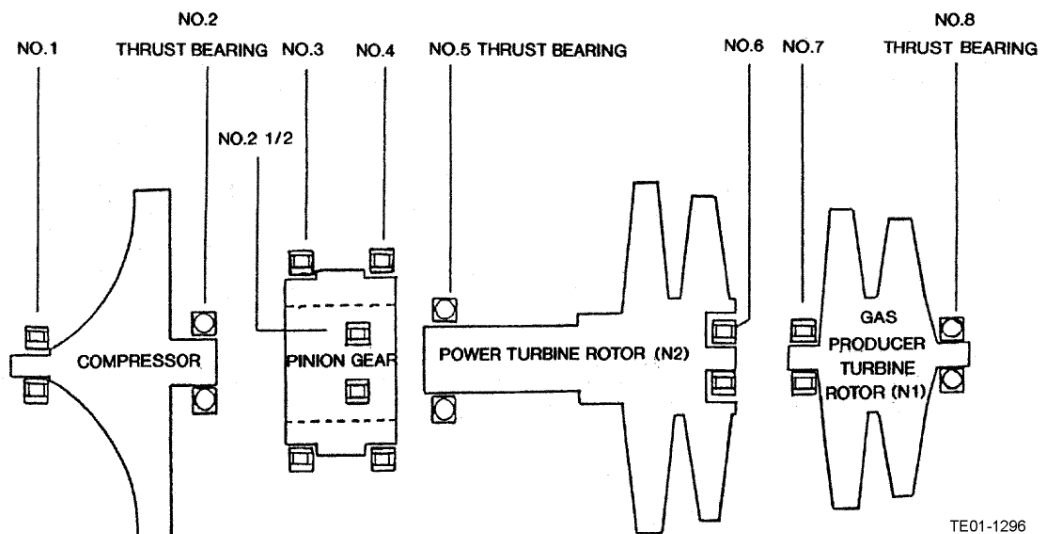


FIGURE 5: MAIN ENGINE BEARING LOCATIONS

Figure Courtesy of Rolls-Royce

The PT rotor consists of a PT coupling outer nut, PT shaft that couples to the pinion gear (this is also referred to as the PT shaft-to-pinion gear coupling) in the accessory gearbox, PT coupling inner nut, stages 3 and 4 wheels, metallic ring gasket, stage 3 wheel labyrinth seal, and the PT coupling bearing inner

race (**FIGURE 6**). Both PT wheels are investment castings of stainless steel, and the blades are cast integral with the wheels, just like the GPT wheels. The PT wheels are splined together with face-type (curvic coupling) splines similar to the GPT wheels. The wheels and labyrinth seal are clamped together by the power turbine coupling/bearing inner race (also referred to as the inner shaft) and the power turbine coupling inner nut which threads onto it. The rearmost part of the PT coupling bearing inner race is the inner race of the No. 6 roller bearing (See **FIGURE 5**) that supports the back end of the rotor. The front end of the PT rotor is supported by the No. 5 ball bearing (thrust bearing) on the PT shaft-to-pinion gear coupling. The PT shaft-to-pinion gear coupling is splined to the stage 4 wheel with curvic coupling splines. The PT coupling outer nut threads onto the stage 4 wheel, and this nut retains the power turbine shaft to the stage 4 wheel. The PT shaft-to-pinion gear coupling is splined on both ends. It splines into the power turbine shaft and into the helical power train drive (pinion) gear in the accessory gearbox. This coupling transfers torque from the power turbine rotor to the power turbine gear train in the accessory gearbox.

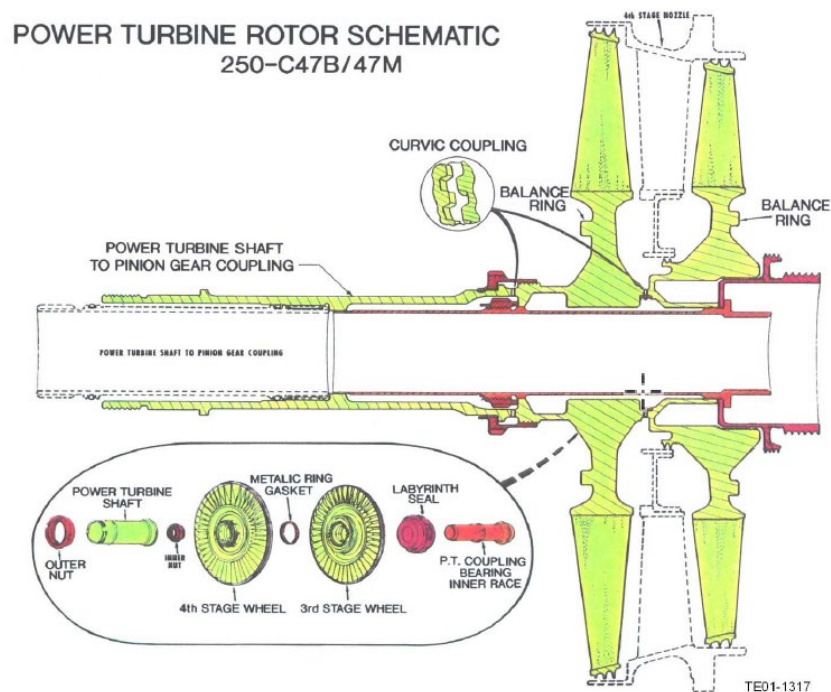


FIGURE 6: PT ROTOR SCHEMATIC

Figure Courtesy of Rolls-Royce

1.3 Torquemeter Assembly

The torquemeter assembly is incorporated in the accessory gearbox to provide a hydraulic pressure signal which is directly proportional to output torque. The power turbine gear train has two stages of helical gearing. Helix angles are such that both stages of reduction produce a forward axial thrust on the helical torquemeter gearshaft. If friction is neglected, this axial thrust is directly proportional

to the torque transmitted through the gears. The accessory gearbox housing has a cast passage which delivers pressurized oil to the inside of the torque-meter support shaft that is then ported to the torque-meter piston. The accessory gearbox receives engine oil from an airframe mounter oil tank through a scavenge oil filter. The oil tank is vented to the interior of the accessory gearbox and the accessory gearbox is vented overboard.

A ball bearing transmits helical gear thrust from the rotating helical torque-meter gearshaft to the nonrotating torque-meter piston. The torque-meter piston is free to slide axially on the nonrotating and axially retained support shaft. The sliding torque-meter piston serves as a variable orifice valve which admits regulated engine pressure oil from the support shaft to the oil chamber formed by the piston and the flange on the support shaft; pressure inside the oil chamber is directly proportional to torque (**FIGURE 7**).

Oil pressure in the oil chamber is directed to the torque-meter pressure sensing port on the front side of the accessory gearbox. The accessory case mounted transducer converts torque-meter oil pressure into an electrical signal; this signal is required by the Electronic Control Unit (ECU) for torque limiting and is also required by the airframe indicating system.

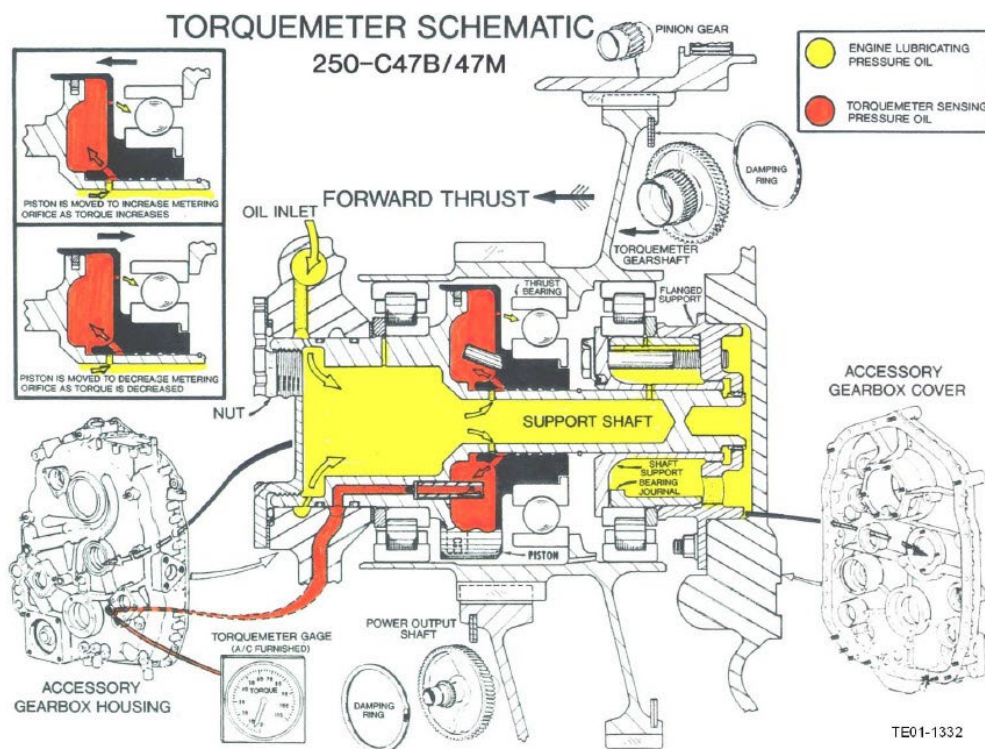


FIGURE 7: TORQUEMETER SCHEMATIC

Figure Courtesy of Rolls-Royce

1.4 Engine Maintenance History

According to the maintenance records, the accident engine was a RR Model 250-C47B, serial number (SN) CAE-847268. The day before the accident flight the engine had accumulated 8,767.7 hours time since new (TSN), 10,277 cycles since new (CSN), and the turbine and compressor models accumulated 415.2 hours time since overhaul (TSO), and 460 cycles since overhaul (CSO). The accident engine was installed on the helicopter, N20BH, on May 24, 2023, it had accumulated 10,059 hours TSN and 12,471 CSN at that time.

The last two maintenance inspection activities on the accident engine were the 150-hour/12-month engine maintenance inspection conducted on April 17, 2024, by Brainerd Helicopter Services Inc. in Rolla, Missouri in accordance with Rolls-Royce maintenance manual Chapter 72, Table 606 and the 300-hour/12-month engine maintenance inspection conducted on January 5, 2024, by Brainerd Helicopter Services Inc. in Brainerd, Minnesota in accordance with Rolls-Royce maintenance manual Chapter 72, Table 606. The engine, at the time of the accident, had accumulated 127.2 hours time since the last 150-hour/12-month³ engine maintenance inspection and 266.6 hours time since last 300-hour/12-month⁴ engine inspection.

The last 300-hour/12-month engine compressor wash on the engine was conducted on April 17, 2024, by Brainerd Helicopter Services Inc. in Rolla, Missouri in accordance with Rolls-Royce maintenance manual Chapter 72, Table 606. The engine at the time of the accident had accumulated 127.2 hours since the last engine compressor water wash; the time remaining until the next 300-hour/12-month engine compressor water wash was 172.80 hours or 4 months.

According to the turbine assembly service record cards, the accident turbine assembly, SN CAT-44390, was first installed in the accident engine, SN CAE-847268, new on November 10, 1997, but was immediately removed and repaired due to issue relating to "smoking" with no time having been accrued. The turbine assembly was repaired and reinstalled back in the engine on February 3, 1998. The turbine assembly remained on the accident engine its entire life being removed three times for overhaul. The last overhaul of the turbine model occurred on May 21, 2023⁵ by Allied Propulsion Mansfield, Texas; the turbine assembly had accumulated 8,304.5 hours TSN and 9,758 CSN when removed the accident engine. All the turbine wheels were installed new including the GP tie bolt; a FAA Form 337 "Major Repair and Alteration" for the overhauled turbine on May 21, 2023 (**APPENDIX A**).

³ The time remaining until the next 150-hour/12-month inspection was 22.80 hours or 4 months.

⁴ The time remaining until the next 300-hour/12-month inspection was 33.40 hours or 5 months.

⁵ The turbine assembly was removed from the accident engine on November 2, 2021, and sent for overhaul when it was reinstalled on the accident engine on May 21, 2023.

TABLE 1 provides pertinent information about the turbine assembly and the turbine wheels installed (**APPENDIX B**). The turbine assembly was installed in the accident engine on May 24, 2023. Times and cycles listed in **TABLE 1** are at the time of the accident.

TABLE 1: TURBINE ASSEMBLY WHEEL INFORMATION				
Item	Part Number	Serial Number	Time Since New (Hour)	Cycles Since New
Turbine Assembly	M250-10557	CAT-44390	10,059.8	12,471
Stage 1 Turbine Wheel	M250-10227	X668284	10,059.8	12,471
Stage 2 Turbine Wheel	M250-10658	X676126	10,059.8	12,471
Stage 3 Turbine Wheel	M250-10748	X679276	10,059.8	12,471
Stage 3 Turbine Wheel	23066744	X660218	10,059.8	12,471

1.5 Full Authority Digital Electronic Control System Description

The FADEC is a single-channel system comprised of two major components, the ECU and the hydromechanical unit (HMU). Along with these components, helicopter and engine mounted sensors provide inputs such as main rotor speed (NR), ambient pressure (P1), engine compressor inlet temperature (CIT), GP and PT speed (NG and NP respectively), and measured power turbine gas turbine temperature (MGT). If the ECU fails completely, fuel flow will remain fixed (constant) until analog manual fuel control is selected.

The HMU is mounted on the lower aft right-hand side of the engine accessory gearbox (driven by the N1 geartrain) and the ECU is mounted on the cabin roof just aft of the hydraulic servo actuator support on the right-hand side of the roof. The ECU controls, monitors, and limits the engine while maintaining helicopter rotor speed (NR). The control connection between the helicopter and the engine is both electrical and mechanical. This interface includes a combination of power lever angle (PLA) input, hard wired discrete, and analog signals.

The software program installed in the ECU is in a "Flash" EEPROM (electrically erasable programmable read only memory) integrated circuit located on the computer board assembly. The version of software installed in the ECU is identified by the last four digits (dash number) of the ECU part number (e.g., - 7001), and is inscribed on the name plate located on the top surface of the unit. The software version number is also stored in the Flash EEPROM to allow verification of the software version with the part number inscribed on the identification plate.

Fault information is stored in the EEPROM during all phases of ECU operation. This provides a history of any fault occurrences with the ECU or associated control system elements for troubleshooting purposes. This information is retained until the ECU is removed and the information purposely cleared during a maintenance

action. FADEC system faults and engine limit exceedances are recorded and sent to the aircraft instrument display.

The ECU incorporates testing and monitoring of its operation with immediate response to engine limit exceedance or system failure. In ECU model No. EMC-35R, which is the model number of the accident ECU (See Section 1.6 titled "Electronic Control Unit Data Download for Accident Engine") an independent electronic PT speed governor called the reversionary governor has been added. In the event of an ECU failure, the reversionary governor provides basic PT speed control using a limited set of parameter inputs and assumes control in the event of a fault that renders the primary governor incapable of continued safe control of the engine. If the reversionary mode is not capable of controlling the engine, a "fail fixed" mode occurs where fuel flow to the engine is frozen at its last good value.

1.6 Electronic Control Unit Data Download for Accident Engine

According to the engine maintenance records, the ECU was PN M250-10695, SN JG3ALK0766; this was confirmed with the data plate (**PHOTO 3**) that indicated that it was a Triumph Engine Control Systems, model No. EMC-35R, manufacture PN 11599ASSY115220-1A5-24. Normally the ECU data can be downloaded easily by the operator or by someone with the proper software and electrical connections; however, the on-scene engine evaluation deemed that of the ECU was damaged and would need to be shipped to Triumph Engine Controls in West Hartford, Connecticut, for readout.

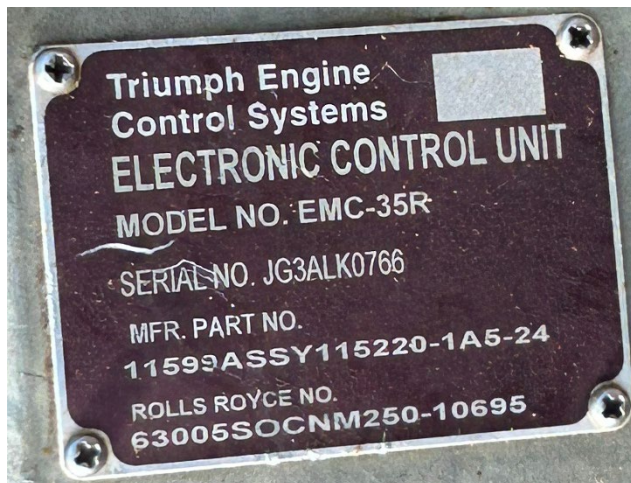


PHOTO 3: ACCIDENT ENGINE ECU DATA PLATE

Photo Courtesy of Rolls-Royce

The ECU data was downloaded by Triumph on September 26, 2024, and several data reports were generated. The following data was consistent throughout all the reports:

Data Source: ECU Data Time: 9/26/2024 12:29:43 PM Aircraft Model: Bell 407
Engine Model: 250-C47B ECU Version: 257-5400 ID: E844
User Name: 793613 Engine SN: CAE-847268 ECU SN: JG3ALK0766
Compressor SN: CAC-44421 Turbine SN: CAT-44390 HMU SN: JGALM0747
Engine Gearbox SN: CAG-47268 Aircraft ID: 53242

The summary report indicates that the engine operating (running) time (counter) was 2,298.39 hours and the number of engine starts was 2,297; it also included the faults/anomalies listed in **TABLE 2** that occurred during the accident flight. Faults/anomalies are recorded when the parameter exceeds the normally defined range of values for that parameter.

TABLE 2: TIME STAMPED FAULTS DURING INCIDENT FLIGHT		
FAULT TIME	FAULT NAME	DESCRIPTION
2298:25:56.976	QFltRG ⁶	Q Fault from Rev. Gov.
2298:25:57.096	QRawFlt	QRaw Fault

Review of the ECU data indicated that there were two faults related to torque (QFltRG and QRawFlt), which were declared during the accident flight based on the last engine run fault history and time stamped fault history reports. The QFltRG and QRawFlt faults occurred fractions of a second apart (**TABLE 2**) from each other in the time-stamped fault history report. The accumulated and time stamped fault history reports also captured an MGT (turbine temperature) exceedance event (MGTSmTOut). Because the MGTSmTOut exceedance occurred approximately 100 hours prior to the final engine operating time, it can be considered unrelated to the field event.

According to Rolls-Royce, QRawFlt torque sensing is disabled on the primary governor and QFltRG torque sensing is disabled on the reversionary governor. Therefore, the fact that both faults were recorded so close in time together was consistent with the ECU primary and backup (reversionary) modes having been activated and both modes reporting a torque out-of-range.

In Section 1.3 titled "Torquemeter Assembly", engine torque is measured in terms of oil pressure and is a function of torque transmitted through the helical gears in the accessory gearbox. Loss of oil quantity and oil pressure would eventually result in torque out-of-range faults. On scene photographs of the wreckage site showed the right side of the helicopter heavily oil stained in a vertical pattern consistent with the oil spraying onto the surface while the helicopter was stationary (**PHOTO 4**).

⁶ Rolls-Royce uses the abbreviation Q to stand to engine torque



PHOTO 4: HELICOPTER FUSELAGE, RIGHT SIDE, COVERED IN OIL - WRECKAGE SITE

Photo Courtesy of Rolls-Royce

The summary report shows the engine operating time as 2,298.39 hours which translates to 2,298 hours, 23 minutes, and 24 seconds; this time is less than the fault times listed in **TABLE 2**. According to Roll-Royce, the engine run time interval counter from the summary report was 117.12 seconds which would need to be added to the engine operating time of 2,298 hours, 23 minutes, and 24 seconds; this gives a time total time of 2,298 hours, 25 minutes, and 21 seconds. Again, this is less than the faults times listed in **TABLE 2**. Rolls-Royce acknowledges that if there is a sudden loss of power to the ECU before it could do its normal shutdown calculations, there may be errors in the times recorded.

Rolls-Royce issued Commercial Service Letters (CSL), Nos. 6063 and 6076, both applicable to the M250-C47 model engine relating ECU history verification and proper determination of engine run times and conversion of time stamp format⁷. The ECU stores information which is used to determine maintenance actions and is, therefore, imperative that the stored information be accurate. The CSLs listed above acknowledge several instances where the information in the ECU did not reflect the history of the engine it was controlling. This bad/incorrection information can be generated by transferring incorrect information to the ECU, or installing an ECU which has information from another source stored in it. Furthermore, there have been several instances where a fault or exceedance was found during a routine download or

⁷ CSL No. 6063 was issued on December 15, 1997, and CSL No. 2 6067 was originally issued on September 29, 2014. The current version of CSL No. 6076 is revision 1 dated August 4, 2000.

when troubleshooting for another cause. To address this, Roll-Royce recommends downloading and reviewing ECU history information on a regular basis/periodic interval to minimize the possibility of finding information that necessitates unscheduled or unanticipated maintenance activities and prior to any ECU removal and replacement.

Additionally, when changing an ECU on an aircraft, the history of the ECU should be reviewed to make sure no maintenance is required prior to ECU removal. The ECU information can then be downloaded using the Maintenance Terminal Software (MTS). The replacement ECU can then be installed, and its history can be reviewed to verify it is free from faults and exceedances. The history information can then be uploaded to the replacement ECU. According to the maintenance records, the accident ECU, SN JG3ALK0766 was installed on the engine on April 7, 2022. It has accumulated a total time of 9,743.6 hours at that time.

2.0 On-Scene and Salvage Yard Helicopter Airframe and Engine Damage

The accident helicopter was recovered and transported to Interstate Aircraft Recovery salvage yard in Boise, Idaho for storage. Persons from Rolls-Royce and FAA traveled to the salvage yard to assess the aircraft and engine damage and witness the engine removal for additional examination. The NTSB did not travel for the initial on-scene examination of the airframe and engine nor for the follow-on examination at the Interstate Aircraft Recovery facility. The following is a compilation of information provided by Rolls-Royce. After documentation was completed, the engine was placed in a shipping container and sent to the Rolls-Royce facility in Indianapolis, Indiana for examination and disassembly.

The inlet duct, an airframe supplied part, appeared intact and undamaged but was discolored/sooted. The compressor consists of a single titanium centrifugal stage impeller with 36 equally spaced blades located on the forward face that are curved in a clockwise direction ALF. The 36 inducer blades consist of 18 full length blades and 18 short inducer blades equally spaced between the full-length blades. With the compressor impeller installed in the compressor support, the 18 full length blades are visible, and the leading edges of all the full-length blades exhibited hard body impact damage, tears/rips, missing material, and distortion (**PHOTO 5**); the damage was in the direction opposite rotation. One of the compressor front support struts appeared bent.

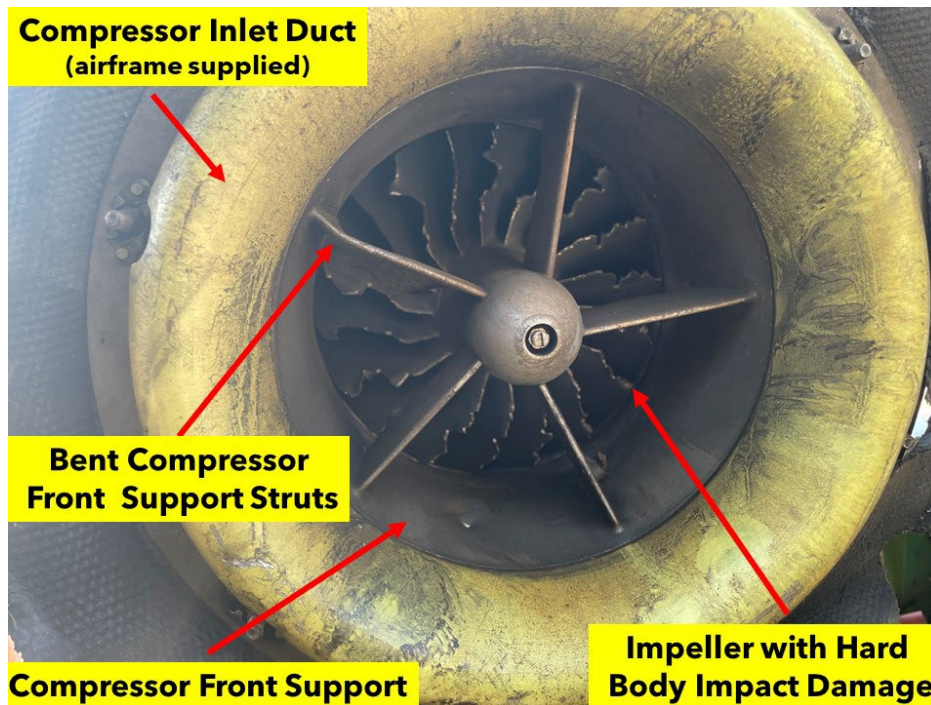


PHOTO 5: COMPRESSOR IMPELLER HARD BODY IMPACT DAMAGE

Photo Courtesy of Rolls-Royce, Modified by the NTSB

On-scene photos only showed the right side of the engine; therefore, no description of the left side of the engine could be made at this time. The right side of the engine exhaust duct, which is an airframe supplied part and is mounted to the engine exhaust collector support, was pot-marked outwards. The right side of the engine exhaust collector support was pot-marked outwards, and the right side exhibited a large exit penetration through-hole. The edges of the through-hole folded were folded outwards and was missing material (**PHOTOS 6** and **7**). The compressor scroll collects the air from the diffuser and directs it to two elbows; each elbow, integral compressor scroll, directs air rearward to the two compressor discharge tubes. The right compressor scroll elbow appears to be intact and undamaged. Compressor discharge air tubes, integral with combustion assembly deliver compressed air from the outlet of the elbows to the combustion outer case. The right compressor discharge tube was pot-marked outwards and exhibited a small exit penetration through-hole. The connected right air tube adapter that connects the compressor scroll elbow to the compressor discharge tube was intact and the tubes remained clamped together.

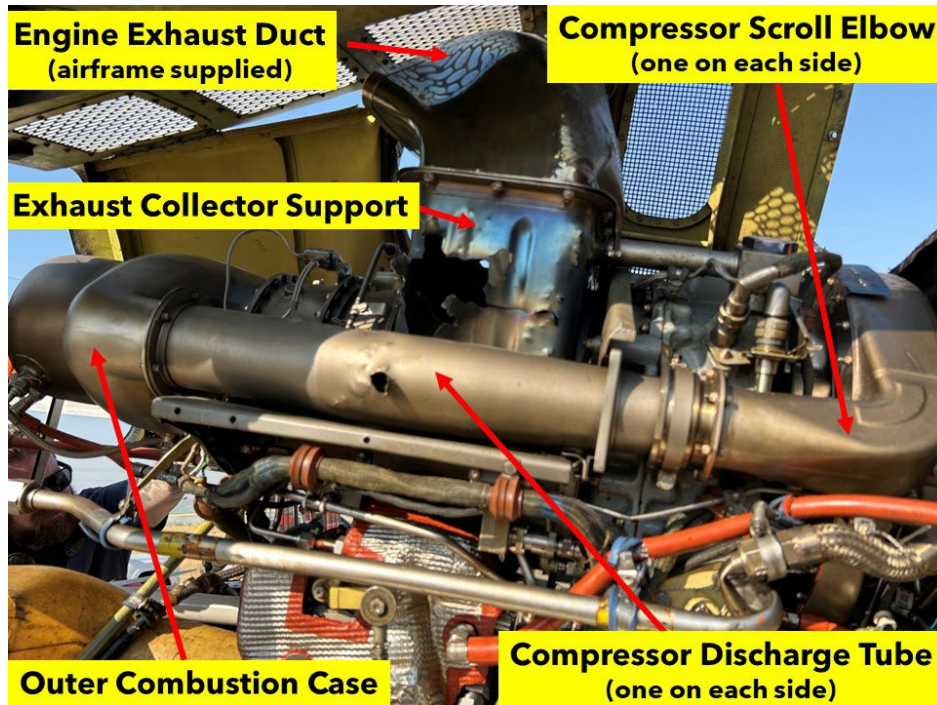


PHOTO 6: RIGHT SIDE OF ENGINE - EXIT PENETRATION THROUGH HOLES IN THE EXHAUST DUCT, EXHAUST COLLECTOR SUPPORT AND COMPRESSOR DISCHARGE TUBE

Photo Courtesy of Rolls-Royce, Modified by the NTSB

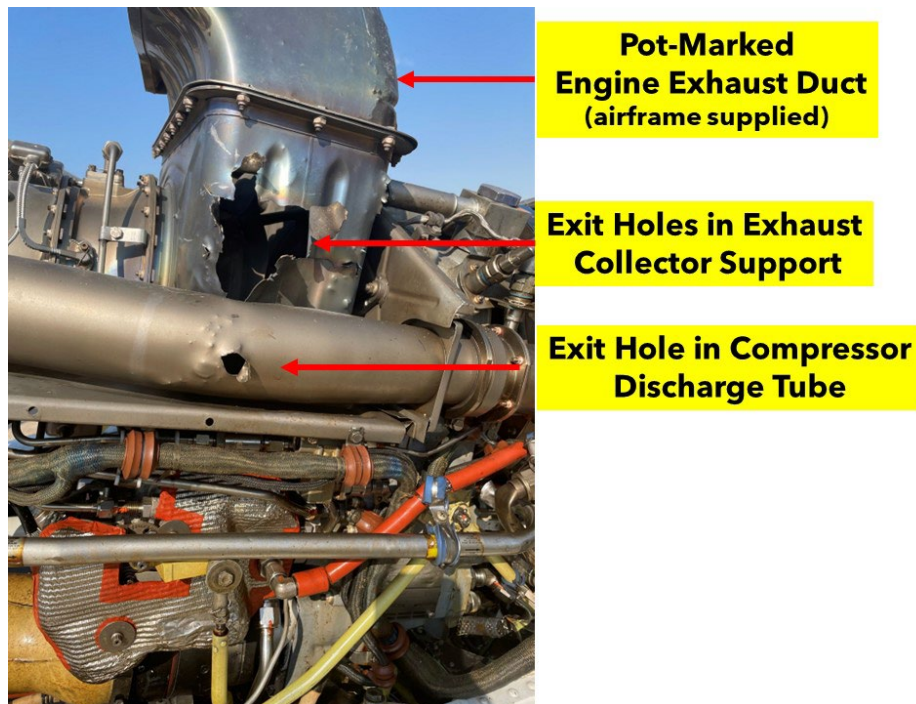


PHOTO 7: RIGHT SIDE OF ENGINE - EXIT PENETRATION THROUGH HOLES IN THE EXHAUST DUCT, EXHAUST COLLECTOR SUPPORT AND COMPRESSOR DISCHARGE TUBE

Photo Courtesy of Rolls-Royce, Modified by the NTSB

3.0 Helicopter Engine Damage

Persons from Rolls-Royce, Brainerd Helicopter Services, and the NTSB met at the Rolls-Royce facility in Indianapolis, Indiana on August 28, 2024, to commence examination and disassembly of the accident engine SN CAE-847268. The group completed their work on August 29, 2024.

3.1 General Observations - Before Engine Disassembly

The engine was removed from its shipping container and placed in a work stand. The compressor exhibited hard body impact damage (**PHOTO 8** - left) and turned freely by hand; continuity was confirmed with the accessory gearbox. Multiple hard body impact locations showed similar size and shape impacts, and material transfer was observed. Several of the struts in the compressor front support exhibited trailing edge impact damage consisting of tears and rips and were pushed forward. Looking through the exhaust collector support, the stage 4 turbine wheel (PT stage 2 turbine wheel) was observed. The stage 4 turbine wheel was completely corn-cobbed with all the airfoils fractured transversely across the platform (**PHOTO 8** - right).

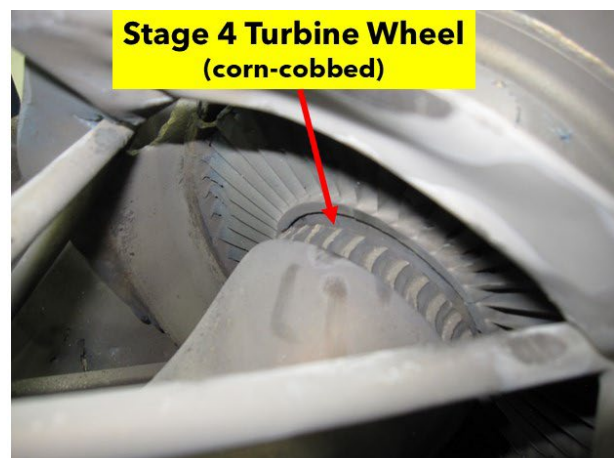
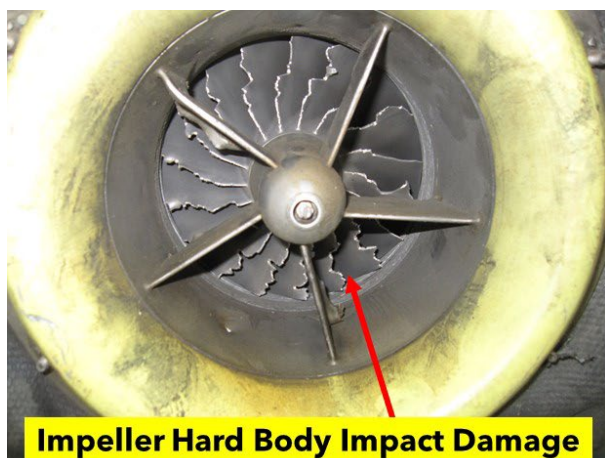


PHOTO 8: COMPRESSOR DAMAGE (LEFT) AND CORN-COBBED STAGE 4 TURBINE WHEEL (RIGHT)

The exhaust collector support exhibited multiple exit hole penetrations on the right left, left side and bottom (**PHOTO 9**). The deflector shield within the exhaust collector support also exhibited exit holes. The horizontal firewall shield assembly exhibited a hole at the bottom of the shield near the drain port; the shield did not exhibit any signs of thermal distress or fire damage (**PHOTO 10**).

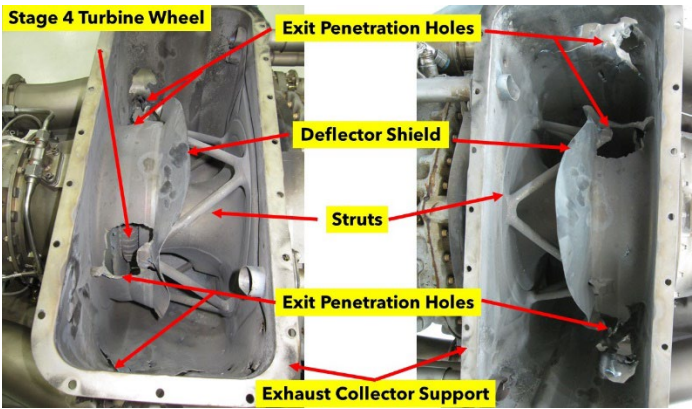


Photo 9: Exit Penetration Holes in Exhaust Collector Support

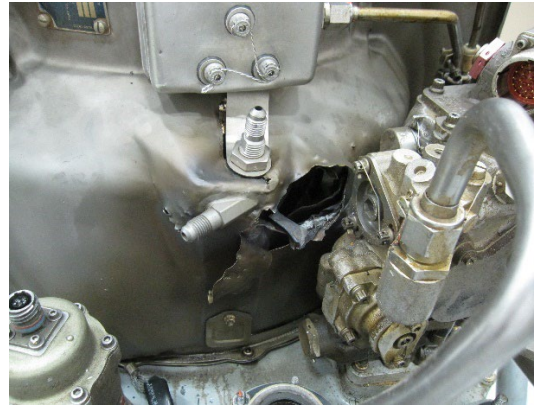


PHOTO 10: EXIT PENETRATION HOLE IN HORIZONTAL FIREWALL SHIELD

A fragment of curvic coupling was found between the horizontal fire shield and the turbine case (**PHOTO 11**). The fragment has five partial teeth with each tooth smeared over and flattened.



PHOTO 11: RECOVERED FRAGMENT OF CURVIC COUPLING TEETH

The freewheeling clutch (an airframe supplied component) was removed, and it rotated smoothly in both directions. The clockwise direction ALF, the clutch mechanism was engaged and turned the K-flex adapter plate and in the counterclockwise direction ALF the shaft turned by the K-flex adapter plate did not turn with it; this is consistent with a properly functioning freewheeling clutch.

3.2 Combustion Section Disassembly

Both the right and left compressor discharge tubes exhibited exit penetration holes (**PHOTO 12**). The outer combustion case and combustion liner were removed from the engine. The outer combustion case was in good condition with no burn-throughs or exit holes.



PHOTO 12: EXIT PENETRATION HOLES IN THE COMPRESSION DISCHARGE TUBES

The combustion liner was intact and did not exhibit any significant heat distress, burn-throughs, or signs of fuel nozzle streaking such as localized hot spots. No visible cracks were observed in the cooling air holes or the louver liner holes. The swirl vanes and fuel nozzle port were in good condition as were the spark igniter ports; no anomalies were noted. The fuel nozzle port exhibited light rub/contact wear consistent with contact from the fuel nozzle tip. The fuel nozzle tip exhibited similar rub/contact wear consistent with contact with the combustion liner fuel nozzle port. The fuel nozzle also exhibited a build-up of black coking on the spray tip, but the fuel holes appeared to be unobstructed (**PHOTO 13**). The igniter plug also exhibited coke build up on the tip (**PHOTO 14**).



PHOTO 13: COKE BUILD-UP ON FUEL NOZZLE TIP



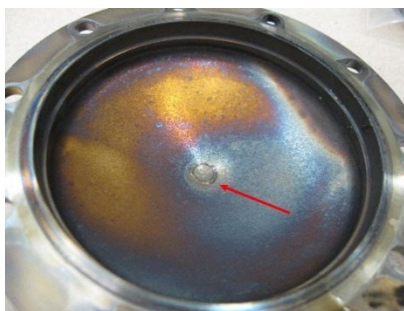
PHOTO 14: COKE BUILD-UP ON IGNITER PLUG

Turning of the compressor by hand, the GPT did not rotate along with it; however, the accessory gearbox did. Therefore, continuity was confirmed between the compressor and accessory gearbox but not to the GPT. The GPT was decoupled from the compressor.

3.3 Turbine Module Disassembly

The horizontal firewall shield was distorted at the interface flange/retainer lip between the horizontal and the vertical firewall shield. The horizontal firewall shield has three access panels used to access the attachment bolts used to secure the accessory gearbox to the turbine module. The center access panel, at the 6:00 o'clock position, had what appeared extra two nuts wedged underneath the access panel and a washer was found in the horizontal fire shield flange.

The No. 8 ball bearing oil sump cover was removed from the GPT bearing support and the inner surface of the cover exhibited a circular impact mark consistent with the head of the tie bolt and tie bolt spanner nut (**PHOTO 15**). The tie bolt was fractured towards the forward end aft of the stage 2 turbine wheel support land (**PHOTO 16**) and slid out easily through the stage 1 turbine wheel stub shaft. The fractured tie bolt measured about five inches in length. The tie bolt spanner nut remained attached to the aft portion of the tie bolt and the lock tabs on the crimp washer were crimped. The No. 8 bearing oil jet was present, secure, and intact. The No. 8 bearing looked in good condition and the stage 1 wheel spun freely by hand.



**PHOTO 15: NO. 8 BALL BEARING SUMP COVER
IMPACT**

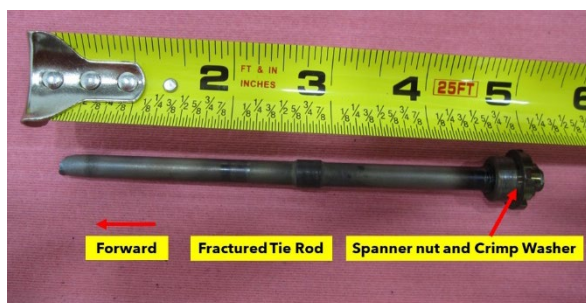


PHOTO 16: FRACTURED TIE BOLT

The turbine module was removed from the accessory gearbox cover. The turbine-to-compressor coupling shaft was found fractured circumferentially and the fractured end, sticking out of the accessory gearbox/turbine shaft-to-pinion gear coupling, was distorted, bent, and compressed (**PHOTO 17** - left side). When placed against an exemplar turbine-to-compressor coupling shaft, the accident shaft found still installed in the accessory gearbox cover was about 3 inches short (**PHOTO 17** - right side); the fractured shaft measured about 6.25 inches (longer piece). The turbine-to-compressor coupling shaft was removed from the accessory gearbox and the forward part of the shaft that engages the helical pinion gear was fractured

longitudinally, exhibited thermal distress and material transfer, and the end was flared out (**Photo 17** - center yellow box).

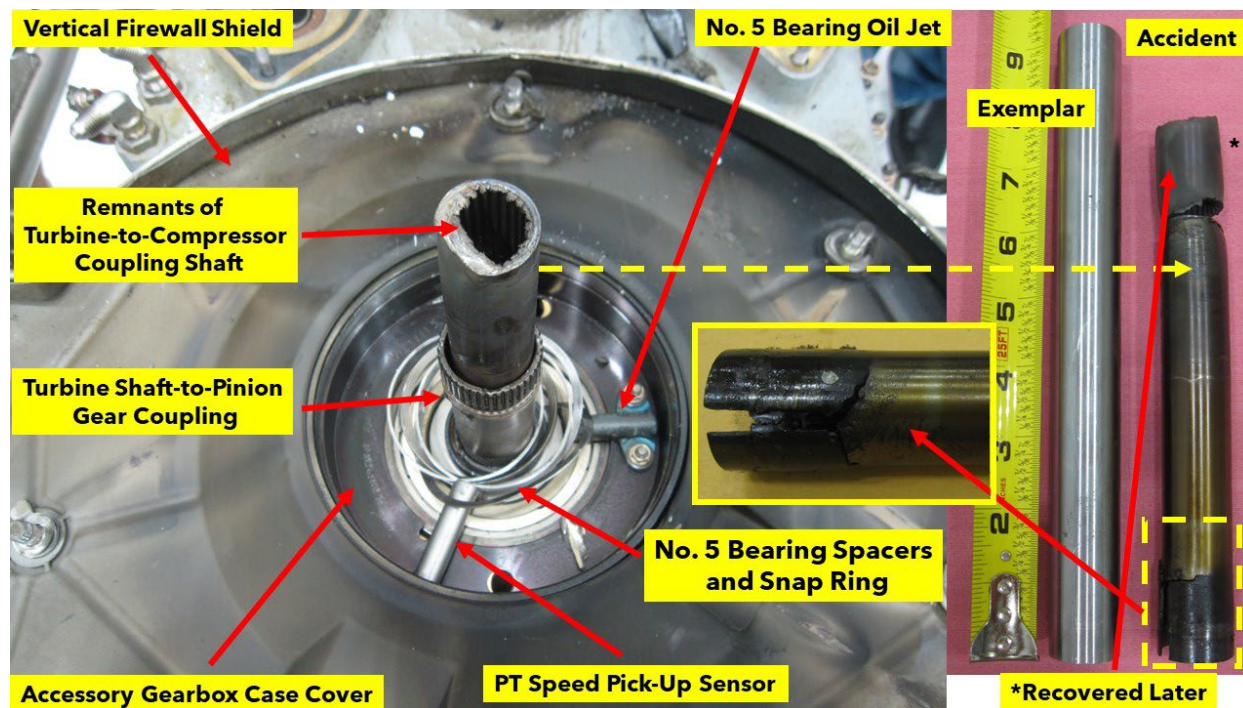


PHOTO 17: FRACTURED TURBINE-TO-COMPRESSOR COUPLING SHAFT

The turbine shaft-to-pinion gear coupling was bound/stuck within the helical pinion gear in the accessory gearbox cover and would not slide out. The helical pinion gear aft face was deformed/flattened consistent with contact from the power turbine shaft. The oil jet that supplies oil to the No. 5 thrust bearing was secure and intact. The N2 (PT speed) magnetic pickup, which is mounted on the right top of the accessory gearbox cover and supplies the N2 speed signal to the ECU, was intact (See **PHOTO 17**).

The No. 5 thrust bearing (ball bearing), which is retained and supported in the exhaust collector support, remained attached to the stage 4 turbine wheel stub shaft. All the No. 5 thrust bearing rolling elements appeared shiny, intact and in good condition. The No. 5 thrust bearing cage and inner race were in good condition (**PHOTO 18** - right); however, the outer race was fractured (**PHOTO 18**). The No. 5 thrust bearing spacers and the snap ring had become disengaged from the bearing housing and were found lying on the accessory gearbox cover (See **PHOTO 17**). The No. 5 thrust bearing would not rotate on the stage 4 turbine wheel stub shaft. The No. 5 thrust bearing spanner nut secures the No. 5 bearing to the stage 4 turbine wheel stub shaft (PT stage 2) and serves at the N2 speed sensor; it was intact and exhibited slight contact on the spanner flats consistent with contact with the magnetic pickup (**PHOTO 18** - left).

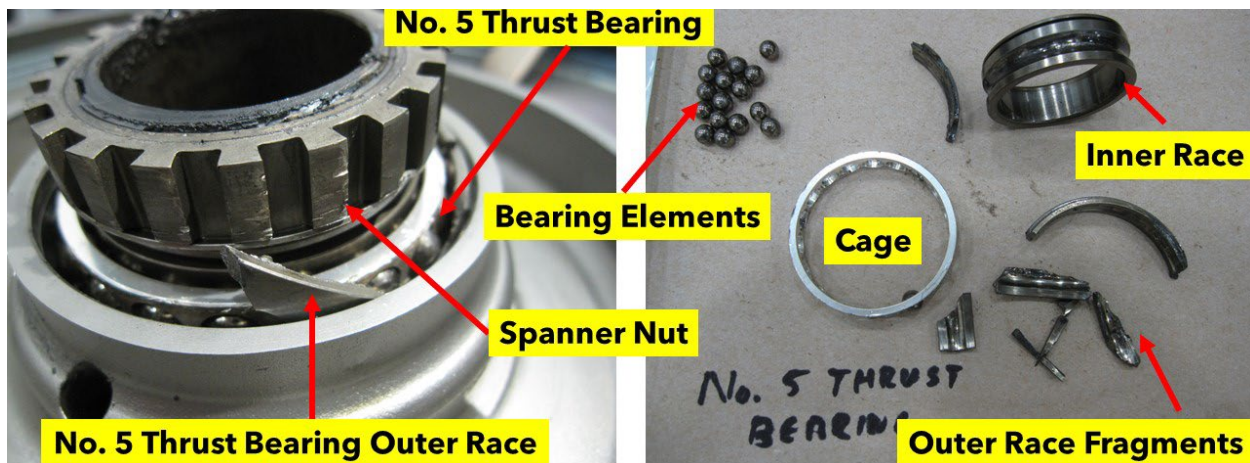


PHOTO 18: NO. 5 THRUST BEARING DAMAGE

The stage 3 turbine nozzle (PT stage 1) ring was intact, and the trailing edges exhibited airfoil impact damage, rips, tears, and missing material. The leading edges exhibited no significant damage.

All the blades of the stage 3 turbine wheel (PT stage 1) were present and fractured transversely across the airfoil at various span lengths; all the blade tips were missing (**PHOTO 19** - left). The airfoils were slightly bent in the direction opposite rotation and exhibited rips, tears, and slight heat discoloration. The curvic coupling teeth on the front side of the stage 3 turbine wheel that connects it to the stage 4 turbine wheel was fractured and missing. A fractured section of the turbine-to-compressor coupling shaft, about 1.75 inches long, was found resting loose; it was distorted and exhibited heat distress and material transfer (**PHOTO 19** and see **PHOTO 17** for dimension). The No. 6 roller bearing inner race and PT coupling shaft were fractured in-line with both the front end of the tie bolt and the fractured turbine-to-compressor coupling shaft (**PHOTO 19** - right).

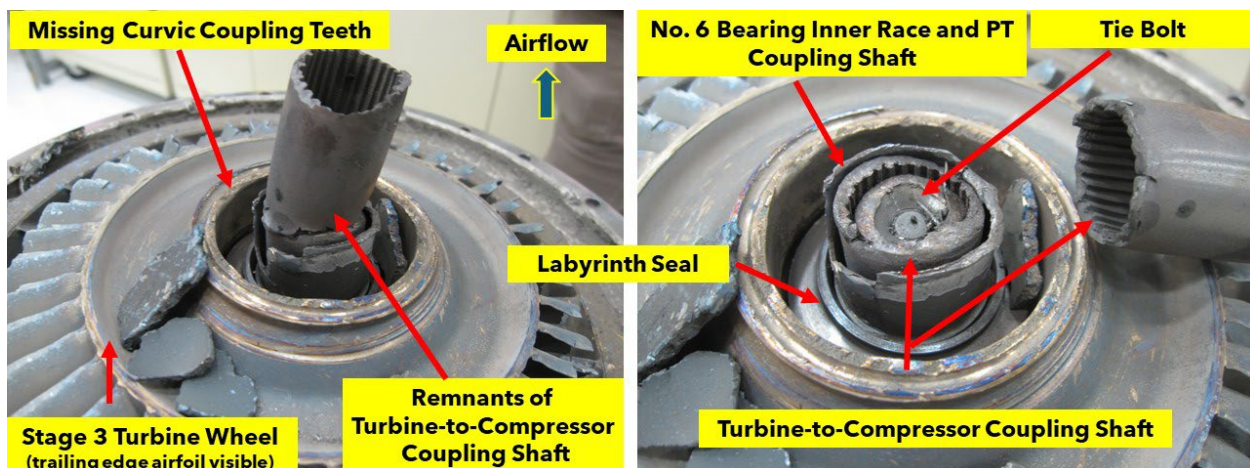


PHOTO 19: FRAGMENTS OF TURBINE-TO-COMPRESSOR COUPLING SHAFT AND FORWARD END OF TIE BOLT

All the stage 4 turbine nozzles (PT stage 2) were present, intact, and exhibited some leading edge impact damage but considerably more trailing edge impact damage consisting of rips, tears, and missing material. Integral with the stage 4 turbine nozzle is an outer air seal shroud, which acts as a seal for the stage 3 turbine wheel blade tips; the outer shroud was fractured about 180° around (**PHOTO 20** - left).

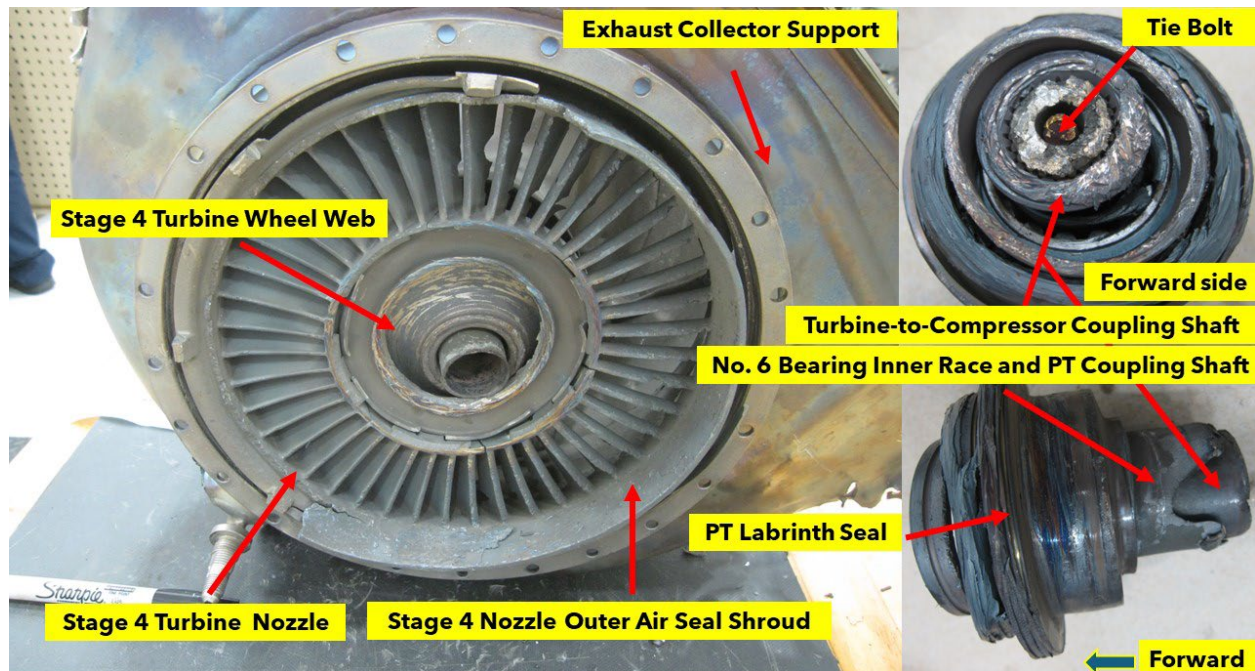


PHOTO 20: STAGE 4 TURBINE NOZZLE AND PT LABRINTH SEAL DAMAGE

Removal of the stage 3 turbine wheel exposed the PT labyrinth seal and better access to the fractured tie bolt, turbine-to-compressor coupling shaft and the No. 6 bearing inner race and PT coupling shaft (See **PHOTO 20**). The PT labyrinth seal exhibited heat distress, material transfer, heavy wear, and distortion. The PT labyrinth seal is composed of a set of inner and outer knifed edge seals; both sets of seals had areas where the knife edges were flattened and no longer there and an area where they were still visible but heavily worn.

There are four equally spaced MGT thermocouple probes mounted to the PT support; the bare wires of the thermocouple probe extend through the PT support and the outer band of the stage 3 turbine nozzle shield and into the gases leaving the GPT rotor. When all four were removed, the wire ends were fractured (**PHOTO 21**).



PHOTO 21: FRACTURED THERMOCOUPLE PROBE

The stage 4 wheel and PT outer shaft were removed from the exhaust collector support (**PHOTO 22**).

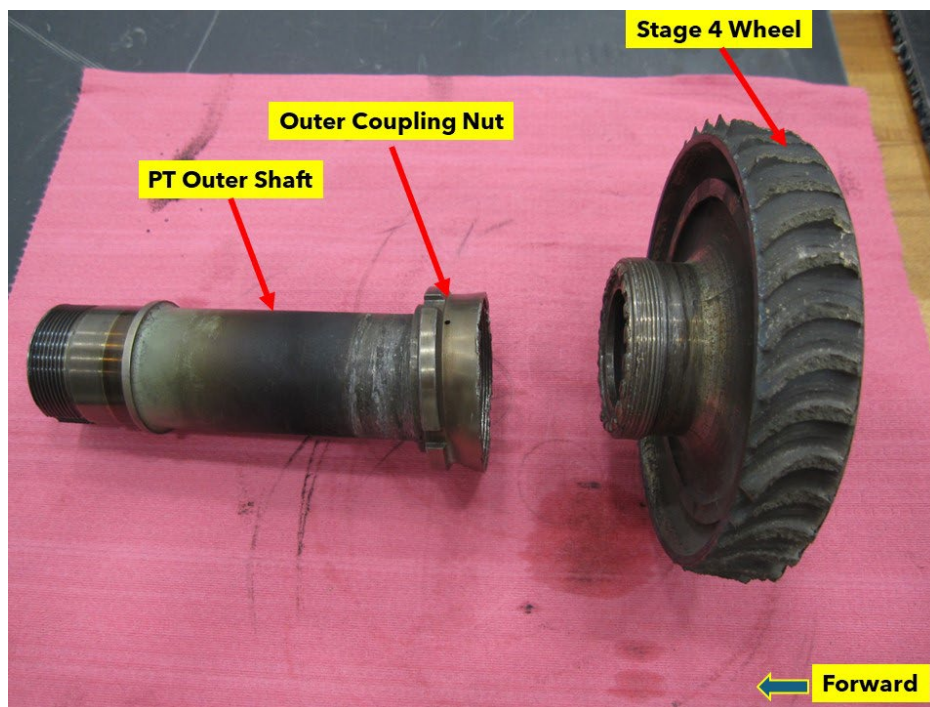


PHOTO 22: STAGE 4 WHEEL AND PT OUTER SHAFT DAMAGE

The PT outer shaft exhibited circumferential contact rub, and material transfer near the back part of the shaft (**PHOTO 23**). The front of the PT outer shaft exhibited contact rub and smeared material consistent with contact with the aft end of the gearbox pinion gear (**PHOTO 23** -top left) and the aft face exhibited heavy rotational contact rub, wear, smeared material, and heat distress (**PHOTO 23** -top right). All the curvic coupling teeth from the aft end of the PT outer shaft were obliterated.

The outer coupling was distorted, missing material, and heavily rubbed on the forward end consistent with contact with the stage 4 wheel web (**PHOTO 23** -top right).

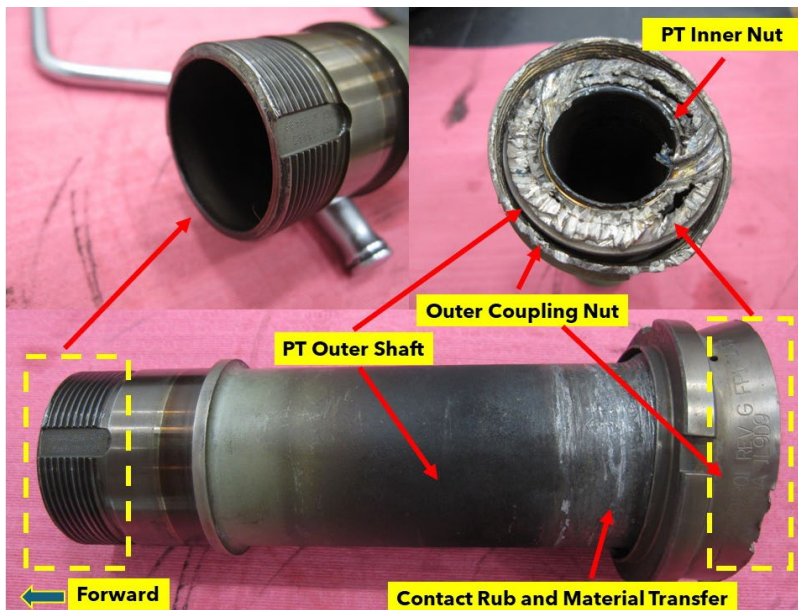


PHOTO 23: PT OUTER SHAFT DAMAGE - CLOSE UP

As previously documented, the stage 4 turbine wheel was corn-cobbed with all the blades fractured transversely at the blade platform. The small fragments of blade airfoil that remained were bent in the direction opposite rotation. The curvic coupling teeth on the front of the wheel were still present and visible but heavily damaged and smeared. The curvic coupling teeth on the aft side of the stage 4 turbine wheel were obliterated. Circumferential rub marks were noted on the aft side of the stage 4 turbine wheel web (**PHOTO 24**).

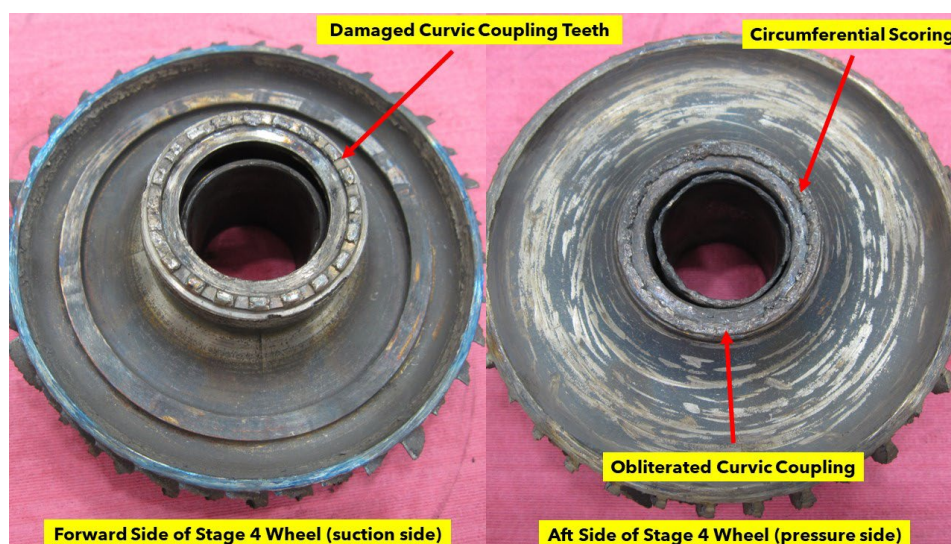


Photo 24: Stage 4 Wheel Damage

The stationary labyrinth seal remained captured in the exhaust collector support. The knife edges were heavily worn down (**PHOTO 25** - left). All the stage 4 nozzle airfoils were present, and the leading edges exhibited minor damage while the trailing edges exhibited more extensive airfoil damage consisting of rips, tears, and missing material. The stage 4 nozzle inner stationary seal was distorted, pushed outwards, exhibited heat distress and the knife edges were obliterated (**PHOTO 25** -right).

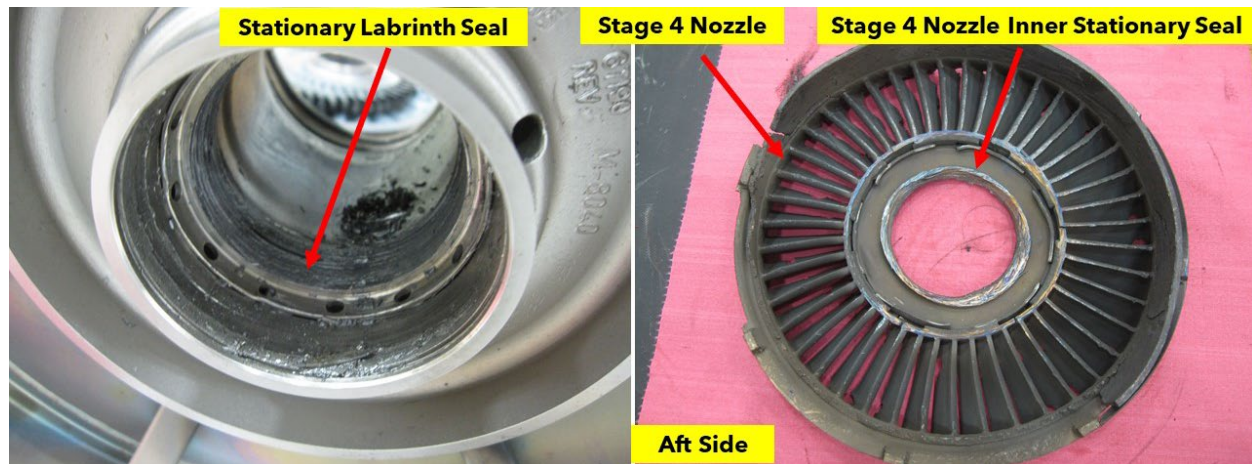


PHOTO 25: PT ROTATING LABRINTH SEAL AND STAGE 4 NOZZLE STATIONARY SEAL DAMAGE

All the blades on both the stage 1 and 2 turbine wheels were present and fractured transversely across the airfoil; the stage 1 turbine wheel blades were fractured about 50% span while the stage 2 turbine wheel blades at about 75% (**PHOTO 26**). The curvic coupling on the stage 1 turbine wheel was present; however, the curvic teeth exhibited damage and were flattened and rounded (**PHOTO 26** - left). The Nos. 6 and 7 roller bearing housing remained attached to the GPT support and the anti-rotation pins were in good condition. The No. 7 roller bearing was intact, and the roller elements were all present and whole; however, the No. 7 bearing was seized and would not rotate. A piece of the fractured stage 2 wheel stub shaft and tie bolt were visible (**PHOTO 26**- right) in the center of the No. 7 roller bearing. The forward part of the Nos. 6 and 7 bearing housing was compressed and exhibited rotational and thermal damage with a considerable amount of the forward end missing. The airfoils on the stage 1 and 2 nozzles were all present and exhibited varying degrees of impact damage, tears, and missing material.

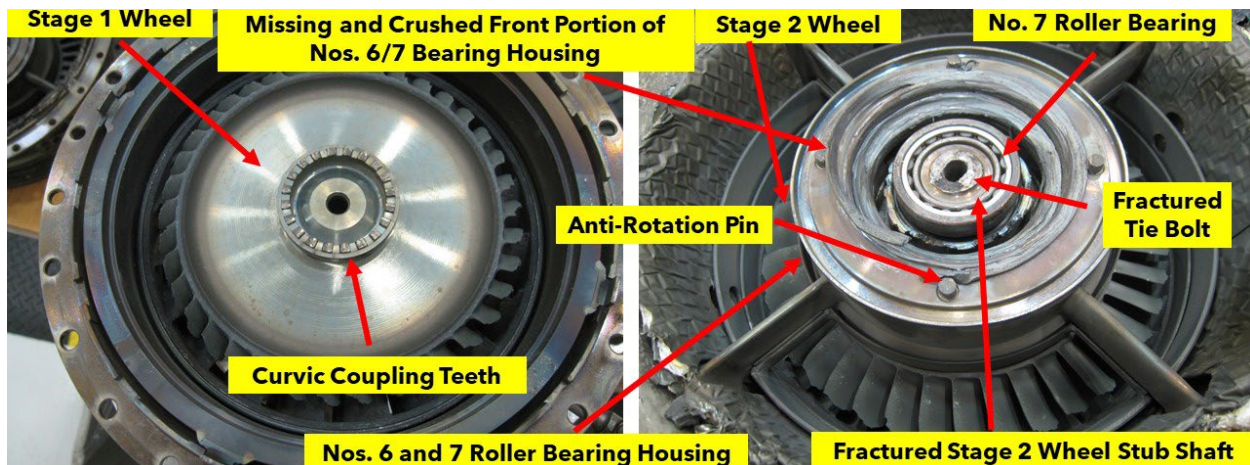


PHOTO 26: GPT WHEEL DAMAGE

3.4 Accessory Gearbox Module Disassembly

The accessory gearbox assembly consists of a gearbox housing, gearbox cover, GP gear train, PT gear train, oil pump assembly, oil filter assembly, and the necessary oil tubes to carry pressure and scavenge oil as required by the lubrication system. The gearbox housing and cover were separated to expose the various gears and bearings (**PHOTOS 27** and **28**). All the gears and bearings were in good condition, oil wetted, and rotated smoothly without resistance.

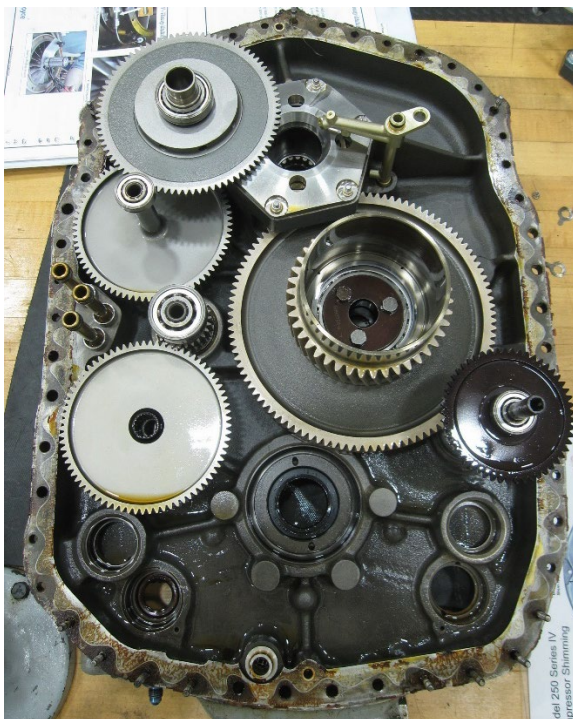


PHOTO 27: PT DRIVEN GEAR TRAIN IN ACCESSORY GEARBOX COVER



PHOTO 28: GP DRIVEN GEAR TRAIN IN ACCESSORY GEARBOX HOUSING

The helical pinion gear assembly with the turbine shaft-to-pinion gear coupling still attached was removed from the accessory gearbox cover. The Nos. 3 and 4 roller bearing were in good condition and spun freely by hand (**PHOTO 29**). All the teeth on the helical pinion gear were intact and in good condition. The aft face of the pinion gear exhibited heat distress and was compressed (mushroomed outward) consistent with contact with the PT outer shaft (**PHOTO 30**). The turbine shaft-to-pinion gear coupling was fractured and no longer coupled to the inside spur teeth of the helical gear but remained seized within the helical gear bore. It also exhibited heat distress/discoloration near the aft face of the helical gear.

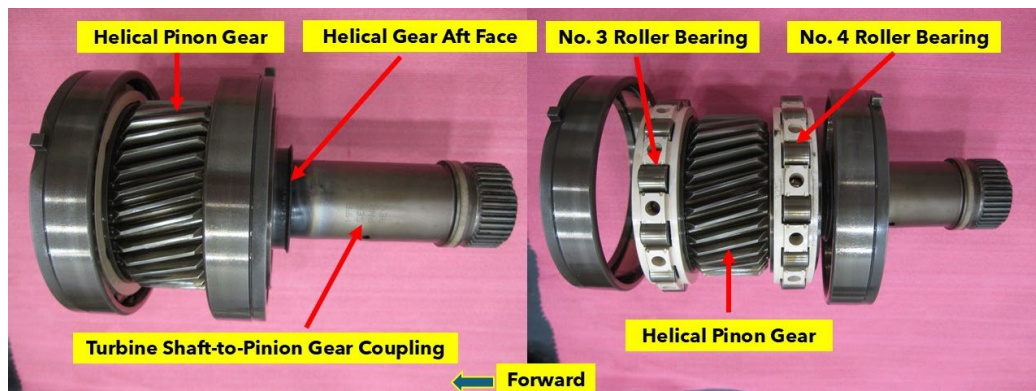


PHOTO 29: HELICAL GEAR AND NOS. 3 AND 4 BEARING CONDITION

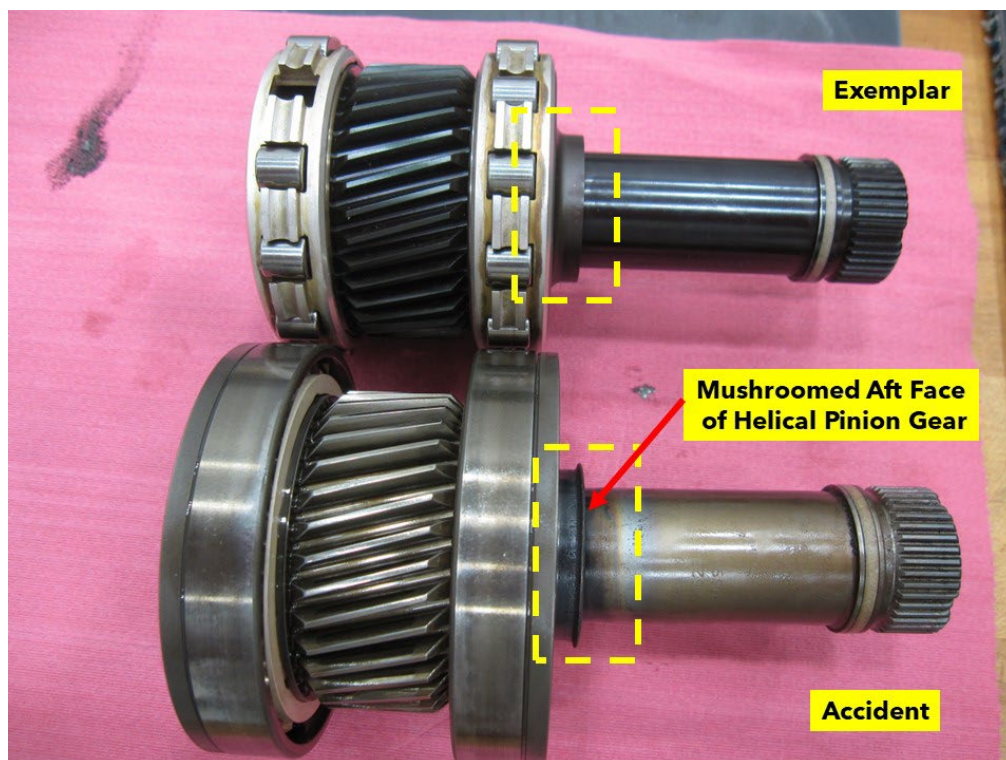


PHOTO 30: HELICAL GEAR AFT FACE DAMAGE

Both magnetic chip detectors were removed from the accessory gearbox housing. Both exhibited minor debris (**PHOTO 31**).



PHOTO 31: MAGNETIC CHIP DETECTORS FROM THE ACCESSORY GEARBOX HOUSING

3.5 Compressor Module Disassembly

The compressor spun freely and smoothly by hand. The compressor impeller and the diffuser were removed for examination. The impeller inducer part of the airfoil exhibited hard body damage while the exducer part of the airfoil exhibited shiny contact wear consistent with contact with the shroud housing (**PHOTO 32**). The shroud housing exhibited material transfer in the inducer section and circumferential rub along the mid body and exducer end as the air heads into the diffuser (**PHOTO 33**). The diffuser airfoils exhibited impact damage consisting of tears, rips, and material loss; all the airfoils were present but not all exhibited impact damage (**Photo 34**).

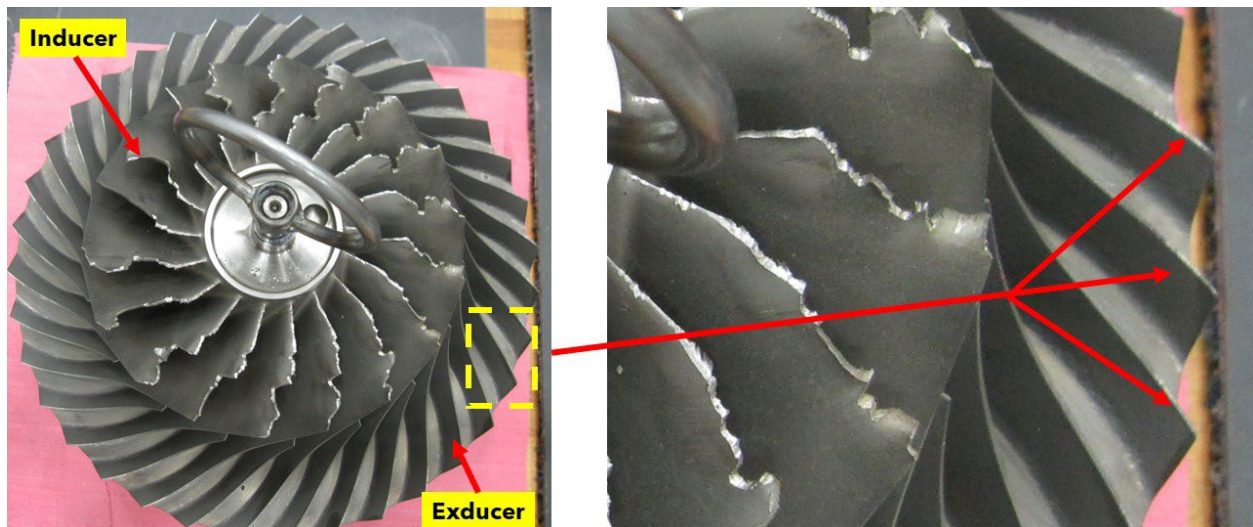


PHOTO 32: IMPELLER IMPACT DAMAGE AND CONTACT RUB

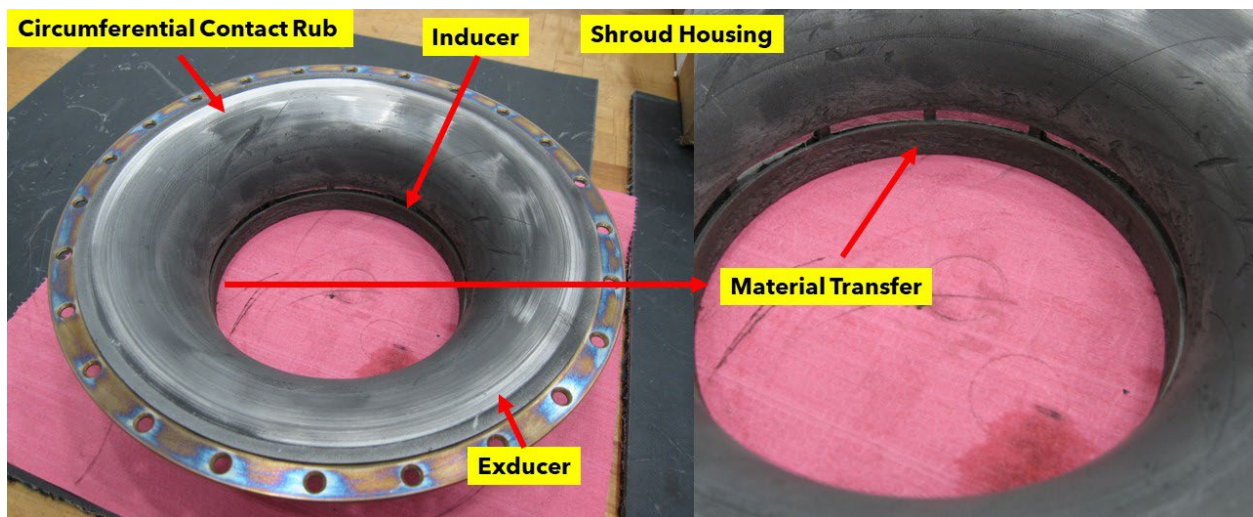


PHOTO 33: IMPELLER SHroud HOUSING CONTACT RUB AND MATERIAL TRANSFER

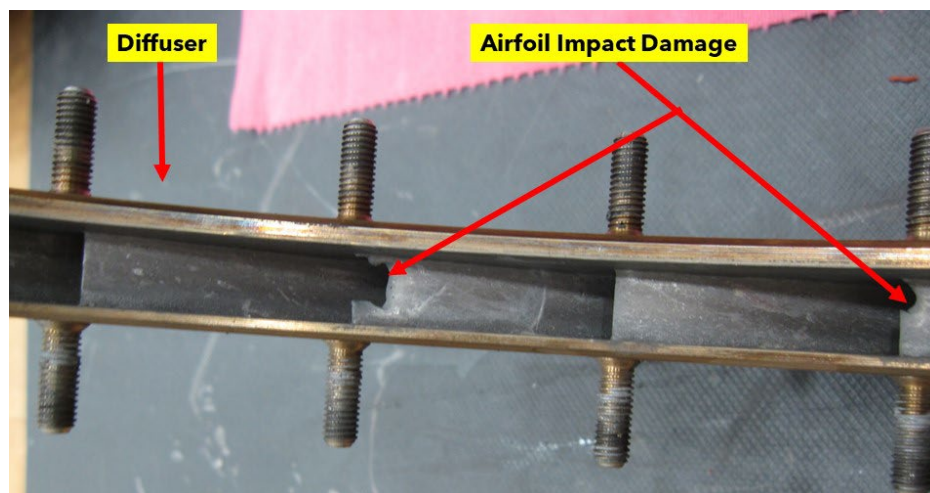


PHOTO 34: DIFFUSER AIRFOIL IMPACT DAMAGE

The compressor front support struts exhibited trailing edge impact damage, and the trailing edges were bent in the direction of rotation (**PHOTO 35**).

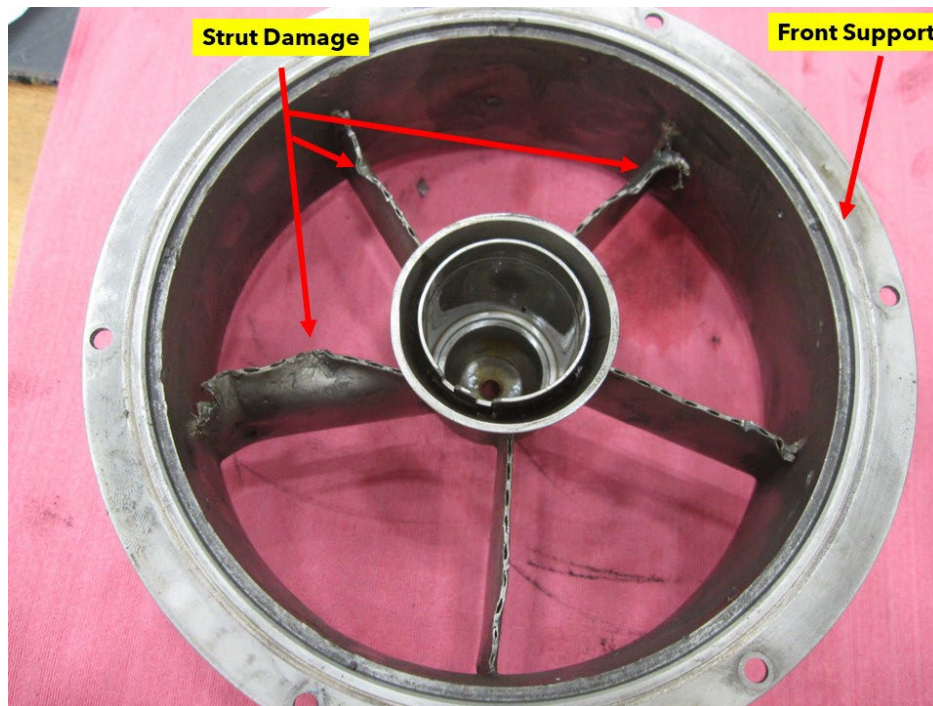


PHOTO 35: TRAILING EDGE DAMAGE OF THE COMPRESSOR FRONT SUPPORT

4.0 Metallurgical Analysis

Parts were submitted to the RR material engineering department in Indianapolis, IN for further destructive analysis. See Roll-Royce material Evaluation Report No. 24FAE-076 for complete details. This report will only discuss significant metallurgical findings. Material composition and material hardness of the parts examined were consistent with the part's manufacturing specifications. No parts were found with any pre-existing anomalies or fatigue fractures; RR considered the damage to the turbine section as secondary damage following loss of axial and radial control of the components during the crash sequence.

4.1 Impeller

The impeller base material and the areas of material transfer were subjected to backscattered electron scanning electron microscopy (SEM) images with energy dispersive X-ray spectroscopy (EDS). The areas of transferred material had high concentrations of iron alloy type material, the impeller is made of a titanium alloy, as well as nickel, cobalt, and molybdenum which are not found in the base material.

4.2 Helical Gear Assembly

The forward end of the turbine shaft-to-pinion gear coupling the forward splines were seized inside the helical pinion gear and the aft face of the helical gear was deformed and heat distressed (See **PHOTOS 29** and **30**). The turbine shaft-to-pinion gear coupling exhibited a circumferential fracture aft of the forward splines (**PHOTO 36**). The forward Teflon seal was not present in the Teflon seal groove. The pinion gear coupling was thermally distressed at the fracture and aft into the forward Teflon seal groove.

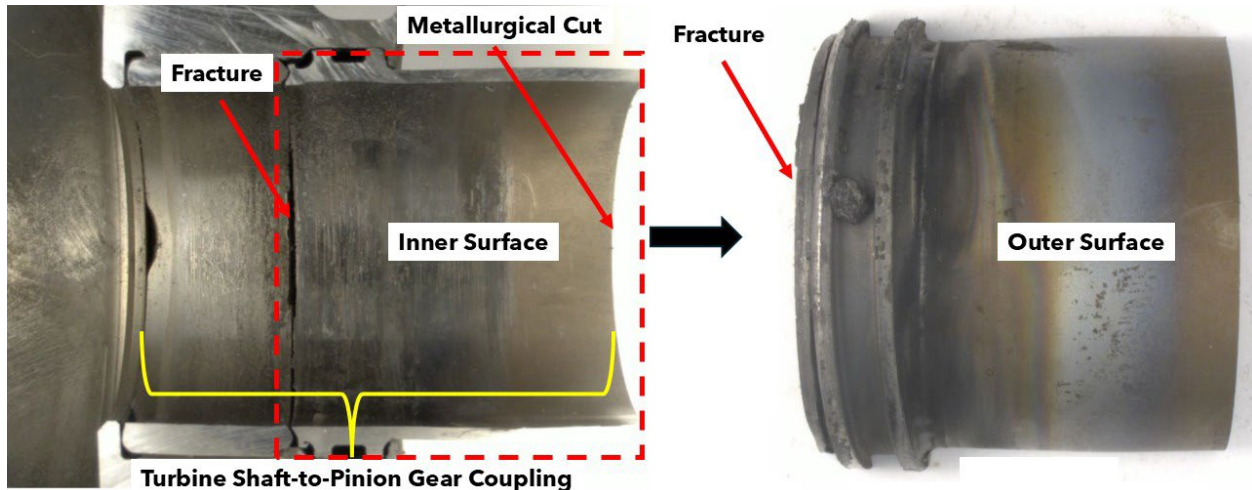


PHOTO 36: TURBINE-TO-PINION GEAR COUPLING FRACTURE

Photo Courtesy of Rolls-Royce, Modified by NTSB

4.3 Power Turbine Outer Shaft and Coupling Nut

The PT outer shaft and outer coupling nut was found disconnected from the stage 4 turbine wheel (See **PHOTOS 22** and **23**). The aft face of the PT outer shaft exhibited eccentric rub damage that resulted in obliteration of the curvic teeth and other defining features of remnant shafting material inside the PT outer shaft. According to RR, the rub damage between the pinion gear and PT outer shaft is consistent with contact following loss of axial control in the No. 5 bearing and loss of continuity in the turbine shaft-to-pinion gear coupling.

The outer coupling nut was not a RR manufactured part but a manufactured under the FAA Parts Manufacturer Approval (PMA) program. The nut was flared outboard and exhibited dimples that were not fully formed to the PT outer shaft. Being a PMA (non-Rolls-Royce part), no further examination on the part was conducted.

4.4 No. 5 Bearing

The No. 5 bearing thrust bearing was in relatively good condition except for the fractured outer race. The outer race fragments were subjected to SEM

imaging which showed chevron marks and ductile dimples features consistent with overload failure. Roller ball indentations from the raceway onto the forward and aft shoulders and the overload fractures were consistent with a non-uniform load in the power turbine shafting.

4.5 Turbine-to-Compressor Coupling Shaft

The turbine to compressor coupling shaft was fractured in two places: at about the interface of the PT outer shaft and stage 4 turbine wheel and about the interface between the stage 4 turbine wheel and stage 3 turbine wheel. The fracture surfaces were flared outboard and heavily smeared. The forward end of the turbine to compressor coupling exhibited axial and circumferential cracks (See **PHOTOS 17, 19, and 20**). The fracture surface exhibited structure dominated features consistent with brittle overload fractures. No features consistent with fatigue progression were observed.

4.6 Stage 4 Turbine Wheel

All the blades of the stage 4 turbine wheel were fractured near the root and exhibited and exhibited rub damage to the leading edges of the remnant blade material and the aft rim face (See **PHOTOS 8, 22, and 24**). The aft curvic teeth were completely rubbed away and the forward curvic teeth were rubbed to approximately one-half height (See **Photo 24**). Visual examination of the blade fracture surfaces did not find any evidence of fatigue. One representative blade was removed from the wheel for detailed examination using optical and backscattered SEM images. Detailed SEM images of the fracture surface revealed dendritic features and ductile dimples consistent with overload.

4.7 Tie Bolt

The forward portion of the tie bolt was fractured, and the forward portion was retained in the fractured stage 2 turbine wheel stem (See **PHOTO 16 and 19**). Optically, the fracture surface exhibited a relatively uniform surface roughness with shear lips and the material near the fracture was necked; all of which are consistent with tensile overload. SEM images of the fracture surface, which exhibited ductile dimples consistent with overload.

5.0 MGT Measuring System

5.1 MGT Measure System Description

The MGT thermocouple assembly is an equal resistance branch harness with four integral MGT thermocouple probes. Each MGT thermocouple probe

consists of a single element assembly with a bare wire junction. The equally spaced thermocouple probes extend outside of the power turbine support for the harness. The bare wire junction of each thermocouple probe extends through the power turbine support and the outer band of the stage 3 turbine nozzle shield and into the gases leaving the GPT rotor. Each thermocouple probe generates a direct current (DC) voltage which is directly proportional to the gas temperature it senses. The thermocouples and thermocouple harness are wired in parallel. This provides an average of the four voltages representative of the gas producer turbine outlet temperature. The flexible thermocouple harness consists of two branches of equal resistance connecting the four probes and a terminal branch, with two eyelet terminals, for connection to the airframe mounted ECU and the helicopter furnished MGT indicator circuit (**FIGURE 8** and **PHOTO 37**). An engine furnished thermocouple terminal assembly (also referred to as a terminal block) is secured to the right side of the exhaust collector support shield, just forward of where the firewall shield slips into the exhaust collector support shield (**PHOTO 38**).

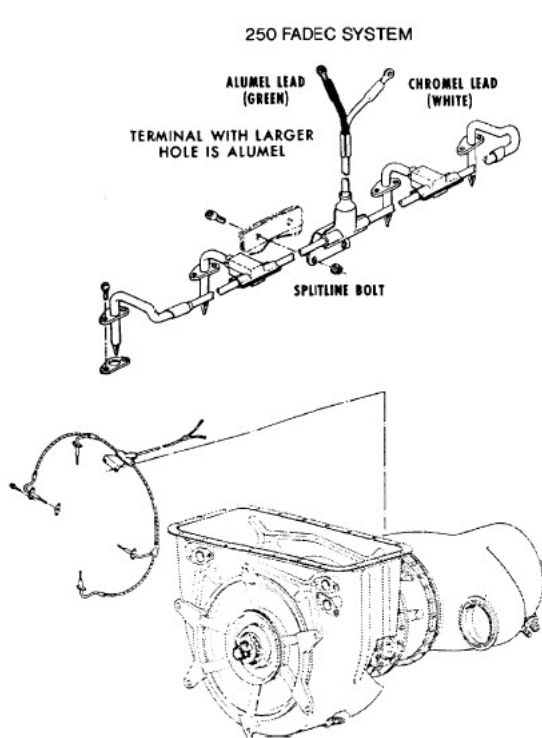


Figure 8: MGT Thermocouple Harness Assembly
Figure Courtesy of Rolls-Royce

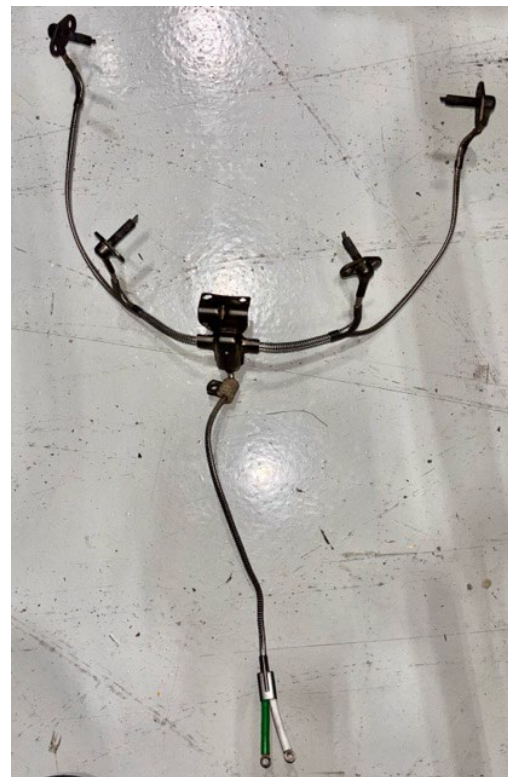


PHOTO 37: ACCIDENT ENGINE MGT THERMOCOUPLE HARNESS ASSEMBLY
Photo Courtesy of Rolls-Royce

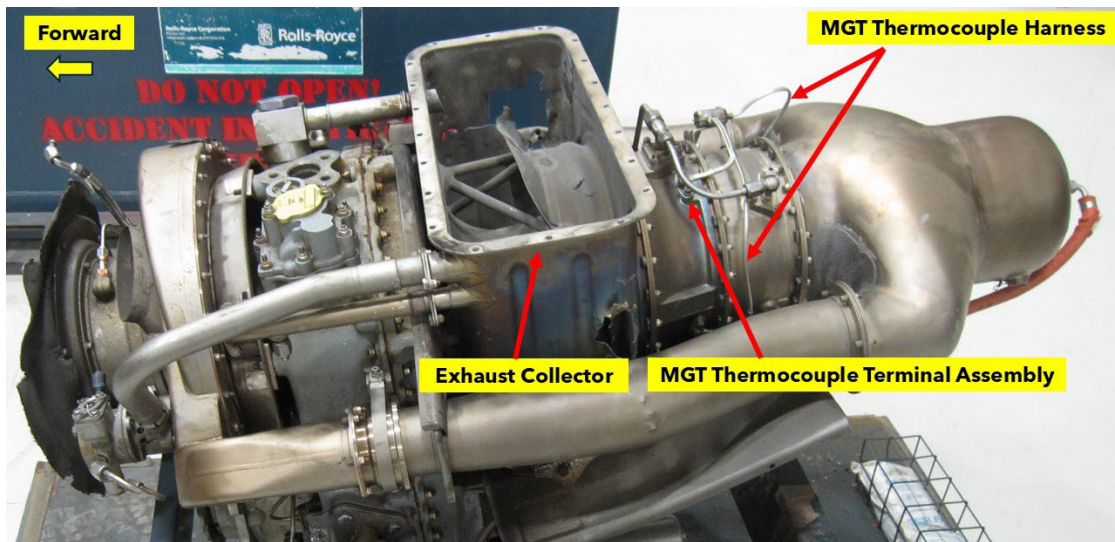


PHOTO 38: THERMOCOUPLE HARNESS AND THERMOCOUPLE TERMINAL ASSEMBLY (BLOCK) LOCATION

The thermocouple terminal assembly has a 10-32 almel (AL) stud and an 8-32 chromel (CR) stud. The thermocouple harness, the engine harness and the accessory harness almel and chromel eyelet terminals fit over the almel and chromel studs on the thermocouple terminal assembly. Self-locking nuts retain the eyelet terminals on the studs (**PHOTO 39**). A ceramic insulator is provided to prevent the MGT thermocouple harness shorting with the thermocouple terminal assembly. On the accident thermocouple terminal assembly, the ceramic insulator appeared intact.

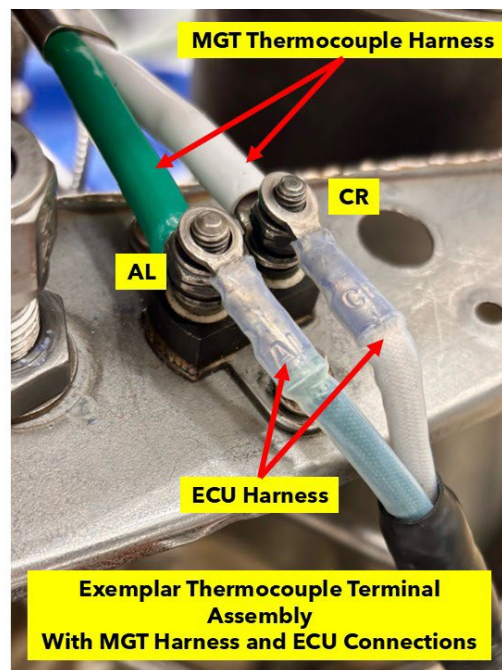
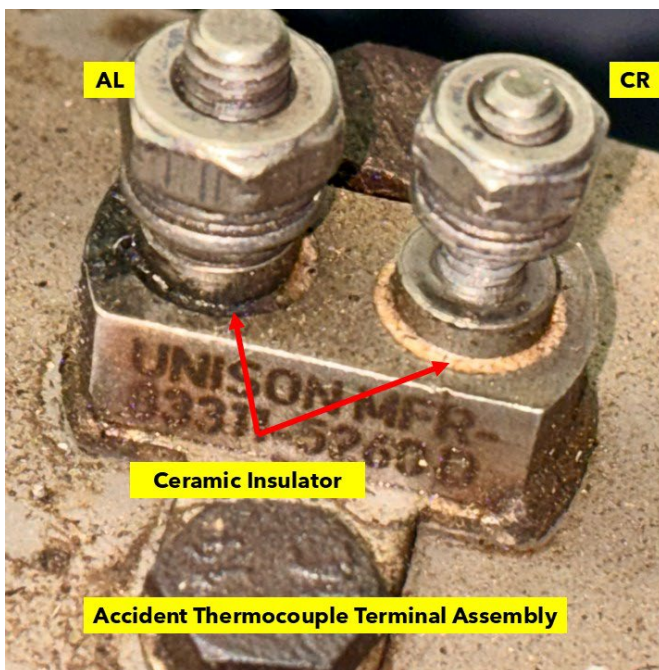


PHOTO 39: THERMOCOUPLE TERMINAL ASSEMBLY

As it relates to the MGT Measuring System, the ECU will record fault data for highest peak value and time exceeding turbine run temperature limit and highest peak value and time exceeding engine start temperature limit. As stated before, no faults were recorded on the ECU for the accident flight.

5.2 MGT Measure System Maintenance

According to the RR 250-C47B Operation and Maintenance Manual, Section 72-00-00 titled "Engine - Inspection/Check", scheduled inspections are given in Tables 603 - 608. A NOTE was included that stated that "Scheduled Inspections given in Table 606 can only be used if the operator is using an approved third generation (HTS) MIL-PRF-23699 oil". According to the maintenance records, the accident engines were serviced with Aeroshell 560 oil. The Aeroshell Turbine Oil 506 specification sheet states that this oil is a third generation, high performance oil fully approved as a high thermal stability (HTS) oil that meets military performance (MIL-PRF) MIL-PRF-23699G Grade HTS standards; thus, for this helicopter Table 606 applies.

In Table 603, the MGT indicating system check is required as part of the 150-hour inspection and in Table 606, the MGT indication check is part of the 300-hour inspection. In both cases it states that

During ground run with engine at 100% N₂, Monitor MGT using (MT) Maintenance Terminal Software, analog parameter page. Compare MT value with aircraft MGT gage. Must agree within 5°C. If not within limits, use thermocouple simulator to identify problem.

Table 604, which is the 300-hour inspection, calls out for the inspection of the thermocouple assembly (TOT/MGT).

As previously mentioned in Section 1.3 titled Engine Maintenance History, the last 300-hour/12-month engine maintenance inspection was conducted on January 5, 2024, by Brainerd Helicopter Services Inc. in Brainerd, Minnesota in accordance with Rolls-Royce maintenance manual Chapter 72, Table 606. The 300-hour/12-month inspection was conducted 266.6 prior to the accident.

Submitted by:

Jean-Pierre Scarfo

Aerospace Engineer – Powerplant Lead

APPENDIX A - TURBINE ASSEMBLY SN CAT-44390 FAA FORM 337 - MAY 2023

(11)

 US Department of Transportation Federal Aviation Administration		MAJOR REPAIR AND ALTERATION (Airframe, Powerplant, Propeller, or Appliance)		OMB No. 2120-0020 Exp: 8/31/2014	Electronic Tracking Number
INSTRUCTIONS: Print or type all entries. See Title 14 CFR §43.9, Part 43 Appendix B, and AC 43.9-1 (or subsequent revision thereof) for instructions and disposition of this form. This report is required by law (49 U.S.C. §44701). Failure to report can result in a civil penalty for each such violation. (49 U.S.C. §46301(a))					
1. Aircraft	Nationality and Registration Mark 20BH		Serial No. 53242		
	Make BELL		Model 407	Series	
2. Owner	Name (As shown on registration certificate) CHEMAIR HELICOPTERS. INC.		Address (As shown on registration certificate) 318 E. ROCKST City JEFFERSON State WI Zip 53549-2159 Country USA		
3. For FAA Use Only					
4. Type		5. Unit Identification			
Repair	Alteration	Unit	Make	Model	Serial No.
☐	☐	AIRFRAME		(As described in Item 1 above)	
☒	☐	POWERPLANT	ROLLS ROYCE	250-C47B	CAT-44390
☐	☐	PROPELLER			
☐	☐	APPLIANCE	Type		
			Manufacturer		
6. Conformity Statement					
A. Agency's Name and Address			B. Kind of Agency		
Name DAVID R. PARRAS Address 313 VICTORY LANE City MANSFIELD State TX Zip 76063 Country USA			☒ U. S. Certified Mechanic ☐ Foreign Certified Mechanic ☐ Certified Repair Station ☐ Certified Maintenance Organization		
			C. Certificate No.		
			A&P3092815		
D. I certify that the repair and/or alteration made to the unit(s) identified in item 5 above and described on the reverse or attachments hereto have been made in accordance with the requirements of Part 43 of the U.S. Federal Aviation Regulations and that the information furnished herein is true and correct to the best of my knowledge.					
Extended range fuel per 14 CFR Part 43 App. B ☐		Signature/Date of Authorized Individual 			
7. Approval for Return to Service					
Pursuant to the authority given persons specified below, the unit identified in item 5 was inspected in the manner prescribed by the Administrator of the Federal Aviation Administration and is ☒ Approved ☐ Rejected					
BY	FAA Fit Standards Inspector	Manufacturer	Maintenance Organization	Persons Approved by Canadian Department of Transport	
	FAA Designee	Repair Station	Inspection Authorization	Other (Specify)	
Certificate or Designation No. 		Signature/Date of Authorized Individual 05/21/2023			

FAA Form 337 (10/06)

Page 1

NOTICE

Weight and balance or operating limitation changes shall be entered in the appropriate aircraft record. An alteration must be compatible with all previous alterations to assure continued conformity with the applicable airworthiness requirements.

8. Description of Work Accomplished

(If more space is required, attach additional sheets. Identify with aircraft nationality and registration mark and date work completed.)

N20BH
Nationality and Registration Mark

05/21/2023
Date

MODEL 250-C47B TURBINE P/N 23063354 S/N CAT-44390

T.T. 8304.5 T.S.O.-0- T.S.I.-0-

1. Overhaul Inspected.
2. Sent all required items to Metro Aviation Repair Station#CRS: HDNR610E for Non-Destructive Testing under tracking #Eng14143.
3. Installed the following New Wheels:
 - 1st Stage Wheel P/N M250-10227 S/N X668284
 - 2nd Stage Wheel P/N M250-10658 S/N X676126
 - 3rd Stage Wheel P/N M250-10748 S/N X679276
 - 4th Stage Wheel P/N 23066744 S/N X660218
4. Installed the following New Items:
 - #1 Nozzle P/N M250-10518 S/N MK267951, Omega Ring P/N 23060164 Batch#7365665901,
 - PT Blanket P/N 23008555 Batch#7365563426, #8 Thrust Plate P/N M250-10982 Batch#7365986539,
 - #8 Bearing Cage P/N 23031494 Batch#7365694264, #8 Nut P/N 6840407 Batch#7365660420,
 - Inner PT Shaft P/N 23071313 S/N GK590623, Outer PT Shaft P/N 23038136 S/N WN62499,
 - Washer Cup P/N 6889319 Batch#7365300840, Tie Bolt P/N 23008030 S/N NC94669,
 - Spline Adapter P/N 23076529 S/N GK591948, Adapter Lock Nut P/N 23076531 Batch#7364505194,
 - Blanket Fireshield P/N 23005743 Batch#7365160751, T.O.T. Harness P/N 23034927 S/N FF497633,
 - N1 Coupling P/N 23032345 S/N UT267449, N2 Coupling P/N 6889069 S/N GK591623,
 - Tie Bolt Nut P/N 6840406 Batch#7365332182, 19-24 Seal P/N 23090547 Batch#1212352682,
 - Oil Slinger P/N 6888602 Batch#7365927707, 35-37 Seal P/N 23033862 Batch#7364735257,
 - Sump Cover P/N M250-10355 Batch#7365727210, Cover Oil GP P/N 6898945 Batch#7365733913,
 - U Ring P/N 6893603 Batch#7365679774, Oil Nozzle P/N 23001832 Batch#7365650124,
 - Outer PT Nut P/N E23001801 S/N FP1-257, Inner PT Nut P/N 23030982 Batch#7365698588,
 - Igniter Lead P/N 23060816 S/N JH2203276, Oil Screen P/N 23001827 Batch#7365502981,
 - #5 Retaining Ring P/N 23090049 Batch#7365305238, U-Ring Gasket P/N 6875350 Batch#7365702054,
 - Damper Segment P/N 6844422 Batch#7365675539, Thrust Plate P/N 6870796 Batch#7365794515.
5. Installed the following New Bearings:
 - #5 P/N M250-10795 S/N NWF21-2945, #6 P/N M250-10117 S/N NWK20-0836,
 - #7 P/N M250-10117 S/N NWD21-1850, #8 P/N M250-10244 S/N NWF20-0327, & #7 Race P/N 6870031 S/N NWC20-0771.
6. Installed the following Overhauled Items:
 - #2 Nozzle P/N M250-10635 S/N X677559, #3 Nozzle P/N 23064583 S/N X559347,
 - #4 Nozzle P/N 23064596 S/N X63079, PT Support P/N 23088840 S/N MK41628, GP Support P/N 23066731 S/N MK45813,
 - Containment Ring P/N 23054648 S/N DD517057, #5 Seal P/N 23032327 S/N CAL7919,
 - #1 Nozzle Shield P/N 23073566 S/N 09-01-14, Combustion Liner P/N 23064570 S/N DC0911-246,
 - Combustion Case P/N M250-10867 S/N 262151, Exhaust Collector P/N M250-10217 S/N EXA10094,
 - Vertical Firewall P/N 23032326 S/N CAL7986, #3 Nozzle Shield P/N 6892832 S/N CAL7920,
7. GP Rotor Curvic engage 3.416 and PT Rotor Curvic engage 2.396.
8. Balanced GP Rotor P/N 23074531 S/N X677559 by Action Aircraft, Approved Cert. #A9UR626J under W/O #A20222973 tracking #22-16888, AND PT Rotor P/N 23064627 S/N 45109 under W/O #A20222977 tracking #22-16902.
9. C/W Run-out of Turbine Supports and Nozzles.
10. Checked N1 and N2 Fwd and Aft Clearances.
11. Checked Target Oil Flow to All Bearings.
12. Pressure check of #8 Oil GP Cover passed with no leaks.
13. Complied with all Torques and Safeties.
14. Complied with the following:
 - CEB-72-6068, CEB-72-6064, CEB-72-6080, CEB7-2-6086, CEB-72-6088,
 - CEB-72-6089, CEB-72-6090, CEB-72-6073, CEB-72-6083

All work done I/A/W Rolls Royce 250-C47 Overhaul Manual CSP22001 2nd Edition, Rev. 20, Dated September 15,2019.

END

☐ Additional Sheets Are Attached

APPENDIX B - TURBINE ASSEMBLY SN CAT-44390 RECORD SHEET

(15)

Assembly Record Turbine Assem



Part V
Page No. 3

Turbine Serial Number CAT- 44390

Engine Model 250- C47B

		Installed			Removed		
		Turbine		Component	Turbine		Component
Nomenclature	Part Number	Date	TT	TT	Date	TT	TT
	Serial Number		Cycles	Cycles		Cycles	Cycles
1st Stage Wheel	23053299	22 Dec 08	4631.8	0.0	8-30-13	6432.5	1800.7
	X576332		5586	0		7694	2108
1st NOZZLE SHIELD	23064380	22 DEC 08	4631.8	0.0	11/2/21	8304.5	3672.7
	N/A		5586	0		9758	4172
1ST STG WHEEL	M250-10227	8-30-13	6432.5	NEW	11/2/21	8304.5	1872.5
	X612534		7694	NEW		9758	2064
2ND STG WHEEL	M250-10658	8-30-13	6432.5	NEW	11/2/21	8304.5	1872.5
	X617346		7694	NEW		9758	2064
1st Stg Wheel	M250-10227	5/21/23	8304.5	0.0			
	X668284		9758	0.0			
2nd Stg Wheel	M250-10658	5/21/23	8304.5	0.0			
	X676126		9758	0.0			
3rd Stg Wheel	M250-10748	5/21/23	8304.5	0.0			
	X679276		9758	0.0			
4th Stg Wheel	23066744	5/21/23	8304.5	0.0			
	X660218		9758	0.0			

F-2785D (12/98)

