



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

February 9, 2021

AIRWORTHINESS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB No: CEN20FA035

A. ACCIDENT

Operator: Panther Helicopters, Inc.
Aircraft: Bell 407, Registration N79LP
Location: Gulf of Mexico
Date: December 7, 2019
Time: 0917 central standard time

B. GROUP

Group Chairman:	Chihoon Shin National Transportation Safety Board Washington, District of Columbia
Member:	Keith Kibodeaux Federal Aviation Administration Baton Rouge, Louisiana
Member:	Lance Panepinto Panther Helicopters Belle Chasse, Louisiana
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Member:	Jon Michael Rolls-Royce Indianapolis, Indiana
Member:	Nora Vallée Transportation Safety Board of Canada Quebec, Canada
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LIST OF ACRONYMS

ADS-B	Automatic Dependent Surveillance – Broadcast
ATT	aircraft total time
CCA	circuit card assembly
CEFA	combined engine filter assembly
CFR	<i>Code of Federal Regulations</i>
CSL	Commercial Service Letter
CT	computed tomography
ELT	emergency locator transmitter
ETSO	engine time since overhaul
FAA	Federal Aviation Administration
FADEC	full-authority digital engine control
FSDO	Flight Standards District Office
HMU	hydromechanical unit
KIAS	knots indicated airspeed
LA	Louisiana
Ng	engine gas producer speed
Np	engine power turbine speed
Nr	helicopter rotor speed
NTSB	National Transportation Safety Board
NVM	nonvolatile memory
N1	gas producer turbine-to-compressor
N2	power turbine-to-pinion gear
PCL	pitch control link
P/N	part number
PRCS	pedal restrictor control system
S/N	serial number
STC	supplemental type certificate
TCDS	type certificate data sheet
TRDS	tail rotor drive shaft

C. SUMMARY

On December 7, 2019, at 0917 central standard time¹, a Bell 407 helicopter, N79LP, went missing in the Gulf of Mexico about 25 nautical miles southeast of Grand Isle, Louisiana (LA). The commercial rated pilot was missing and a passenger was fatally injured. The helicopter was registered to and operated by Panther Helicopters, Inc., under the provisions of Title 14 *Code of Federal Regulations (CFR)* Part 135 as a business flight. Visual meteorological conditions prevailed in the area and the flight operated on a company visual flight rules flight plan. The flight had departed from oil platform WD109 and was en route to oil platform WD73. According to the operator, the weather was reported as wind from 050 at 10 knots, broken clouds at 1,700 ft, no precipitation, and visibility of 5 miles in haze. A worker on WD73 reported gray skies with the clouds about 800 to 1,000 ft and 7 to 10 miles of visibility.

According to the Federal Aviation Administration (FAA), at 0915 the pilot contacted WD73 and reported he was 10 minutes away. At 1011, when the helicopter did not arrive at WD73, the platform personnel reported them overdue. The company called the FAA and the United States Coast Guard to report the helicopter overdue and an alert notice was issued at 1112. The Coast Guard recovered several pieces of small debris from the accident helicopter, including a cargo door, a compressed gas cylinder, and seat cushions. The debris was found near platform ST41, about 25 miles west of where the main wreckage was eventually located. The main wreckage was located on the sea floor about 190 ft deep and about 350 ft southwest of the last (Automatic Dependent Surveillance – Broadcast) ADS-B point. Prior to recovery of the helicopter, on December 16, 2019, a shrimp trawler unintentionally caught the helicopter in its nets and dragged the wreckage about 3 miles. When the trawler stopped, the wreckage eventually broke loose and sunk back to the sea floor. The main wreckage was later recovered from the Gulf of Mexico on December 20, 2019 and arrived in LA on December 21, 2019.

On December 22, 2019, the Airworthiness Group Chairman performed initial documentation of the recovered wreckage at Southern Aircraft Recovery in Baton Rouge, LA. The engine electronic control unit (ECU) and the cockpit caution and warning panel were retained for further investigation.

On January 8, 2020, members of the Airworthiness Group convened at Southern Aircraft Recovery to examine the recovered wreckage. The examination revealed anomalous wear of the power turbine pinion gear and adjacent bearings. Subsequently, the engine was sent to Arrow Aviation in Lafayette, LA. On January 9, 2020, members of the Airworthiness Group convened at Arrow Aviation to conduct a disassembly and examination of the engine. Selected components from the disassembly were retained for further investigation. On January 10, 2020, members of the Airworthiness Group convened at the FAA Baton Rouge Flight Standards District Office (FSDO) in Baton Rouge, LA to review the maintenance records from the incident helicopter.

D. DETAILS OF THE INVESTIGATION

1.0 HELICOPTER INFORMATION

1.1 HELICOPTER DESCRIPTION

The Bell 407 is type certificated under FAA type certificate data sheet (TCDS) No. H2SW. The Bell 407 has a four-bladed main rotor system that provides helicopter lift and thrust, and a two-bladed teetering tail rotor system that provides thrust to counteract main rotor torque effect

¹ All times in this report are central standard time unless otherwise indicated.

and control helicopter yaw. The helicopter is equipped with one Rolls-Royce (formerly Allison) Model 250-C47B turboshaft engine, mounted behind the main gearbox, which has a maximum continuous power rating of 600 shaft horsepower per engine TCDS No. E1GL. The helicopter was equipped with a skid-type landing gear.

The terms “left”, “right”, “up”, and “down” are used when in the frame of reference of looking forward from the aft end of the helicopter, i.e. aft looking forward (ALF). All locations and directions will be viewed from ALF unless otherwise specified. Additionally, clock positions are in the ALF frame of reference unless otherwise specified.

1.3 HELICOPTER AND ENGINE HISTORY

The accident helicopter, airframe serial number (S/N) 53027, was manufactured in June 1996. At the time of the accident, the helicopter Hobbs meter indicated 3,816.7 hours and the helicopter had an aircraft total time (ATT) of 8,500.8 flight hours. According to the operator, the accident helicopter was acquired in the autumn of 2017, and an FAA special registration number assignment form showed airframe S/N 53027 received registration N79LP on October 11, 2017 and was registered to Panther Helicopters, Inc.

Engine S/N CAE-847031 was installed on N79LP and at the time of the accident the engine had an estimated total time of 7,584.7 hours and an engine time since overhaul (ETSO) of 1,690.6 hours. The engine was originally installed new onto airframe S/N 53020 on April 19, 1996 and was removed on March 11, 2008 at a total time of 436.5 hours. The engine was subsequently installed on airframe S/N 53027 on the same day.

2.0 ON-SCENE AND POST-RECOVERY WRECKAGE EXAMINATION

On December 22, 2019, the Airworthiness Group Chairman performed initial documentation of the recovered wreckage at Southern Aircraft Recovery in Baton Rouge, LA. The ECU was retained and preserved by the NTSB Recorders Laboratory for future download of recorded data. See Section 5.0 of this report for additional details of the ECU data download. The cockpit caution and warning panel was recovered in the wreckage and retained for bulb filament analysis. See Section 6.0 of this report for additional details of the bulb filament analysis.

On January 8, 2020, members of the Airworthiness Group convened at Southern Aircraft Recovery to examine the recovered wreckage.

2.1 STRUCTURES

2.1.1 OVERVIEW

The helicopter structure comprises the main fuselage, the tail boom and empennage, and a skid-type landing gear. The main fuselage contains the cockpit, cabin, bladder-type fuel tanks, and baggage compartment. The main fuselage supports the engine, main rotor gearbox, and the main rotor and its controls. The intermediate fuselage connects the tail boom to the main fuselage. The tail boom and empennage contain the tail rotor drive system and the tail rotor and its controls. The left and right horizontal stabilizers are mounted about mid-length of the tail boom. Vertical end plates are mounted to the outboard edge of each

horizontal stabilizer. The upper and lower vertical fins are mounted near the aft-end of the tail boom and are co-located with the tail rotor gearbox.

2.1.2 OBSERVATIONS

The main fuselage was fractured, folded, and twisted in multiple locations, but remained together via wiring as well as netting from the shrimp trawler (**Figure 1**). The cockpit and a portion of the cabin, containing the rear-facing seats, were present. The left and right cockpit seats remained attached to the airframe hard points and the restraints in both seats remained buckled.



Figure 1. The recovered helicopter wreckage.

The rear portion of the fuselage, containing the forward-facing cabin seats and the baggage compartment, was present but partially attached to the main wreckage. The cabin roof structure was fractured at the main transmission deck and the engine deck. A portion of the aft cabin bulkhead, where the forward-facing cabin seat backs are located, was separated and not recovered. The main fuel tank bladder was mostly separated from the airframe but no punctures were observed. The fuel tank bladders underneath the rear-facing seats were present in the fuselage.

The forward transmission fairing, engine fairing, and the oil cooler fairing were not recovered. The forward fairing, covering the main rotor hydraulic servoactuators, was separated from the main fuselage and recovered. The engine air inlet particle separator and its fairing remained installed on the roof of the airframe. The cockpit and cabin doors were not recovered.

The forward portion of the tail boom remained connected to the intermediate fuselage but was fractured at the tail boom tube structure at the painted registration marks (**Figure 2**). The engine oil reservoir was partially attached to the intermediate fuselage. The drain plug and oil filler cap were not installed on the reservoir but remained attached via ball chain. No residual oil was observed within the reservoir. The oil cooler blower and radiator remained attached to the intermediate fuselage. The blower could not be manually rotated. The remainder of the tail boom, including the vertical and horizontal stabilizers, was not recovered.



Figure 2. The separated section of intermediate fuselage and tail boom.

The left longitudinal skid tube was whole but separated from both lateral cross tubes immediately above the skid tube saddle. The floats on the left longitudinal skid remained attached to the skid tube. The right longitudinal skid tube remained attached to the aft lateral cross tube, which remained attached to the main fuselage. The right longitudinal skid tube was separated from the forward lateral cross tube, immediately above the skid tube saddle. The forward lateral cross tube was separated from the main fuselage and exhibit deformation.

2.2 MAIN ROTOR SYSTEM

2.2.1 OVERVIEW

Power from the engine accessory gearbox is transferred through a freewheeling unit to the main rotor gearbox via the engine-to-transmission (input) drive shaft. Kaflex couplings on both the forward and aft ends of the input drive shaft allow for minor

misalignment. The accident helicopter was equipped with a rotor brake which was installed between the engine accessory gearbox output flange and the aft Kaflex coupling of the input drive shaft. The main rotor gearbox contains a single-stage sun and planetary gear system that turns the main rotor shaft (also known as the main rotor mast). The main rotor hub is splined onto the main rotor shaft. The main rotor gearbox is attached to the airframe via pylon assemblies containing elastomeric mounts for vibration dampening.

The main rotor hub is composed of a yoke which is mounted between an upper and lower [hub] plate. Each main rotor blade is connected to the yoke via a grip assembly. An elastomeric thrust bearing, which accommodates blade pitch changes, a pitch horn, and an elastomeric shear (pivot) bearing attach to the blade grip. An elastomeric lead-lag damper bearing, installed inboard of the pitch horn, is connected to the pivot bearing as well as both the upper and lower hub plates. The four main rotor blades are identified by color and the shape² of identification stickers adhered to each rotor blade, presented in the order of advancing rotation: 'blue' (diamond), 'orange' (square), 'red' (triangle), and 'green' (circle). The main rotor blades are composite in construction, with a fiberglass spar, fiberglass skin, and Nomex honeycomb core. Blade pitch control is achieved via pitch change links (PCL) connected between each blade's pitch horn and the rotating swashplate. The accident helicopter was previously equipped with a Frahm-type damper, normally mounted to the top of the main rotor hub for vibration attenuation, which was removed prior to the accident.

2.2.2 MAIN ROTOR OBSERVATIONS

The main rotor head remained attached to the main rotor shaft. The yoke exhibited multiple fractures. All four main rotor spindles and grips remained attached to the yoke. The 'blue' PCL remained attached to the rotating swashplate but was fractured near its upper rod end that remained attached to its pitch horn. The 'orange' PCL remained whole and attached on both ends to its pitch horn and the rotating swashplate, but its pitch horn had fractured from its spindle. The 'red' PCL remained whole and attached on both ends to its pitch horn and the rotating swashplate. The 'green' PCL remained attached to the rotating swashplate but was fractured about 2/3 of the way up its tube; the remainder of the 'green' PCL and its pitch horn were not recovered. The vibration absorber remained installed on the main rotor head.

Two of the four main rotor blades did not exhibit fragmentation and were generally whole (**Figure 3**). For the remaining two main rotor blades, only their inboard sections, from the blade attachment bolt bores outboard about 72-74 inches, were recovered. The inboard sections of these blades did not exhibit fragmentation. An outboard section of a blade, about 113 inches in length up to the blade tip end, was recovered; this section was missing the majority of its afterbody.

² Stickers of a certain shape and color are normally placed on the Bell 407 main rotor blades to identify them. The stickers are typically found on the blade grip and the inboard end of the blade.



Figure 3. The recovered main rotor blades.

2.2.3 MAIN ROTOR DRIVE SYSTEM OBSERVATIONS

The main rotor gearbox remained attached to the transmission deck. The gearbox housing exhibited extensive corrosion due to saltwater immersion. The main rotor gearbox chip detectors were removed and exhibited extensive corrosion, but no magnetic chips were present. The engine-to-transmission driveshaft remained connected to the main rotor gearbox via its forward Kaflex coupling. The engine-to-transmission driveshaft's aft Kaflex coupling was fractured, with portions of the coupling attached to the aft flange of the engine-to-transmission driveshaft as well as the freewheeling unit shaft flange. The rotor brake disc remained attached to the aft Kaflex coupling, and the remainder of the rotor brake assembly remained attached to a portion of the engine accessory gearbox housing. The steel drive shaft between the engine accessory gearbox and the oil cooler remained attached to the aft end of the freewheeling unit shaft. The aft bearing of the freewheeling unit was able to be rotated by hand but the forward bearing could not be manually rotated.

2.3 TAIL ROTOR SYSTEM

2.3.1 OVERVIEW

Power from the freewheeling unit is transferred to the tail rotor via the tail rotor drive system. The tail rotor drive system contains a total of 6 tail rotor drive shafts (TRDS): 1 steel TRDS³ is mounted between the freewheeling unit and the oil cooler blower followed by 5 aluminum TRDS⁴ between the oil cooler blower and the tail rotor gearbox. The 5 aluminum TRDS are supported along the tail boom structure by 4 hanger bearings. In this report, the aluminum TRDS are numbered 1 through 5 from the forward to aft position, respectively. Each aluminum TRDS is connected to each other via flexible coupling disc

³ The steel TRDS is also known as the forward short shaft.

⁴ The forward-most aluminum TRDS is also known as the aft short shaft.

packs. A flexible coupling disc pack is also found between the No. 5 TRDS and the tail rotor gearbox input flange. The tail rotor gearbox, mounted near the aft end of the tail boom, changes the direction of drive and also reduces the output speed of rotation at the tail rotor. The tail rotor gearbox output shaft connects to the tail rotor yoke.

The two-bladed tail rotor is a semi-rigid (teetering) rotor system. Each tail rotor blade, composite in construction, is attached to the tail rotor yoke via two spherical bearings. The two spherical bearings accommodate blade pitch changes. The tail rotor blades are identified by color as 'white' and 'red'.

2.3.2 TAIL ROTOR OBSERVATIONS

The two tail rotor blades remained attached to the yoke (**Figure 4**). The tail rotor blades did not exhibit fragmentation and were generally whole. Each of the two tail rotor PCLs were whole and remained attached to their respective tail rotor blade and the pitch change spider. The input control lever remained installed, but the input rod end tube was fractured and separated.



Figure 4. The recovered tail rotor and tail rotor gearbox.

2.3.3 TAIL ROTOR DRIVE SYSTEM OBSERVATIONS

The majority of the tail rotor gearbox housing was consumed by corrosion due to saltwater immersion. The output gear and output shaft were present, but the input pinion was not present. Sections of the tail rotor drivetrain remained installed in the intermediate fuselage section, but the TRDS exhibited fractures that were located adjacent to the fractures on the intermediate fuselage. The steel TRDS remained attached to the freewheeling unit, and the oil cooler blower forward flange remained attached to the aft

end of the steel TRDS. The splines between the oil cooler blower shaft and the flange did not exhibit anomalous wear.

2.4 FLIGHT CONTROL SYSTEM

2.4.1 OVERVIEW

The cockpit flight control system is composed of cyclic, collective, and directional (pedal) controls. The mechanical linkages for the pilot (right seat) flight controls are routed below the pilot and passenger seats, aft to the center of the helicopter, and vertically, in a compartment known as the “broom closet”, to the cabin roof. On the cabin roof, the cyclic and collective flight control linkages connect to three hydraulic actuators that are installed on the hydraulic rack in front of the main rotor gearbox. The three hydraulic actuators are identified as left, collective (center), and right. The left and right main rotor hydraulic actuators provide hydraulic assistance for the cyclic control while the collective main rotor hydraulic actuator provides hydraulic assistance for the collective control.

The pedal control linkages are routed from the cabin roof back to the tail rotor hydraulic actuator, located in the intermediate fuselage (between the main fuselage and tail boom), and then to the tail rotor. The tail rotor hydraulic actuator provides hydraulic assistance for the pedal controls. The Bell 407 is equipped with an airspeed-actuated pedal restrictor control system (PRCS).⁵

2.4.2 COCKPIT FLIGHT CONTROL SYSTEM OBSERVATIONS

The pilot controls were located on the right seat and the cyclic, collective, and pedal controls were installed. The co-pilot (left seat) cyclic and collective were not installed, but the pedals were installed with a lockout kit. The collective control was present in the cockpit but fractured and separated from its base. The collective control remained connected to its base via wiring. The throttle twist grip was found in the idle position. The cyclic control remained installed and was fractured in multiple locations, but remained connected via wiring. Multiple fractures were observed throughout the cockpit flight control linkages were observed between the broom closet linkages up to the hydraulic rack, but no evidence of disconnection was observed.

Both left and right sets of pedals were present, but the lateral control tube was fractured about midpoint of the tube. The tail rotor control tubes were present in the “broom closet” and within the cabin room structure but was fractured above the forward-facing cabin seats. The tail rotor hydraulic servo was present in the intermediate fuselage with remnant control linkages rod ends connected to it. The tail rotor control lever remained attached to a remnant piece of tail rotor gearbox housing with its fulcrum and its input rod end still connected, but the input rod had fractured and separated from the tail rotor control tube.

⁵ The PRCS restricts tail rotor authority at higher airspeeds by automatically adjusting the left pedal [forward] stop. When the helicopter accelerates above 55 knots indicated airspeed (KIAS), the PRCS solenoid energizes, engaging a cam which limits forward travel of the left pedal by 25%. When the helicopter decelerates below 50 KIAS, the PRCS solenoid de-energizes, disengaging the cam, allowing full forward travel of the left pedal. Pulling the emergency release cable for the PRCS allows for manual disengagement of the PRCS pedal stop. The emergency release cable has a copper witness wire to prevent inadvertent disengagement of the PRCS pedal stop.

2.4.3 ROTOR FLIGHT CONTROL SYSTEM OBSERVATIONS

The three main rotor hydraulic actuators remained attached to the hydraulic rack, located on the roof of the cabin in front of the main rotor gearbox. The right hydraulic actuator's forward rod end was fractured at its threads, but the rod end remained attached to the hydraulic rack. The left and center hydraulic actuators were whole.

2.5 ENGINE

2.5.1 OVERVIEW

The Rolls-Royce Model 250-C47B is a turboshaft engine that comprises a single-stage centrifugal compressor, a single can-type combustor, and a turbine assembly that incorporates a two-stage gas producer turbine and a two-stage power (free) turbine. The gas producer turbine and the power turbine are not mechanically connected and rotate independently of each other. The gas producer turbine drives the compressor as well as most of the engine-mounted accessories. The power turbine delivers power to the helicopter rotor system via the engine accessory gearbox. The accessory gearbox drive splines deliver power to the main rotor.

An airframe-mounted oil reservoir supplies oil to the [engine] pressure oil pump, which is filtered, via an oil filter element rated at 80 microns, and supplied to the engine bearings, splines, and gears. Within the gearbox, oil is delivered to the power turbine pinion gear and the Nos. 3 and 4 bearings via an oil delivery tube (also called the piccolo tube) and an oil nozzle on the aft side of the Nos. 3 and 4 bearing support housing ([Figure 5](#)). A mesh screen at the forward end of the oil delivery tube specifies a maximum opening of 0.020 inches. The engine oil system is a dry sump design. Scavenge pumps move the oil to a scavenge oil filter, with the filtering element rated at 3 microns, which is subsequently cooled by the oil cooler and returned to the oil reservoir. Two magnetic chip detectors are utilized to detect magnetic particles, which can indicate degradation of a gear or bearing, within the scavenge oil prior to it entering the scavenge oil filter. The engine installation on the Bell 407 does not have a chip fuzz burn capability.

The engine incorporates a full authority digital engine control (FADEC) system. The FADEC system is composed of an airframe-mounted ECU and an engine-mounted hydromechanical unit (HMU). The ECU, manufactured by Triumph Engine Control Systems, monitors engine parameters and performance, as well as the helicopter's power demands, and delivers the necessary control commands to the HMU. As a result, the HMU delivers a metered fuel flow to the engine in accordance with ECU control commands. The ECU continuously monitors the FADEC system for faults and will alert the pilot of specific faults that could significantly impact engine performance. Faults that are considered minor will not be alerted to the pilot during flight, but will be recorded and displayed during engine shutdown. The recorded fault history can be retrieved by maintenance personnel using a computer with the requisite software. Additionally, whenever certain engine parameters are exceeded, the ECU will record the exceedance in a separate incident recorder dataset; this dataset is only accessible by the engine and ECU manufacturers.

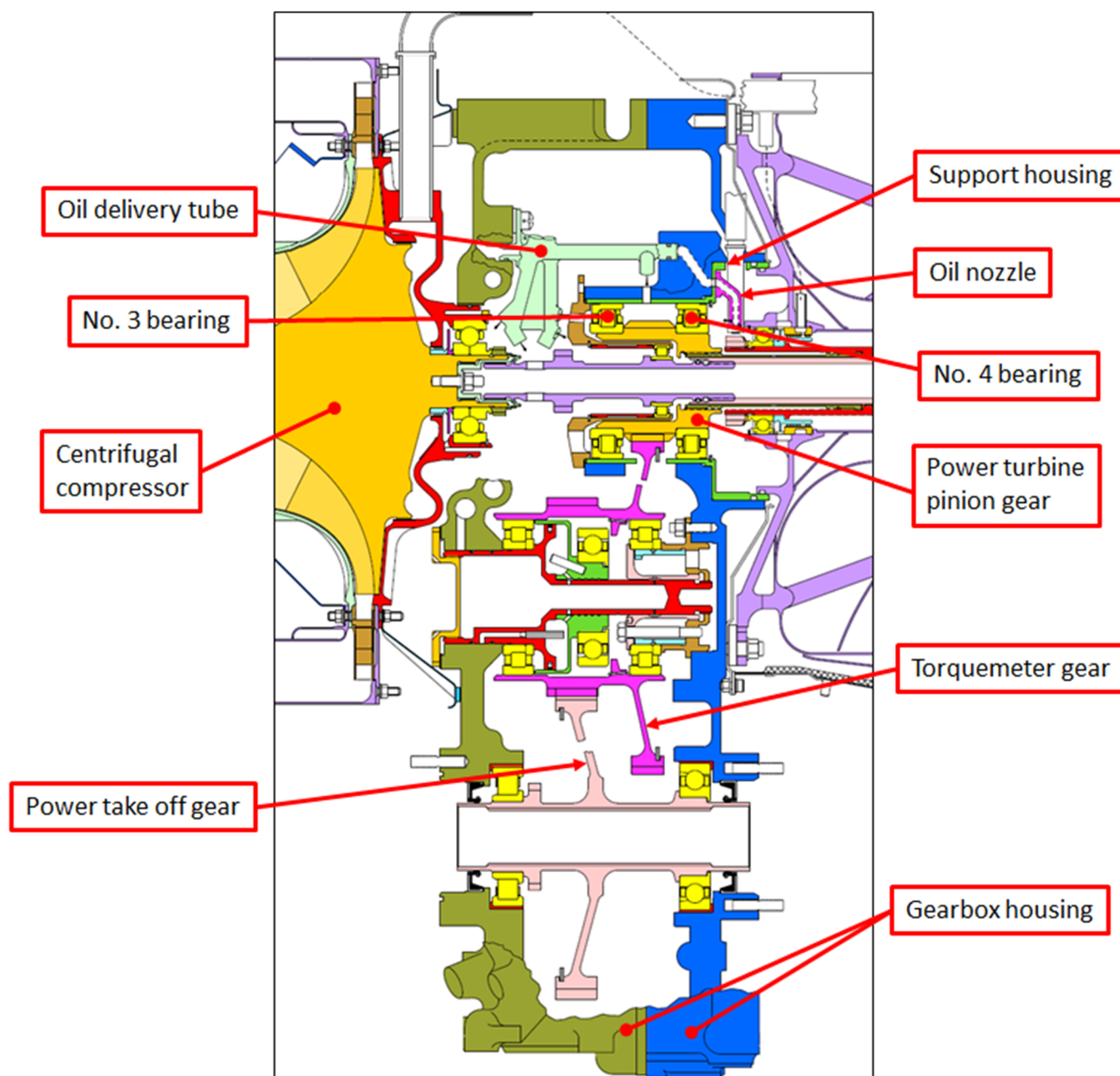


Figure 5. Schematic showing selected components within the engine accessory gearbox.

2.5.2 ENGINE OBSERVATIONS

The engine was recovered detached from the airframe except for the wiring harness, which was removed to separate the engine from the airframe. The engine mounts were present but exhibited fractures. The majority of the accessory gearbox housing was consumed by corrosion due to saltwater immersion, thus the compressor section was partially separated from the recovered combustion and turbine sections (**Figure 6**). The centrifugal compressor impeller remained installed within the compressor section. The leading edges of the impeller blades were caked in mud, but no anomalous damage was visible.

The airframe-mounted fuel filter remained attached to the airframe and was removed from its mount and disassembled. The fuel filter bowl contained about 0.25 ounces of liquid with a color and odor similar to that of Jet A fuel. The fuel filter was clear of contaminants. The throttle lever was present on the engine and was indicating about 15 degrees.



Figure 6. A view of the area where the engine accessory gearbox housing is normally present. The red arrow points to the area of the power turbine pinion gear and the Nos. 3 and 4 roller bearings.

Several gears and engine accessories from the accessory gearbox were recovered separate from the engine assembly. The power turbine pinion gear, part of the power turbine-to-pinion (N2) gear train, was found loose in the accessory gearbox and exhibited severe wear and smearing damage on its gear teeth and bearing shoulders (**Figure 7**). The No. 4 [roller] bearing, normally installed on the aft end of the power turbine pinion gear, was severely worn and its roller elements were found loose in the gearbox cavity containing it and the pinion gear (**Figure 8**).⁶ Nine of the twelve roller elements from the No. 4 bearing were recovered. For the No. 3 [roller] bearing, normally installed on the forward end of the power turbine pinion gear, the outer ring was present and exhibited severe wear.⁷ The inner race, roller elements, and bearing cage for the No. 3 bearing were not recovered. The torque meter gear, which meshes to the power turbine pinion gear, was not recovered. The power takeoff gear, which meshes to the torque meter gear, remained connected to the assembly containing the freewheeling unit, rotor brake, and the steel TRDS. The oil nozzle and oil pump remained attached to a separated piece of the accessory gearbox.

⁶ The Rolls-Royce 250-C47B bearings are numbered from 1 through 8, with the No.1 bearing located at the front of the engine and the No. 8 bearing is located at the rear of the engine. The No. 4 bearing supports the aft end of the power turbine pinion gear.

⁷ The No. 3 bearing supports the forward end of the power turbine pinion gear.



Figure 7. The recovered power turbine pinion gear exhibited smearing damage.



Figure 8. Roller elements from the No. 4 bearing found in the bearing support housing.

The engine was shipped to Arrow Aviation in Lafayette, LA for further examination. See Section 3.0 of this report for details of the engine examination at Arrow Aviation.

2.6 MISCELLANEOUS ITEMS

The emergency flotation system was installed under the provisions of Supplemental Type Certificate (STC) SR01450LA. All floats were outside their covers, but did not show evidence of inflation, e.g. the floats had a vacuum-deflated appearance. The compressed gas reservoir was recovered separated from the main wreckage, but photos from the recovery showed it remained attached to a fairing panel. The valve assembly remained attached to the reservoir. The valve pull cable and ball were outside of the valve but remained attached to the clevis connection but the remainder of the activation pull cable was not present.

An Artex ME406HM emergency locator transmitter (ELT) was recovered, separated from the main wreckage, and placed in a container of water for preservation purposes. On the front of the ELT, a switch was found in the “ARM” position.

3.0 ENGINE EXAMINATION AT ARROW AVIATION

On January 9, 2020, members of the Airworthiness Group convened at Arrow Aviation to conduct a disassembly and examination of the engine.

The combined engine filter assembly (CEFA), which is an engine-mounted assembly for fuel and scavenge oil filtration, was separated from the wreckage. The CEFA's oil filter bypass indicator had not extended, consistent with the filter not in bypass mode (**Figure 9**). Residual oil and fuel, along with salt water, were present in the CEFA, including the filter bowls. The fuel filter element was removed and no debris was observed. The scavenge oil filter element was removed and magnetic debris was found on the filter element and its filter bowl (**Figure 10**).

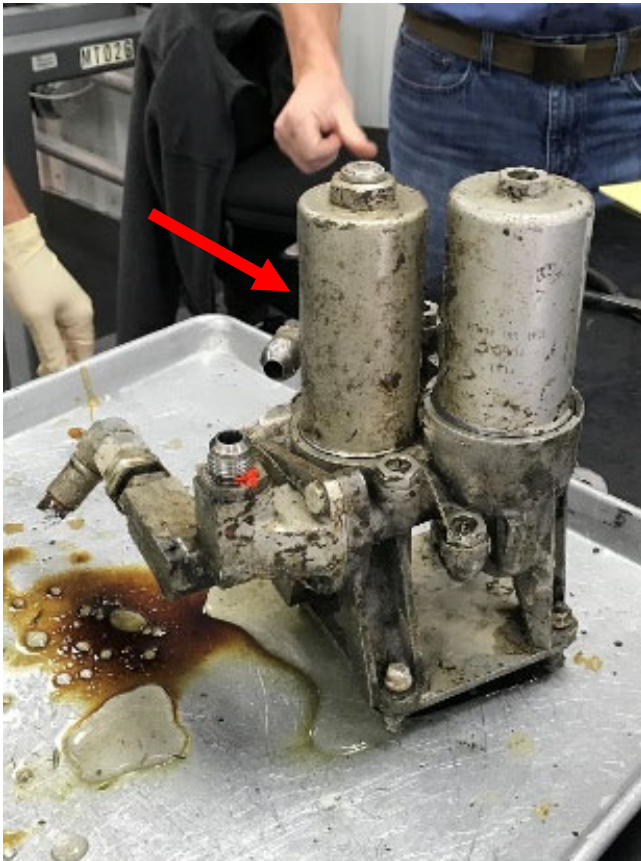


Figure 9. The recovered CEFA. The red arrow points to the scavenge oil filter assembly.

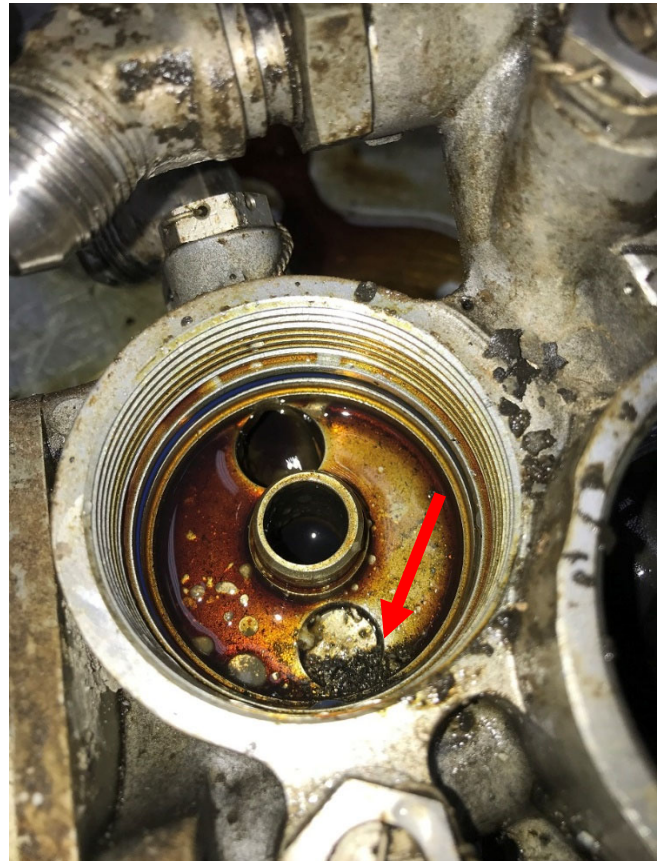


Figure 10. Magnetic debris (red arrow) found in the scavenge oil filter housing of the CEFA.

The HMU contained remnant fuel, which was collected. The splines that drove the HMU did not exhibit anomalous wear. Both gearbox chip detector tips were fractured and not recovered, but the chip detectors remained connected to their wiring. The thermocouple harness was removed and all probes were present but corroded with mud on the probe surfaces.

Residual oil was observed on the surfaces of the No. 8 bearing⁸ oil scavenge port. The No. 8 bearing oil nozzle was removed and residual oil was present. Black-colored deposits, consistent with coked oil, was present on the nozzle surfaces. The residual oil had a medium dark-brown appearance. The No. 8 bearing did not exhibit anomalous wear. The Nos. 6 and 7 scavenge oil port also exhibited residual oil on its surfaces, and the oil was mixed with mud. The pressurized oil line to the Nos. 6 and 7 bearings⁹ was removed and contained residual oil. The screen in the oil line was removed and it contained residual

⁸ The No. 8 bearing supports the aft end of the gas producer turbine rotors.

⁹ The Nos. 6 and 7 bearings are located between the second stage gas producer turbine and the first stage power turbine. The No. 6 bearing supports the aft end of the power turbine rotors and the No. 7 bearing supports the forward end of the gas producer turbine rotors.

mud. The oil nozzle for the Nos. 6 and 7 bearings was removed and residual oil was present. Black-colored deposits, consistent with coked oil, were present on the nozzle surfaces. The Nos. 6 and 7 bearings did not exhibit anomalous wear.

The outer combustor case was removed and mud was found within the combustion liner and the compressor discharge tubes. The gas producer turbine was removed from the exhaust collector, the latter of which contained the power turbine. Residual mud was found in both stages of the gas producer turbine. The splines on the gas producer section, which transmits drive to the centrifugal compressor via shafting, did not exhibit anomalous wear. The line to the fuel nozzle contained remnant fuel. The fuel nozzle was removed from the outer combustor case and mud was observed on the fuel nozzle surfaces. The nozzle was cleaned of mud and its screen was not deformed.

All blades were present on the two gas producer turbine rotors and the two power turbine rotors. The curvic coupling between the two gas producer turbine rotors did not exhibit anomalous damage. The curvic couplings between the two power turbine rotors and the power turbine outer shaft did not exhibit anomalous damage. Contact marks on the blade track were present on the first stage power turbine rotor, between the 7 and 9 o'clock positions, and the second stage power turbine rotor, from the 7 to 11 o'clock positions. The power turbine inner and outer [coaxial] shafts were removed and neither exhibited anomalous damage. The internal splines within the power turbine outer shaft did not exhibit anomalous wear. The No. 2.5 bearing was present but could not be manually rotated.¹⁰

The accessory gearbox, which normally contains the power turbine pinion gear as well as the Nos. 3 and 4 bearings, was removed from the engine. The oil nozzle for the Nos. 4 and 5 bearings remained attached to the gearbox, and the nozzle was corroded but did not exhibit other damage (**Figure 11**).¹¹ The No. 5 bearing did not exhibit anomalous wear. Corrosion and mud were observed throughout the gearbox, but additional roller elements from the Nos. 3 or 4 bearings were not found in the remnant mud or within the gearbox. The oil delivery tube for the Nos. 3 and 4 bearings, also known as the piccolo tube, exhibited severe corrosion (**Figure 12**). **Figure 13** shows a comparison of the recovered power turbine pinion gear to an exemplar power turbine pinion gear. The oil pump remained attached to a corroded portion of the gearbox and could not be manually rotated.

The spur adapter gear shaft was removed and its gear and spline teeth did not exhibit anomalous wear. The scavenge oil and supply oil lines to the No. 1 bearing were removed, and residual oil was observed within these lines. The centrifugal compressor was removed and its impeller blades were present with no anomalous damage. Additionally, there was no rotational scoring on the impeller shroud. The Nos. 1 and 2 bearings were present, did not exhibit anomalous damage, and had a oil-wetted appearance.¹²

The following engine components were retained: the No. 4 bearing; the piccolo tube oil nozzle; the oil nozzle for the Nos. 4 and 5 bearings; the housing for the Nos. 3 and 4 bearing; the power takeoff gear; the power turbine pinion gear; the scavenge oil filter and its filter bowl; the pressurized oil filter; the N2 shaft; the No. 2.5 bearing and its support; and an oil sample from the CEFA oil filter.

¹⁰ The No. 2.5 bearing supports the gas producer shaft and its bearing support is located within the inner diameter of the power turbine pinion gear.

¹¹ The No. 5 bearing supports the forward end of the power turbine rotors.

¹² The No. 1 bearing supports the forward end of the centrifugal compressor while the No. 2 bearing supports the aft end of the centrifugal compressor.



Figure 11. The oil nozzle (red arrow) located on the Nos. 3 and 4 bearing support housing.

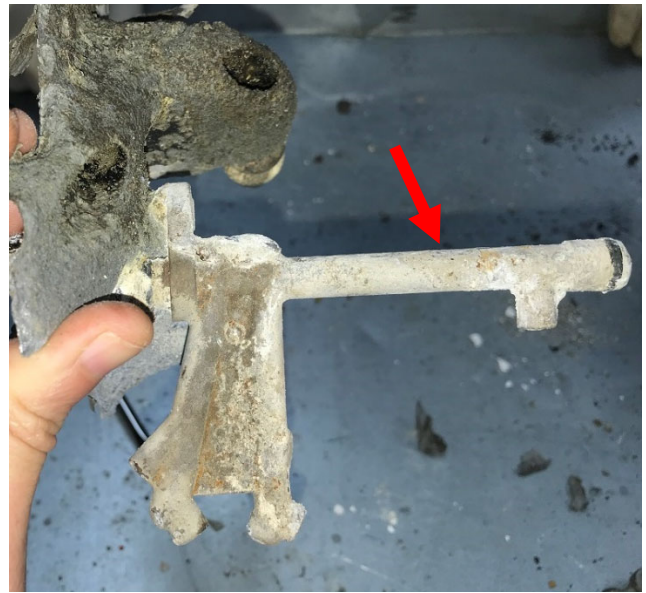


Figure 12. The recovered oil delivery tube (red arrow).



Figure 13. A comparison of the recovered power turbine pinion gear (left) and an exemplar power turbine pinion gear (right). The blue arrow points to the No. 3 bearing shoulder and the red arrow points to the No. 4 bearing shoulder.

4.0 LAB EXAMINATION OF ENGINE COMPONENTS

The piccolo tube and the oil nozzle (for the Nos. 4 and 5 bearings) were scanned using computed tomography (CT), prior to lab examination, in order to document any material within the internal

orifices.¹³ Components retained from the engine disassembly were shipped to Rolls-Royce Materials Engineering Laboratory in Indianapolis, Indiana for metallographic examination.¹⁴

4.1 GEARS AND BEARINGS

Examination of the power turbine pinion gear¹⁵ revealed evidence of fatigue fractures on six consecutive gear teeth. The fatigue fractures originated on the drive side tooth root fillets and exhibited multiple origins. The fatigue fractures progressed toward the coast side (the non-drive and non-contact side) of the gear tooth. No dimensional anomalies were observed at the fracture origins or the gear tooth root surfaces adjacent to the origins. All pinion gear teeth exhibited circumferential rubbing and smearing. The Nos. 3 and 4 bearing journals, on the power turbine pinion gear, also exhibited circumferential rubbing damage and thermal distress, with the No. 3 bearing journal showing substantial deformation and material loss compared to the No. 4 bearing journal. Analysis of the material composition and core microstructure of the power turbine pinion gear, away from areas of thermal distress, showed they met drawing requirements.

The No. 3 bearing outer ring exhibited material removal on its roller path and circumferential rubbing on the forward shoulder corner. The outer ring's raceway and forward shoulder corner had thermal distress. Analysis of the material composition and microstructure of the outer ring, away from areas of thermal distress, showed they met drawing requirements.

The No. 4 bearing outer ring exhibited material removal on its roller path and circumferential rubbing on the aft shoulder corner. Transferred material and roller impressions were observed on the raceway of the inner ring. The inner ring's forward shoulder also exhibited deformation in the forward direction. The inner diameter of the inner ring exhibited circumferential rubbing and transferred material. The outer ring's raceway and forward shoulder corner, the roller diameters, and the inner ring exhibited thermal distress. The recovered rollers all exhibited a circumferential rub step on one end. Analysis of the material composition of the outer ring, inner ring, and rollers met drawing requirements. Microstructure analysis away from the area of thermal distress was only able to be accomplished on the outer ring and a representative roller. The microstructure for both components met drawing requirements.

The No. 2.5 bearing support exhibited circumferential rubbing consistent with contact with the inner diameter of the power turbine pinion gear. The No. 2.5 bearing support was corroded and the aft face of its outer ring was deformed forward at the 12 o'clock position. The area of deformation on the aft face also showed evidence of circumferential rubbing.

4.2 OIL SYSTEM COMPONENTS

The CT scan of the piccolo tube showed material deposits on the internal passageway walls and all of its oil jets appeared to be blocked. Additionally, material was observed within the oil screen of the remnant gearbox housing material attached to the piccolo tube. The piccolo tube was sectioned in multiple locations to analyze the tube, the remnant gearbox housing material, and deposits within the tube. The oil delivery tube and gearbox housing material were consistent with

¹³ For additional details of the CT scan results, see the Computed Tomography Specialist's Factual Report in the docket for this investigation.

¹⁴ For additional details on the lab findings for the engine components, see the Rolls-Royce Materials Evaluation Report No. 20FAE-014 in the docket for this investigation.

¹⁵ The power turbine pinion gear was P/N 6893672 and S/N NN74678.

drawing requirements. The deposits within the oil jets were consistent with byproducts of aluminum (piccolo tube) corrosion and dirt. Additionally, fine metallic particles observed in the deposits were consistent with an iron-based alloy. A representative iron-based alloy particle was measured to be about 0.0008 inches long. Material seen within the oil screen was consistent with byproducts of magnesium (gearbox housing) corrosion.

The CT scan of the oil nozzle for the Nos. 4 and 5 bearings showed material deposits on the internal passageway walls and all of its oil jets appeared to be blocked. The oil nozzle was sectioned in multiple locations for further analysis. The oil nozzle material was consistent with drawing requirements. The blockage material was consistent with byproducts of aluminum (oil nozzle) corrosion and dirt. Additionally, fine metallic particles observed within the deposits was consistent with an iron-based alloy, as well as byproducts of magnesium corrosion. A representative iron-based alloy particle was measured to be about 0.0028 inches long.

5.0 ECU DATA RECOVERY

The ECU for the Rolls-Royce 250-C47B contains NVM which records engine history and engine faults in the maintenance terminal and engine exceedances in the incident recorder tool. The incident recorder captures data from multiple parameters at a 1.2 second interval. (Each interval containing recorded parameters is referred to as a ‘line’ in this section.) When a fault or an exceedance¹⁶ occurs, the ECU will record the last 10 lines prior to the exceedance and 40 lines after the fault or exceedance.

The accident ECU was transported to the NTSB Recorders Laboratory in Washington, District of Columbia, in order to dry and clean the internal circuit card assemblies (CCA). Subsequently, the ECU CCAs were shipped to Triumph Engine Controls to recover the recorded data. On January 23, 2020, the representatives from the NTSB, Rolls-Royce, and Triumph Engine Controls convened at Triumph facilities in West Hartford, Connecticut to recover the recorded data from the accident helicopter’s ECU. Inspection of the CCA identified white-colored particles and debris on some of its components. In order to mitigate the risk of damage by applying power to the CCA, the U40 chip¹⁷ was removed from the CCA and installed onto a test CCA. The NVM was successfully recovered from the U40 chip, which included engine fault history, engine history, and engine incident recording data.

The recovered data from the maintenance terminal showed multiple faults logged in the fault history of the primary governor, all of which related to power turbine or rotor functions. Three incidents were logged in the incident recorder: 1) an engine power turbine speed (Np) high exceedance at timestamp 1769:13:24.864¹⁸; 2) helicopter rotor speed (Nr) droop at timestamp 1769:13:24.936; and 3) a Np overspeed at timestamp 1769:13:24.960. In the ECU incident data, a total of 150 lines were downloaded from the incident history. Lines 1 through 26 contained recorded parameters, while Lines 27 through 150 contained all zeros. Line 1 of the incident data was at timestamp 1769:13:13.032 and Line 27 was at timestamp 1769:13:43.032.

Attachment 1 contains a table of selected parameters from the recovered data and **Figure 13** shows a graph of this data.

¹⁶ A fault is an error that may preclude normal operation of the ECU. An exceedance is when a parameter, such as torque or gas generator speed, operates outside of a predefined limit.

¹⁷ The U40 chip was the NVM to which faults and exceedances are written.

¹⁸ The timestamps are listed in HH:MM:SS.mmm, interpreted as hours:minutes:seconds:milliseconds

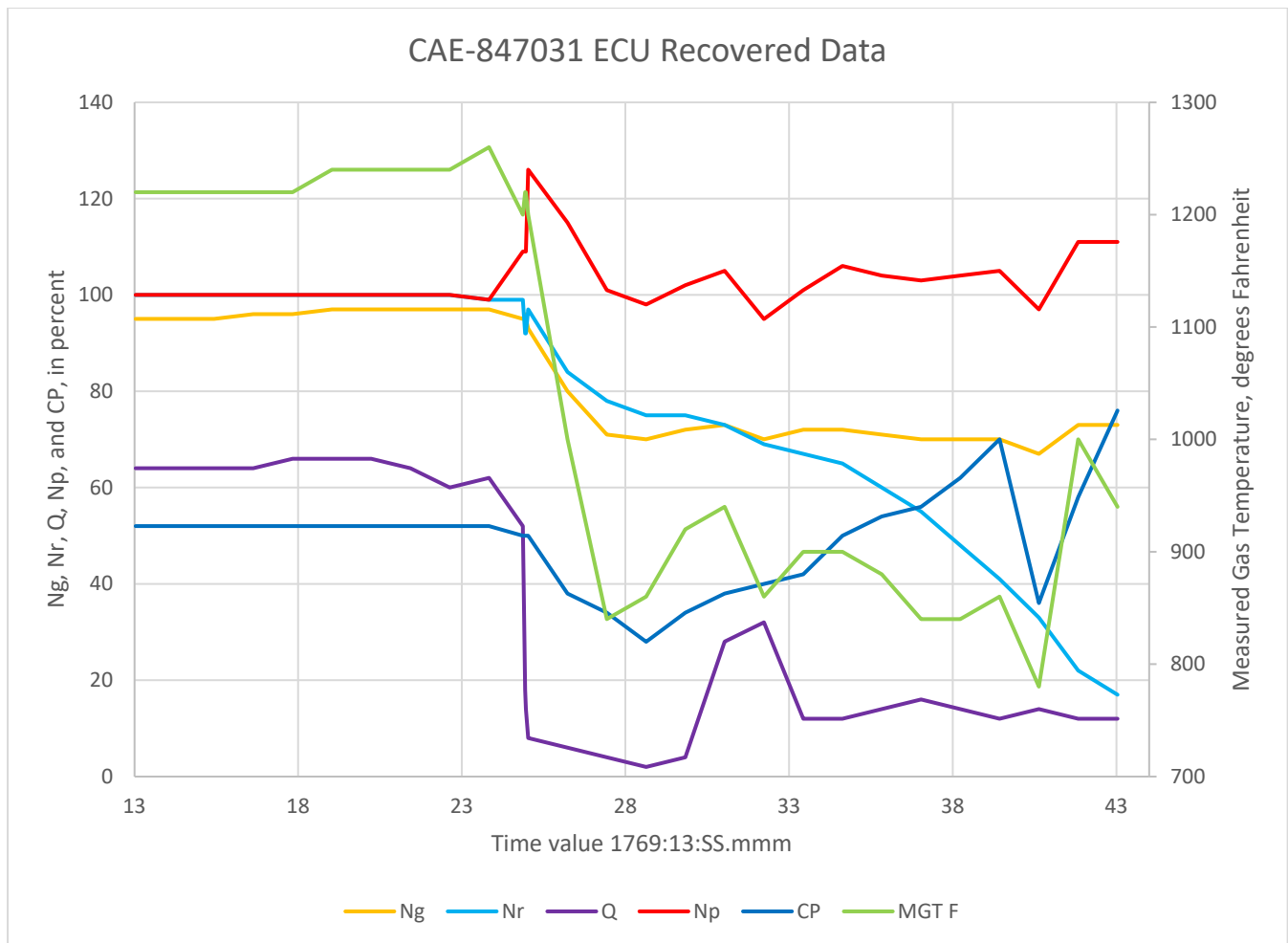


Figure 13. Graph of the recovered data from the ECU.
(Q=torque; CP=collective position; MGT F = measured gas temperature in Fahrenheit)

6.0 CAUTION AND WARNING PANEL

The caution and warning panel was examined by the NTSB Materials Laboratory. Each annunciator light consisted of three bulbs, and the panel was examined using a stereomicroscope with a 5x to 50x zoom. For several bulbs, the glass globe had a clouded appearance and the filaments could not be visually examined; these bulbs were removed from the panel and the individual bulb was x-rayed to examine the filaments. **Tables 1 and 2** lists the filament condition of the annunciator lights of the left and right sides of the caution and warning panel.

Table 1. The left side of the caution and warning panel. The shaded cell denotes annunciator light bulbs that exhibited filament stretching. No annunciator is present to the left of the “AUTO RELIGHT” annunciator. (Amber shading denotes a caution annunciator light.)

FLOAT TEST	FLOAT ARM	BAGGAGE DOOR	L/FUEL BOOST	R/FUEL BOOST	FADEC FAULT
	AUTO RELIGHT	LITTER DOOR	L/FUEL XFR	R/FUEL XFR	RESTART FAULT
ENGINE ANTI-ICE	START	HEATER OVERTEMP	FUEL FILTER	FUEL VALVE	FUEL LOW

Table 2. The right side of the caution and warning panel. The shaded cells denote annunciator light bulbs that exhibited filament stretching. No bulbs were present in the “BATTERY HOT” annunciator. (Red shading denotes a warning annunciator light and amber shading denotes a caution annunciator light.)

FADEC FAIL	ENGINE CHIP	GEN FAIL	BATTERY RELAY	BATTERY HOT	ENGINE OUT
FADEC DEGRADED	XMSN CHIP	XMSN OIL PRESS	XMSN OIL TEMP	ENGINE OVSPD	PEDAL STOP
FADEC MANUAL	T/R CHIP	CHECK INSTR	HYD SYSTEM	CYCLIC CENTERING	RPM

In the Bell 407 rotorcraft flight manual, Section 3 (Emergency/Malfunction Procedures) contains descriptions for various caution and warning panel indications. **Table 3** contains excerpts from Section 3 applicable to those annunciator lights in which filaments were found stretched.

Table 3. Excerpt from Section 3 of the Bell 407 rotorcraft flight manual for the annunciations that exhibited stretched filaments.

<i>Annunciator</i>	<i>Condition</i>	<i>Corrective Action</i>
FADEC FAULT	PMA and/or MGT, Np, or Ng automatic limiting circuit(s) not functional.	Remain in AUTO mode. Land as soon as practical. Applicable maintenance action required prior to next flight.
XMSN OIL PRESS	Transmission oil pressure is below minimum.	Reduce power; verify fault with gauge. Land as soon as possible.
HYD SYSTEM	Hydraulic pressure below limit.	Verify HYD SYS switch position. Accomplish hydraulic system failure procedure.
ENGINE OVSPD	Ng greater than 110% or NP versus TORQUE is above maximum continuous limit (102.1% Np at 100% torque to 108.6% Np at 0% torque)	Adjust throttle and collective as necessary. Determine if engine is controllable; if not, shut down. Maintenance action required before next flight.
ENGINE OUT	Ng less than $55 \pm 1\%$ and/or FADEC senses ENGINE OUT	Verify engine condition. Accomplish engine failure procedure.
CYCLIC CENTERING	Cyclic stick is not centered.	Reposition cyclic stick to center position to extinguish CYCLIC CENTERING light.
RPM (with low RPM audio)	Nr below 95%	Reduce collective and ensure throttle is in FLY detent position. Light will extinguish and audio will cease when Nr increases above 95%.

7.0 MAINTENANCE

7.1 ENGINE INSPECTION CRITERIA

Section 72-00-00 of the Rolls-Royce M250-C47B Operation and Maintenance Manual prescribes several inspections on a recurrent or conditional basis. These inspections are performed at preflight, postflight, 150-hour, 300-hour, and 2000-hour intervals.

The preflight and postflight checks include a general visual inspection as well as a check of the oil supply level. The postflight check also includes a check for extension of the impending bypass indicators for both the scavenge oil filter and the fuel filter.

The 150-hour inspection includes a step to inspect for the extension of the CEFA oil filter bypass indicator and, if extended, to examine and clean various oil system components and to drain and replace the engine oil.

The 300-hour inspection required performance of the 150-hour inspection items as well as additional items, including draining and refilling the engine oil at a 300-hour or 6 month interval, whichever occurred first. However, if an approved, high thermal stability oil was used, the maximum interval between oil changes could be extended to 600-hour or 12 months, whichever occurs first.

The 2000-hour inspection includes a visual examination of the power drive train gears per Rolls-Royce Commercial Service Letter (CSL) 6134. A note associated with this inspection states that it is not applicable to power turbine pinion gear P/N 23084247 and subsequent.

CSL 6134, titled “M250 Series IV Non-intrusive Gear Inspections Procedures and Criteria,” was originally issued December 7, 2009 with Revision 2 (latest) released April 9, 2012. According to CSL 6134, the document “provide[s] a standardize approach for evaluation the condition of M250 Series IV power gears without disassembling the gearbox module. The procedure is aimed primarily at the pinion to torquemeter mesh, but can also be applied to the torquemeter to power take off gear mesh.” The CSL contains procedures to visually inspect, using a flashlight and a mirror, each specified gears’ drive-side gear teeth. Additionally, the CSL provides criteria for indications that would require disassembly, for further evaluation of the gears, and for those that would not require disassembly.

7.2 ENGINE MAINTENANCE HISTORY

The engine gearbox, S/N CAG-47031, was installed new onto engine S/N CAE-847031 on April 15, 1996 and remained installed on that engine until the day of the accident. Below are select items from the records of the gearbox history.

On September 6, 2003, at an engine and gearbox total time of 1,294.7 hours, the engine gearbox was removed, with the reason for removal listed as “3+4 Bearing Mod” on the service record. On September 11, 2003, the Nos. 3 and 4 roller bearings were replaced by Standard Aero (in Manitoba, Canada) and the gearbox was returned to service.

On June 12, 2007, at an engine total time of 1,991.4 hours, the engine gearbox was removed and the 150-hour, 300-hour, and 2000-hour inspections were performed by Premier Turbines (in Neosho, Missouri). The gearbox was reinstalled onto the engine the same day.

On August 23, 2016, as part of an engine overhaul at Dallas Airmotive (in Grapevine, Texas), a 2000-hour nonintrusive gearbox inspection was performed at an engine total time of 5,894.1 hours. On September 14, 2016, the engine S/N CAE-847175 was installed on the accident helicopter at an ATT of 6,752.9 hours. (The accident helicopter was equipped with a loaner engine while the accident engine was overhauled.)

On September 22, 2016, at an ATT of 6,754.8 hours and an engine total time of 5,895.5 hours, the engine was removed from the helicopter due to “metal on upper plug.” A loaner engine, S/N CAE-847175, was installed on the helicopter. (See Section 7.3 of this report for additional details on the metal contamination occurrence in 2016.)

On November 16, 2016, the loaner engine was removed from the helicopter and engine S/N CAE-847031 was installed. The helicopter had an ATT of 6,811.6 hours and an engine had a total time of 5,895.5 hours.

On April 24, 2018, at an ATT of 7,180.7 hours (Hobbs time of 2,496.6 hours), an aircraft discrepancy log entry noted that the CEFA oil filter bypass indicator had extended. The log noted that the CEFA oil filter, P/N 7593359-001, was removed and replaced.

On September 25, 2019, at an ATT of 8,286.6 hours (Hobbs time of 3,602.5 hours), an aircraft discrepancy log entry noted that the CEFA oil filter bypass indicator had extended. The CEFA oil filter was removed and replaced according to the maintenance logbook. According to the operator’s director of maintenance, because no contamination was discovered on the CEFA oil filter, the CEFA oil filter bypass indicator itself was a suspected cause of the repeat bypass indication and was replaced sometime between October 23 and November 6, 2019. A corresponding discrepancy log entry for the CEFA oil filter bypass indicator replacement was not present in the aircraft records reviewed by the Airworthiness Group, and was likely on board the accident helicopter.¹⁹

A 150-hour engine inspection was last performed on November 30, 2019 at an ATT of 8,475.5 hours (Hobbs time of 3,791.4 hours). A 300-hour engine inspection was last performed on December 2, 2019, at an ATT of 8,482.4 hours (Hobbs time of 3,815.0 hours).

A 600-hour/12-month inspection and an engine oil change²⁰ were last performed on May 12, 2019 at an ATT of 7,786.3 hours (Hobbs time of 3,102.2 hours) as well as on October 21, 2019 at an ATT of 8,382.1 hours (Hobbs time of 3,698.0 hours). According to the director of maintenance, during the engine oil change the CEFA oil filter is inspected for contamination and reinstalled if none is found.

A review of the engine and aircraft maintenance records from April 2018 until December 2019 found no entries regarding engine chip indications or contamination discovered in the CEFA oil filter associated with a scavenge oil filter bypass indication. According to the director of maintenance, the CEFA oil filter bypass indicator extending is not a common occurrence but can happen during cold weather conditions.

7.3 ENGINE METAL CONTAMINATION OCCURRENCE IN 2016

According to maintenance records, the recently overhauled [accident] engine was removed from the helicopter on September 22, 2016 due to a chip detector indication. The engine was sent

¹⁹ The aircraft discrepancy log sheets used for N79LP could accommodate 3 separate entries. According to the director of maintenance, at the time of the accident, the discrepancy log sheet would remain in the helicopter until all 3 entries were filled, after which the discrepancy log sheet was transferred to a maintenance binder at the operator’s maintenance facility.

²⁰ According to the director of maintenance, Mobil Jet Oil 254 was used to service the engine. According to the manufacturer’s website, Mobil Jet Oil 254 is approved against the High Thermal Stability classification of MIL-PRF-23699.

to the overhaul facility, Dallas Airmotive, for repair. The repair paperwork, documented under sales order No. RPR44062, cited that there had been a “3rd chip light in 3 hrs after overhaul.” The discrepancy report from the repair paperwork stated:

MIO resulted from oil slinger contacting 19-24 seal dash detail. #8 bearing sleeve has a wear step from contact with the antirotation tab on the retaining plate.

The FAA Form 8130-3 Airworthiness Approval Tag associated with this repair, dated November 9, 2016, stated in part the following in the “remarks” field:

Repaired Engine For MIO. Disassembled Engine into modules to access Compressor for removal of #1 and #2 Bearings, also disassembled the Turbine for removal of #5, 6, 7, and 8 Bearings, Inspect the Gearbox for time continue and serviceability. Performed proper flushing to clear out used oil.

On November 16, 2016, the engine was subsequently installed onto N79LP and remained installed until the accident.

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