NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594

May 3, 2017

POWERPLANTS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB ID No.: ERA15FA221

A. ACCIDENT

Location:	West Columbia, South Carolina
Date:	May 23, 2015
Time:	0921 Eastern Daylight Time
Aircraft:	BR Legend LLC, Turbine Legend, N42BR

B. POWERPLANTS GROUP

Investigator-in-Charge:	Timothy Monville National Transportation Safety Board Ashburn, Virginia
Group Chairman:	Harald Reichel National Transportation Safety Board Washington, DC
Member:	David Gridley GE Aviation Cincinnati, Ohio
Member:	Gavin Hill Federal Aviation Administration Irving, Texas

C. SUMMARY

C.1 Accident Summary

On May 23, 2015, about 0921 eastern daylight time, an experimental amateur built BR Legend LLC Turbine Legend, N42BR, registered to BR Legend LLC, operated by a private individual, collided with trees and a pond approximately 1.2 nautical miles west of the Columbia Metropolitan Airport (CAE), West Columbia, South Carolina. Visual meteorological conditions prevailed at the time and a visual flight rules (VFR) flight plan was filed for the 14 Code of Federal Regulations (CFR) Part 91 personal flight from CAE to Asheville Regional Airport (AVL), Asheville, North Carolina. The airplane was destroyed and the commercial pilot and a dog were fatally injured. The flight originated from CAE about 0914 local time.

After the recovery from the water on the same day as the accident, the wreckage was temporarily stored in a hangar. Two days later, the engine was removed from the airframe, packed into a metal shipping container and shipped to Prime Turbines in Dallas, Texas, an authorized service center for GE/Walter engines and stored until the Powerplant Team arrived. The propeller was not sent with the engine. The team met at the Prime Turbines facility on July 15 to 17, 2015 to teardown and examine the engine. During this teardown, the external engine control accessories, consisting of the fuel control unit (FCU), fuel pump (FP), and the propeller control unit (PCU), were removed and shipped to the manufacturers, Jihostroj, facility at Velesin, Czech Republic where a teardown and detailed examination was performed on October 19, 2015. The propeller was retained until January 17, 2017, when it was transported to the Turbine Power Tech facility in Deland, Florida where it was dis-assembled and examined.

No pre-existing conditions were found on the engine, FCU, PCU and propeller that would have prevented normal operation. The FP exhibited scoring and cavitation damage on the side seals, consistent with historical operation consistent with long term fuel starvation.

The airframe fuel boost pump, part number 2003-B, serial number 103252, was removed from the airplane and sent to the manufacturer, Weldon Pump, in Oakwood Village, Illinois, where a functional test and teardown was performed on May 6, 2016. The manufacturers report noted the following performance discrepancy: With a 28-volt electrical supply, the fuel boost pump outlet fuel flow was measured to be 55 gallons per hour (gph); well below the factory requirement of 105 gph. Further examination revealed that the pump outlet adapter fitting was installed deeper than that allowed by the AND10064 specification for this interface, which impeded the maximum open position of the internal non-return poppet valve, thereby restricting the pump outlet fuel flow. After the incorrectly installed adapter fitting was removed, the pump performance was 109 gph, an acceptable factory test pressure.

D. DETAILS OF THE EXAMINATION

D.1 Engine Information

D.1.1 Engine History

The accident engine was a Walter M601D, serial number (S/N) 874001-D Series 487 and was manufactured in October 1987 at the Walter company in Prague, Czech Republic. After the purchase of the Walter Company by GE in 2008, the engine was designated a GE/Walter, Model M601D. According to the engine logbook, it was installed on a Let 410 airplane until October 24, 1990, at which time it had accumulated 1498 hours time since new (TSN) and was removed, pending a scheduled overhaul. According to the engine logbook, the recommended time-between-overhaul (TBO) for this model was 1,500 hours or 2250 cycles or 5 years, whichever comes first.

The logbook further revealed that the engine remained unused from October 1990 until January 8, 1999, a period of 8 years and 2 months, when a ‘test run’ was performed on it. After this ‘test run’, it again sat idle for another 4 years and 10 months until October 23, 2003, when it was installed onto the accident Turbine Legend airplane, registration N42BR. In conflict with the GE Aviation maintenance manual, there was no record of any preservation or de-preservation work done on the engine at any time. According to the GE Aviation Czech maintenance manual part No. 0982051, Chapter 72.03.00: ‘Operational Ability’, the engine preservation recommendations are:

- Engine preservation is required when the engine will encounter 30 days of inactivity.
- Engine preservation for a period of inactivity between 30 days to 3 months requires the preservation of the inner fuel system. There is no need to change the oil, however the existing oil must remain in the oil tank.
- A maximum of 3-month preservation time is recommended, after which the engine must be preserved again in same manner. The maximum time limit for continued preservation cycles is 5 years which is the TBO limit. A 3-year extension is available if a factory representative inspects the engine. If an engine is to be preserved for a longer period, then it is recommended that a shop revision[1] be performed by the manufacturer.
- A log book entry is required for every preservation action.

The last logbook entry on November 29, 2014, at which time the engine had accumulated 1926.3 hours TSN, with the last 428.2 hours being accumulated on the accident airplane, recorded that the engine had “been inspected…. in accordance with the scope and detail of the FSDO approved maintenance program dated Dec. 8, 2003 and was found to be in condition for safe operation”. No recording of engine start-stop cycles could be found in the engine logbook for the time between November 29, 2014 and the accident date May 23, 2015.

[1] According to GE Aviation Czech, a shop revision is a disassembly, inspection and reassembly of the engine.

D.1.2 Engine Description

The GE/Walter M601D engine is a 2-spool turbo-shaft engine which produces a takeoff power of 515 kilowatts (KW) (Figure 1). One power turbine stage drives the propeller through a 2-stage reduction gearbox. The gas generator consists of a compressor section, which has 2 axial, and 1 centrifugal stages driven by a single turbine. The combustion chamber is a reverse-flow annular type. The engine power management system consists of a fuel pump, which supplies the correct fuel pressure as well as filters the fuel, a fuel control unit (FCU), which governs the gas generator speed, and a propeller control unit (PCU), which governs the speed of the propeller as well as the power turbines since they are directly connected via the reduction gearbox.

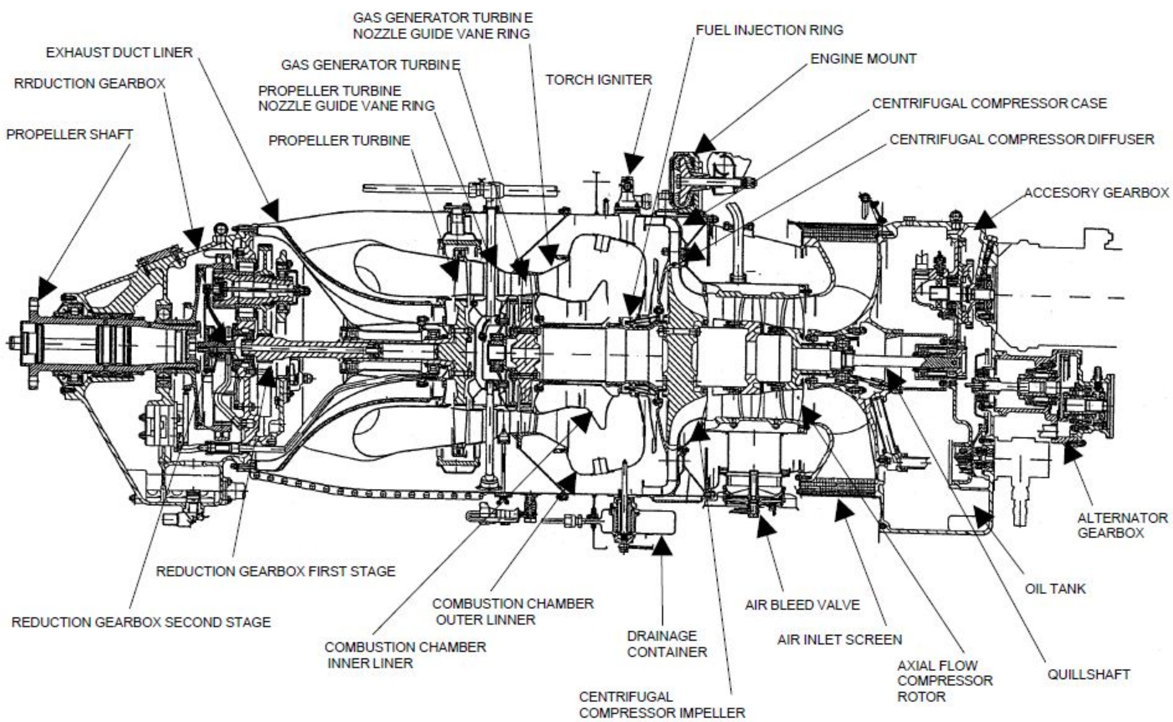

Figure 1 - GE/Walter M601 Engine (Generic)

D.2 Details of the Engine Teardown

D.2.1 General External Condition

The engine was intact and contiguous (Figure 7). All the external tubes, control cables and linkages were present and intact; however, several were bent. The external engine-related accessories were present; however, the starter-generator (S/G) mount flange was fractured and the S/G was not present. The propeller control linkage from the propeller governor to the propeller-reversing cambox was present and continuous; however, it was bent and deformed. The lever arm of the propeller governor was still attached to the forward end of the linkage.

The exhaust case was intact; however, it was buckled around 270 degrees, with the damage occurring from the 10 to 7 o'clock[2] location. The buckling direction was generally outwards except around the right-hand exhaust stub where the direction was inward. The resultant of the buckling was an overall bending condition of the exhaust case which displaced the propeller shaft at the front of reduction gearbox (RGB) by approximately 1 inch to the right (Figure 8). Additionally, the angle of the RGB was changed by approximately 5 degrees to the right. The two exhaust flanges were intact; however, the right-hand stub and flange were deformed and buckled. The two RGB oil transfer tubes below the exhaust case were bent inwards. The inter-turbine temperature (ITT) connectors and boss were still installed in the exhaust case, and appeared to be undamaged. The propeller shaft could not be turned by hand.

The 2-segment compressor/combustor or gas generator (GG) case was intact; however, it was buckled in the section between 11 and 1 o'clock (Figure 9), near the upper engine mount location. The inlet screen was present and undamaged.

The accessory gearbox (AGB) was intact, attached, and appeared to be undamaged. The oil fill and check hardware was present and undamaged (Figure 10), however the fill port was not secure. The fuel pump and fuel control unit (FCU) (Figure 11) were still attached to the AGB and appeared to be undamaged. All the tube fittings and connections to and from the FCU and fuel pump were undamaged and secure.

The ignitor boxes were packed separately from the engine and appeared to be undamaged.

The compressor air bleed valve (ABV) was still attached, undamaged, in the fully open condition and the ABV piston operated freely (Figure 12). The ABV is fully closed at high-power speeds of 93% and above, and is fully open at 63% idle speed and below.

The torque sensor, torque limiter transducers, and auto-feather switch were still attached and undamaged. All the tube fittings and connections were undamaged and secure. In a single engine application, the auto-feather switch is non-functional.

The sheet metal forward firewall assembly was intact; however it was bent and deformed from the 9 to 5 o'clock location. The aft firewall was deformed through 360 degrees.

[2] All directional references to front and rear, right and left, top and bottom, and clockwise and counterclockwise are made aft looking forward (ALF) as is the convention, unless indicated otherwise. Upstream and downstream references are in relation to gas path flow from the compressor inlet to exhaust. Top is the 12 o'clock position. The direction of rotation of the engine is clockwise. All numbering in the circumferential direction starts with the No. 1 position at the 12:00 o'clock position, or immediately clockwise from the 12:00 o'clock position and progresses sequentially clockwise ALF.

D.2.1.1 Fluids, Filters and Chip Detectors

Approximately 1½ quarts of an oil-water mixture was drained from the RGB. The RGB scavenge and pressure oil filters were removed, examined (Figure 13) and found to be clear; however, they were mildly corroded, consistent with water contamination. The RGB chip detector was intact, coated with a water-oil gel, mildly corroded, and free of any metal particles (Figure 14).

The AGB/oil tank contained approximately 1½ gallons of an oil-water mixture, consistent with immersion in water. The magnetic drain plug contained a small number of fine particles (Figure 15) and was oil wetted while the chip detector (Figure 16) was water wetted and clear of particles. The AGB contained approximately 1 gallon of oil-water mixture.

The metal-mesh style main oil filter was removed, examined and found to be free of particles (Figure 17). A light fine gray film in a pattern consistent with partial water immersion which could easily be removed by finger pressure was observed on the mesh.

The metal-mesh style fuel filter was removed from the fuel pump, and found to be clean (Figure 18). The ball check valve at the base of the filter was clean and free to move. The filter cavity was full of fuel (Figure 19 & Figure 20) and approximately 100 milliliters of clean fuel was drained. The fuel filter was re-installed into the fuel pump for integrity during future transport to the manufacturer. When the fuel supply and transfer tubes on the FCU and fuel pump were removed, fuel was observed to be draining (Figure 21) from the FCU and fuel pump. Another approximately 100 milliliters of clean fuel was drained from the FCU and associated tubing (Figure 22). All the fuel collected was straw colored, clean and with a smell consistent with Jet-A.

D.2.2 Power Section

D.2.2.1 Reduction Gearbox (RGB)

The propeller was not present during the engine teardown; however, it was examined on January 17, 2017, at the Turbine Power Tech facilities in Deland, Florida. The propeller shaft could not be turned by hand. The propeller flange was intact; however it was bent 1/8 inch aftwards for an arc of approximately 90 degrees. All the propeller attach bolts were present, undamaged, and still lockwired but were pulled out of the propeller hub. The RGB housing was intact and externally undamaged; however, the propeller shaft was axially displaced aftwards within the RGB by approximately 0.3 inch.

The RGB was disassembled as far as practically possible and the internal components examined. The power turbine (PT) support cone (Figure 23) was intact; however, it had an 8-inch long internal, arc shaped impact mark consistent with contact against the front cast feature of planetary gearcase diaphragm, consistent with an axial impact. The reduction gear support diaphragm was intact (Figure 24) and the 1st and 2nd

stage gears were intact and undamaged. Two of the three planetary gears turned smoothly by hand and freely moved axially against their metering valves while the other planetary gear was hard to turn by hand and difficult to move axially against its metering valve; its bearing was corroded, consistent with water contact. Rotational score marks of the propeller ring gear were observed (Figure 25) on the gear sleeves, which is consistent with an axial contact against the propeller ring gear. The propeller ring gear was intact; however, the inner cone surface was rotationally scored, (Figure 26) consistent with contact against the tripod gear shaft ends (Figure 27) as well as the reduction gear bearing sleeves. Two small magnetically-attractive slivers, consistent with ring gear tooth material, were observed within the ring gear teeth (Figure 28). According to GE/Walter engineering, these slivers are typically produced during a prop sudden stoppage, when the outer ring gear deforms and a subsequent temporary gear mesh mis-match occurs causing the top corners of the planet gear teeth to shear a small sliver of material from the ring gear teeth. According to the GE Aviation Czech engineer, after a prop strike with the engine at a higher power condition, or even with the engine at idle, many slivers are typically found in the RGB, however only two small slivers could be found in this RGB, consistent with the engine being at a very low power condition.

D.2.2.2 Power Turbine (PT)

The PT assembly was intact and all the blades were present; however, the hub was rotationally scored on the forward face (Figure 29), consistent with contact against the interstage stator baffle. The leading edges of all the blades were rotationally scored near the blade root (Figure 30), consistent with contact against the power turbine nozzle guide vane ring (PTNGVR) inner vane platform and at the shroud tips, consistent with contact against the PTNGVR outer shroud. According to the GE Aviation Czech engineer, the PT disk was displaced aftwards approximately 0.2 inches to produce this evidence of rotational contact scoring.

D.2.2.3 Power Turbine Nozzle Guide Vane Ring (PTNGVR)

The PTNGVR was intact, and generally undamaged (Figure 31); however, the aft (with respect to the airflow direction) surface of the PT stator inner vane platform and the shroud support face were rotationally scored, consistent with contact against the rotating PT hub.

D.2.3 Compressor/Combustor or Gas Generator (GG) Case

D.2.3.1 Gas Generator (GG) Case

The GG case was intact; however, was buckled and deformed near the upper engine mount flange. The compressor inlet case was intact and appeared to be undamaged. The inlet screen was undamaged. The right and left torching ignitors were intact and undamaged.

D.2.3.2 Gas Generator Turbine (GGT) and GGT Shroud

The GGT was intact and undamaged (Figure 32). No evidence of circumferential scoring could be observed. The GGT shroud was intact and undamaged. The GGT front roller bearing (N205) cage (Figure 33) was offset due to axial impact, which prevented the GGT rotor from rotating. Otherwise the bearing was intact.

D.2.3.3 Gas Generator Turbine Nozzle Guide Vane Ring (GGTNGVR)

The GGTNGVR was intact and undamaged (Figure 34 & Figure 35)

D.2.3.4 Combustor Liners and Slinger Ring

The combustor inner and outer liners were intact and undamaged. The fuel slinger ring was intact and undamaged.

D.2.3.5 Compressor Rotors and Stator

The compressor rotor, consisting of the two axial compressors and one centrifugal impeller was intact. The 1st (Figure 36) and 2nd stage axial compressor blades were intact, and several nicks on the leading edges were observed. Minor score marks could be observed on the blade tips. The 1st stage axial compressor shroud (Figure 37) exhibited light rotational scoring at the plane of the trailing edge of the blade through 210 degrees, from the 11 to 7 o'clock location (ALF). The 2nd stage axial compressor shroud (Figure 38) exhibited light rotational scoring in the plane of the leading edge of the 2nd stage blade from the 1 to 6 o'clock location (ALF). The impeller vanes and the impeller shroud were undamaged (Figure 39).

D.2.4 Accessory Gearbox (AGB)

The AGB was generally intact and undamaged. After the AGB was removed from the engine, the input shaft was rotated and a corresponding rotation was noted in the AGB gear-train, indicating a mechanical continuity and integrity of the system. All the interior surfaces of the AGB cavity were oil wetted (Figure 40). The AGB was not further disassembled.

D.2.5 Ignitor Units and Ignitor Plugs

The ignitor boxes were intact and slightly dented. The two boxes were P/N 2201.03-8, one unit (Figure 41) was S/N 297-8, the other (Figure 42) S/N 1168-0. There was rust colored corrosion on the contactor points of both units, consistent with immersion in water. The ignitor boxes were bench tested and neither could produce a spark in an exemplar plug. Ignitor box S/N 1168-0 showed evidence of internal coil movement, consistent with overheating and being operated with too long a duty cycle.

The ignitor plugs (Figure 43) were P/N N25F-3, the left-hand unit was S/N R8-X and the right-hand unit was S/N C3X. Both ignitor plugs were tested using a ignitor box from the Prime Turbines facility. Although both produce a spark, the R8-X plug produced a clearly obvious weaker spark than the other. The center electrode of R8-X plug was loose in the body because the supporting insulation material had disintegrated. According to Walter, a mandatory service bulletin No. M601D-16a was issued on May 18, 1989 that required the removal of this type of ignitor plug.

D.3 Engine Controls System - Fuel Control Unit (FCU), Fuel Pump (FP), Propeller Control Unit (PCU), and Propeller

General Note on the Engine Controls System (FCU, FP, and PCU) examination:

When the engine was examined at the Prime Turbine facilities in Dallas, Texas on July 15-16, 2015, the fuel control unit (FCU), fuel pump (FP) and propeller control unit (PCU) were removed from the engine, externally examined, boxed, sealed and shipped to the manufacturer's (Jihostroj) factory in Velesin, Czech Republic, where they were stored until October 19, 2015, when the powerplant team met at the Jihostroj factory to functionally test, if possible, and then tear down and examine the engine controls accessories.

The propeller was retained until January 17, 2017, when it was transported to the Turbine Power Tech facilities in Deland, Florida, where it was disassembled and examined.

D.3.1 FCU, FP and PCU History

A review of the engine's logbook showed the FCU, FP and PCU units were built in Sept 1987 and originally installed onto engine S/N 874001-D, the event engine. The factory manual states that the FCU, FP and PCU recommended overhaul time is identical to the engine. The engine was originally installed in a dual-engine powered LET410 airplane, where it operated for 1498 hours, and then removed in anticipation of a recommended 1500-hour overhaul. It was not returned to the factory for the overhaul, but instead, was sold and installed in the, then new, aircraft N42BR on October 23, 2003 with 1498 hours, time since new (TSN). Thereafter, the engine had an annual inspection in accordance with a FSDO approved maintenance program on December 8, 2003, while typically adding between 30-50 hours annually. The only record of maintenance performed on the engine controls while installed in N42BR was in December 2010, when a 300-hour inspection was performed per a Diemech Turbine inspection guide which included an engine oil and filter change, plus removal and replacement of the high-pressure fuel filter, at 1826 hours TSN. The last entry in the logbook was the airplane annual inspection on November 29, 2014 at 1926 hours TSN.

D.3.2 Engine Driven Fuel Pump (FP)

D.3.2.1 FP Description

The FP, a Jihostroj model P/N LUN6290.03.8 and S/N 873026 is the first of two components of fuel system of the engine. The FP (Figure 2) is a gear-driven, positive displacement, pressure-regulated pump which is driven, via splines by gearing within the engine AGB and supplies fuel flow and pressure required by the fuel control unit as well as a starting circuit for satisfying all the functions of the engine requirements. The FP is mounted on its own dedicated flange on the AGB.

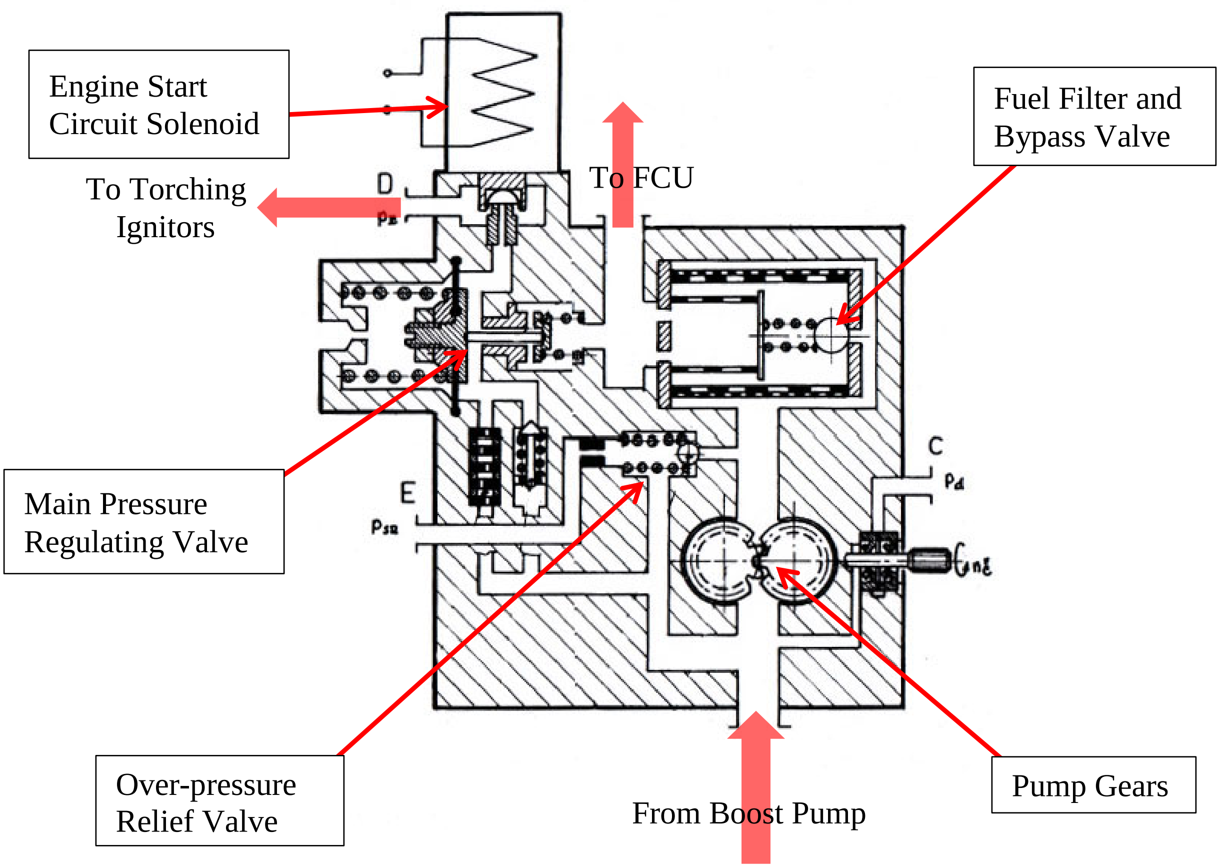

Figure 2 – Fuel Pump (FP) Schematic

D.3.2.2 Initial Findings for FP During the Engine Teardown

The FP, was still mounted on the AGB, was intact and undamaged (Figure 44). The fuel pump input drive spline (Figure 45) was undamaged. The fuel pump was retained for testing and examination at the manufacturer, Jihostroj.

D.3.2.3 Findings for FP During the Factory Examination

The FP and the lockwire seals were intact, undamaged, and since the input shaft rotated freely, a functional test was made. A new component functional test procedure (FTP) was performed on the FP and all the parameters tested were within the functional, manufacturer's limits as acceptable to return to service. After the test, the FP was torn down because of the pilots' last radio call reporting loss of fuel pressure.

Dis-assembly of the FP did not present any technical difficulties and did not reveal any water-inundated related corrosion (Figure 46). The needle bearings of both gear shafts were undamaged. The gear teeth involute surfaces were undamaged; however, both side faces of the gears were rotationally scored due to contact against the brass side-sealing plates (Figure 47), consistent with having been rotated without fuel in the cavity. The side-sealing plates exhibited pit marks, consistent with the damage caused by the effects of cavitation[3]. Additionally, the lip near the inlet in the aluminum housing was similarly pitted (Figure 48), also consistent with the effects of cavitation.

The Jihostroj engineering staff stated that during the last 40 years of overhauling pumps, only two other pumps were known to have sustained similar damage due to cavitation.

GE Aviation Czech and Jihostroj fuel system engineering staff stated that if low fuel pressure was encountered by the fuel pump, evidence of cavitation would be found in the inlet area of the fuel pump. It was also stated that a low fuel pump entry pressure would affect the stability of engine operation. Referencing a similar single-engine application, GE Aviation Czech engineering stated that the GE H80 (Walter M601) powered Thrush 510G installation has a common fuel system with the event airplane. The Thrush, a certified airplane in the restricted category, is equipped with dual (redundant, parallel) fuel boost pumps, intended to positively supply the engine fuel pump with pressure in case of a single boost pump failure.

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[3] Cavitation is the formation of vapor cavities in a liquid – i.e. small liquid-free zones ("bubbles" or "voids") – that are the consequence of forces acting upon the liquid. It usually occurs when a liquid is subjected to rapid changes of pressure that cause the formation of cavities or bubbles where the pressure is relatively low. Collapsing voids that implode near to a metal surface cause cyclic stress through repeated implosion, resulting in surface fatigue of the metal causing a type of pitting wear also called "cavitation".

D.3.3 Fuel Control Unit (FCU)

D.3.3.1 FCU Description

The FCU was a Jihostroj, model P/N LUN6590.03.8 and S/N 873 030 and is the second of two components of fuel system of the engine. The hydro-mechanical FCU (Figure 3) performs the following sub-system functions: (a) starting circuit; (b) altitude compensation; (c) automatic speed governing; (d) acceleration and deceleration control; (e) controls engine maximum power rating setting; (f) protects the engine from exceeding critical parameters; and (g) features a separate emergency circuit for the manual over-ride (MOR) control of fuel supply to the engine. The FCU is mounted on its own dedicated flange on the AGB.

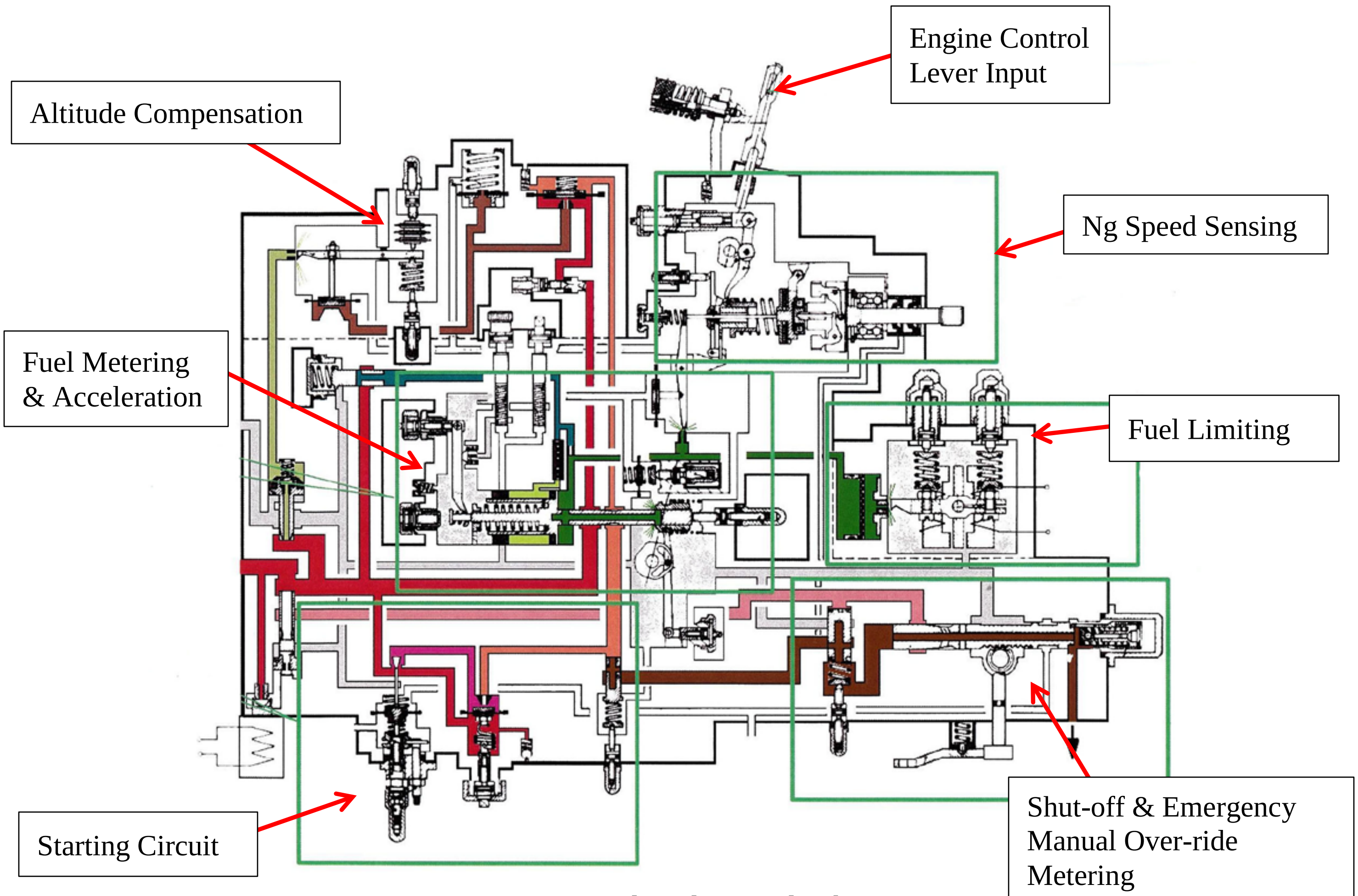


Figure 3 – General Fuel Control Schematic

D.3.3.2 FCU Initial Findings During the Engine Teardown

The FCU, was intact and undamaged (Figure 49). The FCU input drive spline was undamaged (Figure 50). The FCU input linkage from the FCU input shaft to the cambox was intact but deformed. The FCU power input shaft with lever and shut-off/manual over-ride (MOR) input shaft with lever were both present, undamaged and could be rotated. The external propeller cambox assembly was present but was deformed. The electrical connector for the FCU emergency manual over-ride solenoid was intact and undamaged. After this initial inspection, the FCU was retained for shipping to the Jihostroj for testing and examination.

D.3.3.3 FCU Findings During the Factory Examination

The FCU was generally intact; however, it was lightly coated with dry dirt, and lightly damaged due to impact (Figure 51). For new and overhauled FCU's, after the functional test procedure (FTP) is successfully completed, Jihostroj lock-wires all the adjustor screws of the FCU and then places a unique lead security crimped seal on the lock wire to identify post-factory modification. The following adjustors did not have their original crimped seal:

#27 - adjustment screw for the gas generator maximum speed
#19 – idle adjustment screw
#17 - acceleration characteristic adjustment
#45 - electrohydraulic transducer adjustment (EHP)

The FCU input shaft and lever were intact, however the input lever was deformed and the input shaft was bent and difficult to rotate, making the FCU impossible to functionally test. The FCU manual over-ride input shaft and lever were present and could be rotated. The propeller reversing feedback shaft could be rotated. The external propeller cambox assembly was not present. The engine start limiter and electrical connector were present and appeared to be undamaged.

The FCU was completely dis-assembled (Figure 52). In some cavities, a small amount of a gel-like water/fuel mixture adhering to most internal cavities and components was observed, as well as a mild surface corrosion, consistent with contact with water; however, all components were free to rotate, slide or operate. Most shaft bearings were mildly corroded, consistent with water contamination. Otherwise, no pre-impact damage was noted on any internal bearing. The following main components were examined and found to undamaged:

1) Ng (gas generator speed) combiner circuit including the power lever input - The throttle input shaft was intact, and free of corrosion. The connection with the teeter valve was clean and the teeter valve rotated freely.

2) Main metering valve - When the main metering valve external cavity cover was removed, fuel was seen to exit. No evidence of water was found in the cavity. The main metering valve spool was intact and undamaged (Figure

53); however, 4 minor axially oriented score marks were observed. The main metering valve bearing sleeve and seals (Figure 54) were intact and undamaged. The throttle input shaft fork and bearing rotated despite being coated with a water-fuel gel.

3) Flyweight governor and input shafts - The flyweight shaft was free to rotate and the flyweights were free to move (Figure 55); however, the flyweight bearings were mildly corroded, consistent with contact with water. The speeder spring was undamaged.

4) Acceleration restrictor - The two internal accelerator valve filters and the internal teeter valve filters were examined and found to be free of debris.

5) The flapper nozzle (case pressure regulator) was undamaged.

6) Ambient pressure compensator - The ambient pressure compensator cavity contained a small amount of water; however, there was no corrosion in the cavity or on the bellows or on the compensation lever.

7) Emergency circuit and shutoff actuator - The emergency circuit and shutoff actuator input shaft was bent due to impact; however, it still rotated, but with difficulty. The inner translation sleeve was intact and clean as well as the rack and pinion section.

8) The electro-hydraulic transducer blade relay (EHP) was undamaged.

No pre-existing condition was found in the FCU that may have prevented normal operation.

D.3.4 Propeller & Propeller Control Unit (PCU)

D.3.4.1 General Notes Regarding the Propeller and Propeller Control System

The propeller converts the rotational energy of the engine output shaft into useable thrust to move the airplane.

A fixed pitch propeller is the simplest of propeller designs and is used in light, piston engine aircraft. The hub and blades are typically a one-piece component in which angle of attack of the propeller blades are a fixed pitch and cannot be changed during aircraft operation. The fixed blade angle is a compromise between the optimum pitch for takeoff, climb and cruise. In these installations, the rotational speed is controlled only by the engine speed.

A constant-speed (or variable pitch) propeller (See Figure 4) is one in which the blade pitch or angle can be adjusted during flight in order to obtain an optimum value for all phases of flight, such as takeoff, climb or cruise. It is also possible to feather the blades after an engine failure, which is necessary so that the streamlined blades produce the least aerodynamic drag to flight.

If not controlled, the propeller RPM would vary greatly as a function of engine power, blade pitch angle and airspeed, therefore, a propeller (speed) control unit (PCU) is added to the system to make the propeller behave as a constant speed propeller, irrespective of engine power selected or airspeed by automatically varying the blade pitch angle to absorb the pilot-selected engine power. The propeller pitch is controlled by using engine oil pressure to move an internal piston in the propeller hub. The piston moves internal linkage which moves the blades to their appropriate angle. If the pilot commands a change in engine power, or if the airspeed changes, the PCU adjusts the oil pressure, changing the pitch of the blades to maintain the set speed of the propeller. If the propeller is turning too quickly, the blade pitch is automatically changed to take a bigger bite out of the air, creating more thrust and torque, thus slowing the propeller RPM. If the prop is turning too slowly, the blade angle is decreased to take smaller bites, producing less torque and thrust, allowing propeller RPM to speed up. The speed-sensing governor continually adjusts the oil pressure to keep the propeller RPM at constant speed.

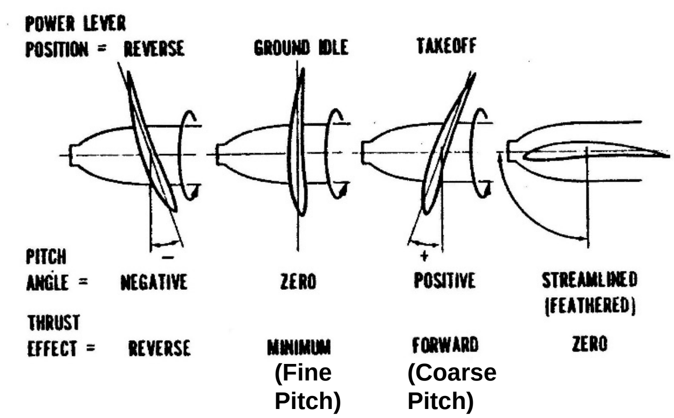


Figure 4 – Propeller Blade Angle Ranges

There are two different internal control systems in propellers (See Figure 5):

<u>Single acting system</u>, which features counterweighted blades and internal large feather springs that constantly push the blades toward high pitch (feather). Since the blades are always being driven to coarse pitch or feather, the propeller only needs a piston with pressure on one side to push back against the counterweights and spring. When the piston pressure is increased, the blades go toward low (flat) pitch. When the piston pressure is decreased, the counterweights and springs drive the propeller back toward high pitch. The counterweights do most of the work to drive the blades to high pitch. The springs help feather when the propeller RPM is low and the centrifugal loads acting on the counterweights do not have enough force to drive the blades completely to feather.

Double acting system, which features a piston that provides force, via engine oil pressure, in both directions to control the propeller RPM. The governor controls the oil pressure on both sides of the piston to increase or decrease the pitch as required. A double-acting propeller normally uses oil pressure from the engine main oil pump or, in the event of an engine failure, requires an emergency electric auxiliary oil pump, to completely feather the blades. Although counterweights help to increase pitch in the event of oil system failure, they are ineffective in feathering the blades when the propeller is spinning at low RPM since there is insufficient centrifugal force generated to drive the propeller blades to feather. In this event, the propeller blades will remain in the last position they were in before the loss of oil pressure.

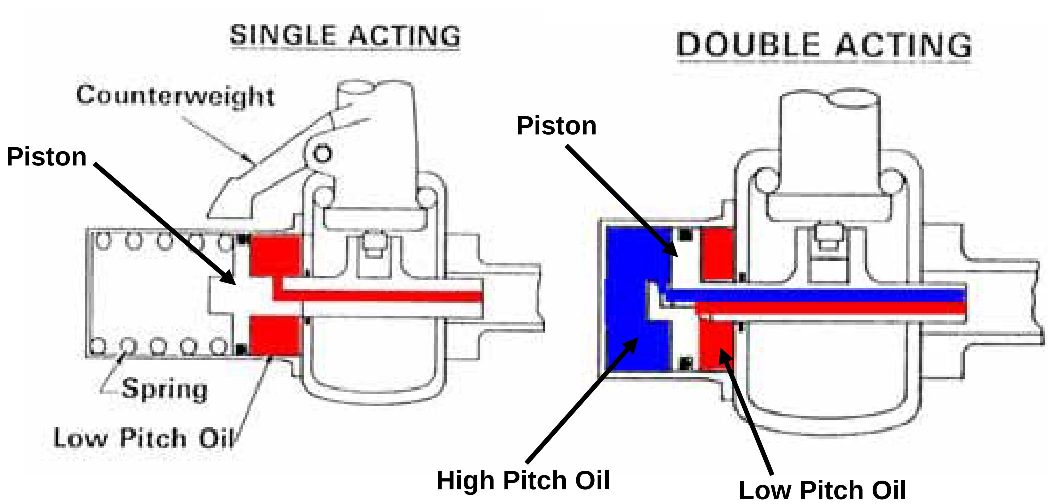


Figure 5 – Schematic Comparing Single and Double Acting Propeller Systems

According to the Avia propeller manual, E-1500, dual acting propellers require an electric feathering pump for emergency conditions:

"D. Feathering

If an engine fails in flight, it is necessary to feather the propeller. Installations using dual acting propellers are usually equipped with feathering system with feathering valve and an electric feathering pump. The system is initialized by a cockpit button or automatically.

a) Manual Feathering

The pilot activates auto feathering by pushing the appropriate cockpit button the feathering pump (LUN7840) and feathering valve (LUN7880). Oil from electric pump is directed to the high pitch channel, feathering the propeller.

b) Automatic Feathering

This action is similar to manual feathering only the activation is automatic based on engine torque evaluation. Usually the automatic system is limited to some engine condition lever range.

c) Emergency Feathering

It is used when the feathering pump is out of operation or it is not installed. Emergency feathering is activated by moving the propeller condition lever onto feather stop. Blades are forced into feather position by counterweights moment and eventually by oil pressure.

> Feathering time is about three times longer than manual and automatic feathering. Emergency feathering can be used at engine stop."

The event airplane was not equipped with an electric feathering pump.

D.3.4.2 Propeller Control Unit (PCU) Description

The PCU was a Jihostroj, model P/N LUN7815.02-8, S/N 873024, a dual-acting PCU which regulates propeller speed by continually transferring oil to one of two sides of the internal propeller piston which in-turn varies the pitch of the propeller blade to maintain the governing speed. The internal flyweights, actuated by the centrifugal force developed by the speed of the rotation, positions a pilot valve so as to cover or uncover ports in the drive gear shaft and control the flow of oil to and from the pitch changing mechanism of the propeller. The centrifugal force exerted by the flyweights is opposed by the force of an adjustable speeder spring. The load exerted by the speeder spring determines the engine RPM required to develop sufficient centrifugal force in the flyweights to center the pilot valve. Oil to operate the propeller's pitch changing mechanism is supplied by a gear-type oil pump at a pressure value limited by a relief valve. The governor is double-acting, using oil pressure to decrease and increase pitch.

D.3.4.2.1 PCU Findings During the Engine Teardown

The PCU (Figure 56 & Figure 57) was still mounted on the RGB was intact; however, it was heavily damaged due to impact. The PCU input drive spline was undamaged (Figure 58). The PCU was removed from the RGB and input drive spline was found undamaged but could not be turned. Oil was observed to be leaking from the transfer ports. The speed control input shaft could be turned and the limit adjust pin was bent due to contact against the maximum speed condition set screw. The input lever was also bent. The two beta control shafts could be rotated with some resistance and the connecting rod was bent as well as the input lever. The propeller position feedback sensor was fractured; however, the carbon blocks and lever were still present. The PCU was retained for examination at the manufacturer.

D.3.4.2.2 PCU Findings During the Factory Examination

The propeller governor was externally impact damaged and could not be functionally tested. The internal cavities and components were all oil wetted and evidence of water ingress was found. The involute gear teeth and the side sealing faces of gear pump were undamaged as were the brass side seals (Figure 59). The rotating main shaft with the pilot valve, the speeder spring (Figure 60) and the flyweights (Figure 61) were mildly corroded, consistent with water contact; however, they were otherwise undamaged and free to operate. The beta valve was undamaged and free to rotate.

The propeller governor features an oil pressure port which is intended to allow oil pressure from the electric feathering pump to feather the propeller in the event of an engine failure that results in the loss of oil pressure. This port was intentionally blocked (Figure 62) as part of the engine installation design.

No pre-existing condition was found in the propeller governor that may have prevented normal operation.

D.3.4.3 Additional Propeller System Components

The M601D engine is equipped with a feathering valve which is located on the accessory gearbox of the engine. In a review of photos taken of the engine in the field, it was confirmed that the feathering valve was not present and the engine mount pad was blanked off with an aluminum cover as part of this Legend installation.

D.3.4.4 Propeller

D.3.4.4.1 Propeller Description

The propeller was an Avia model V508E-AG/84/A, (Figure 6) a 3-bladed, hydraulically controlled, constant speed (variable pitch), double-acting propeller which is fully reversible and featherable.

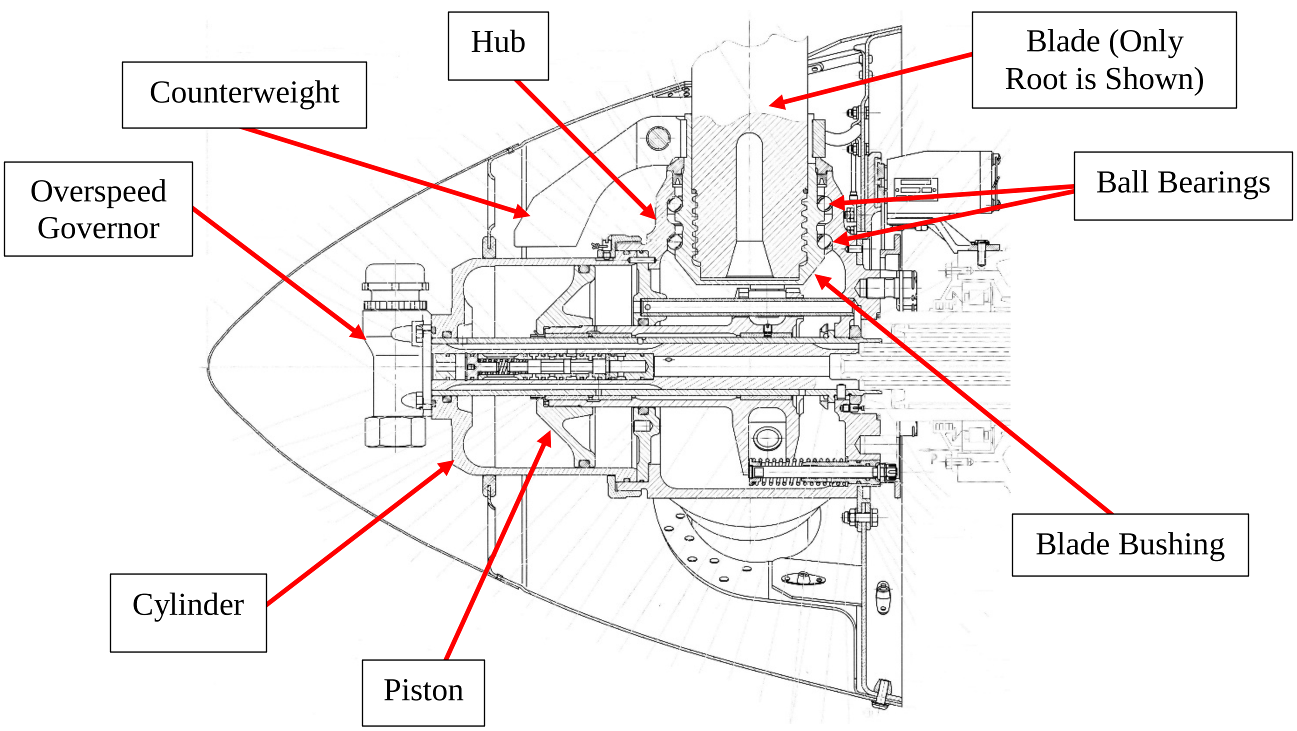


Figure 6 – Propeller Cross Section

The GE/Walter Model M601engine can be equipped with either double-acting and single-acting propellers. The one-piece hub is made from steel with the outer surface cadmium plated. Each propeller blade is supported by two ball bearings at the root. The outer bearing races are part of the hub, whereas the inner bearing races are located on the blade bushing. The blades are made of an aluminum alloy and are screwed into the blade bushings and secured by the counterweight clamps.

The propeller is equipped with an overspeed governor on the cylinder front face, which features an internal spring-loaded weighted valve. Centrifugal forces of the propeller RPM act on the weighted valve and once the spring pressure is overcome, the valve opens, allowing oil from the low pitch area in the hub to the drain till the RPM decreases to correspond with speed setting.

D.3.4.4.2 Propeller Teardown

The propeller was retained until January 17, 2017, when it was transported to the Turbine Power Tech facility in Deland, Florida where it was dis-assembled and examined. The propeller was intact (Figure 63); however, the overspeed governor cover was missing. The spinner was present, however, it was battered, torn and crushed over the hub and counterweights. All 3 blades were bend aftwards in the form of a large radius and with only a minor amount of twist. The leading edges were all undamaged and the front, low pressure surfaces, exhibited no rotation score marks (Figure 64). The counterweights were all in their forward position, which is associated with a flat or fine blade pitch (Figure 65). The counterweight clamp locating keys were all in location and undamaged (Figure 66), confirming that the clamps were in their original location and had not rotated from their indexing position. All the blades were unscrewed from the blade bushings with normal effort and all threads were undamaged (Figure 67).

The cylinder was removed with normal effort and the internal bore was found undamaged (Figure 68). The piston and elastomer piston ring were also undamaged (Figure 69). The sliding fork and tube assembly operated smoothly (Figure 70); however, each of the three lower fork flanges exhibited one impact mark, consistent with contact against the crank flange of the blade bushings (Figure 71) during a propeller strike or impact.

The blade bushings and pitch change blocks were all intact (Figure 72); however, there was mild corrosion on the inner race surface of one bushing, consistent with post-accident contact with water. All the ball bearings and their elastomeric spacers were present and undamaged (Figure 73), except for several that exhibited mild post-accident corrosion. The hub was intact; however, the blade bushing sleeves were fractured at the outer aft lips, consistent with a large axially aftward levered loading of the propeller blades (Figure 74). Additionally, spherical indentations from ball bearing, consistent with static overload were observed on the aft side of outer races (Figure 75).

No pre-existing condition was found in the propeller that may have prevented normal operation.

D.4 Corrective Actions

D.4.1 Overview

The Walter M601D engine is intended to be installed into a LET410 airplane. The Polish built LET410 is a twin-engine installation that features an Avia model V508E-AG/84/A dual acting propeller, identical to the event propeller. The LET410 design incorporates the Avia propeller manual guidance which requires an emergency electric propeller feather pump and appropriate hardware to direct pressure oil to the high-pitched channel, feathering the propeller in a timely manner. The Turbine Legend is a kit airplane manufactured by Legend Aircraft, and although it is powered by the same Walters M601D turbine engine and Avia model V508E-AG/84/A propeller combination is significantly different from the LET410 in that it is a single engine propeller airplane that does not incorporate an emergency electric propeller feather pump.

A review of the accident Turbine Legend airplane systems revealed that there was no emergency electric propeller feather pump installed in the airplane. According to Turbine Legends' owner there is no requirement or engine installation guidance to have such a system installed

Emergency feathering, without an emergency electric propeller feather pump, can also be activated by moving the propeller conditioning lever onto the feather stop; however, this requires the gas generator portion of the engine to still be operating since it drives the engine main oil pump and provides oil pressure to the propeller that is used for pitch control and emergency feathering. If the main oil pump no longer operates, then the only way the blades can be driven into the feather position is by the moment of the counterweights, however this requires the propeller to be rotating quickly for the counterweights to be effective. Additionally, the aerodynamic loads on the propeller blades, which drive the propeller into the feather position, are also very low when the propeller is rotating slowly.

In an installation without an emergency electric propeller feather pump: when an engine loses power due to fuel starvation, then the gas generator section quickly stops rotating and there is no engine oil pressure available to feather the propeller. With no engine power to turn the propeller, it will quickly stop rotating, making the counterweights and aerodynamic pressure on the rotating blades the only driving force to feather the propeller; however, unless the pilot immediately moves the propeller conditioning lever into feather stop, the propeller RPM will be to slow for the counterweights and aerodynamic loads on the blades to be effective, thus locking the propeller pitch into the last selected position at the time of engine failure.

Installation of the dual acting propeller and engine into the Turbine Legend installation without the addition of an emergency electric propeller feather pump presents a latent failure mode. Only under the conditions of a failed engine gas generator and a pilot who is slow to react to a sudden loss of power will this no-feather condition arise. A pilot can practice an engine failure by reducing the engine power to idle and simulating a loss of power event; however, a turbine engine at idle will still supply sufficient oil flow and pressure to the propeller to feather it normally.

D.4.2 FAA Amateur Built Aircraft Regulations and Policies

For a person to build, obtain an experimental airworthiness certificate, register the aircraft, and operate an amateur built aircraft, the applicant must follow the rules of the Title 14 Code of Federal Regulations Section 21-191 (§ 21.191) entitled 'Experimental Certificates'. The FAA provides guidance to the applicant on how to meet the requirements of an experimental certificate by providing Advisory Circulars (ACs), Orders, and Forms. See Table 1 for a full list of all the regulations and policies. Finally, in order to obtain an airworthiness certificate the applicant must fill out various forms and documents and submit them to the FAA before approval for flight is granted.

Title 14 Code of Federal Regulations
- Section 21.191, Experimental Certificates

Advisory Circulars (AC)
- 20-27, Certification and Operation of Amateur-Built Aircraft.
- 21-12, Application for U.S. Airworthiness Certificate, Form 8130-6.
- 39-7, Airworthiness Directives.
- 65-23, Certification of Repairpersons (Experimental Aircraft Builders).
- 90-89, Amateur-Built Aircraft and Ultralight Flight Testing Handbook.
- 90-109, Airmen Transition to Experimental or Unfamiliar Airplanes

Orders
- 8130.2, Airworthiness Certification of Aircraft and Related Products.
- 8130.33, Designated Airworthiness Representatives: Amateur-Built and Light-Sport Aircraft Certification Functions.

Forms
- 8050.88 Affidavit of Ownership
- 8000-38, Fabrication/Assembly Operation Checklist.
- 8130-6, Application for U.S. Airworthiness Certificate.
- 8130-12, Eligibility Statement: Amateur-Built Aircraft.
- 8610-2, Airman Certification and/or Rating Application.

Table 1

14 CFR § 21.191(g), defines an amateur-built aircraft as "an aircraft of which the major portion (more than 51%) has been fabricated and assembled by a person(s) who undertook the construction project solely for their own education or recreation.

a. Amateur-built aircraft may be constructed from—

(1) An amateur builder's original design, or

(2) Purchased plans or kits."

The FAA purposely gives great latitude to experimental aircraft home builders, and therefore offers no airworthiness standards or technical restrictions in the documentation. 14 CFR § 21.191 does not supply technical design guidance to the constructor. In fact, FAA Order 8130.2H states "The FAA should be reasonable in its requests for design data from amateur builders, keeping in mind that in most instances only one aircraft is involved. Accordingly, the amateur builder(s) are not required to have the detailed design data, quality systems, and procedures that holders of TCs and PCs are required to have for the serial production of duplicate aircraft. Often, the amateur builder will only have the information provided with the kit."

With respect to the documentation for kit built airplanes, the FAA makes clear that "It is important to remember that the FAA does not approve or certify aircraft kits or kit manufacturers…. an applicant (builder) may still apply for airworthiness certification upon completion of an aircraft built from this kit.". In contrast, Title 14, CFR Part 25, Airworthiness Standards: Transport Category Airplanes or Title 14, CFR Part 29, Airworthiness Standards: Transport Category Rotorcraft control most aspects of the design and safety features that must be incorporated into the qualifying aircraft.

Most of the FAA supplied technical information and guidance for experimental aircraft home builders to help in the design, fabrication and operation of their aircraft is available in AC 20-27G titled Certification and Operation of Amateur-Built Aircraft issued September 30, 2009 and AC 90-89B titled Amateur-Built Aircraft and Ultralight Flight Testing Handbook, issued April 27, 2015; however, in a review of these ACs, the NTSB found no references to turbine engine installation considerations.

In a meeting in Washington with the FAA Aircraft Certification Office, AIR 113, responsible for AC20-27G, the FAA representative stated that they were aware that the recent availability of relatively inexpensive high tech components, such as turbine engines, and their unique installation considerations has made AC 20-27G dated and in need of revision, and agreed to review and update the document. A time schedule is being developed at the time of this writing.

In a telephone conference with the FAA Aviation Flight Standards, AFS, responsible for AC90-89, the FAA representative agreed that they would consider adding references to turbine installation considerations for amateur built airplanes.

D.4.3 Experimental Aircraft Association

An additional source of information that is available to experimental aircraft home builders is the Experimental Aircraft Association (EAA). The EAA, founded in 1953, “is a community of passionate aviation enthusiasts that promotes and supports recreational flying” and among their goals is “cultivating and providing knowledge, information, and resources”. It has about 200,000 members, belonging to 1000 chapters through the United States and Canada. Each chapter has technical counsellors and subject matter experts available for consultation by any member on most aspects of the design, build and operation of amateur homebuilt aircraft.

During a meeting with EAA representative, he stated that the EAA is interested in safety related technical information and that they can distribute it to their members via their newsletter. He further suggested that to most effectively focus the information was to send it specifically to the amateur home-built subsection of the membership. It was agreed that the EAA staff of technical counsellors, designated airworthiness representatives (DARs), and subject matter experts would review this factual report after it is released, and that the safety aspects of the dual acting propeller be highlighted in an upcoming newsletter.

The EAA has formed the Type Club Coalition (TCC), where organizations and individual owners can collaborate to increase the level of safety in the general aviation community further develop their knowledge and resources. Their website states “If the community can work together to eliminate the common mistakes of aircraft operation, type-specific or otherwise, the overall safety of general aviation (GA) will increase substantially”. Their Mission Statement is “Leverage the knowledge and resources of the coalition to better prepare GA pilots for flight risks associated with known accident "hot spots".” A review of the EAA website revealed that there has been no Turbine Legend TCC group formed.

Harald Reichel
Aerospace Engineer – Powerplants

Figure 7 – GE/Walter M601D Engine, S/N 874001-D - As Received

Figure 8 – Exhaust Case Deformation

Figure 9 – Gas Generator (GG) Case - Buckled

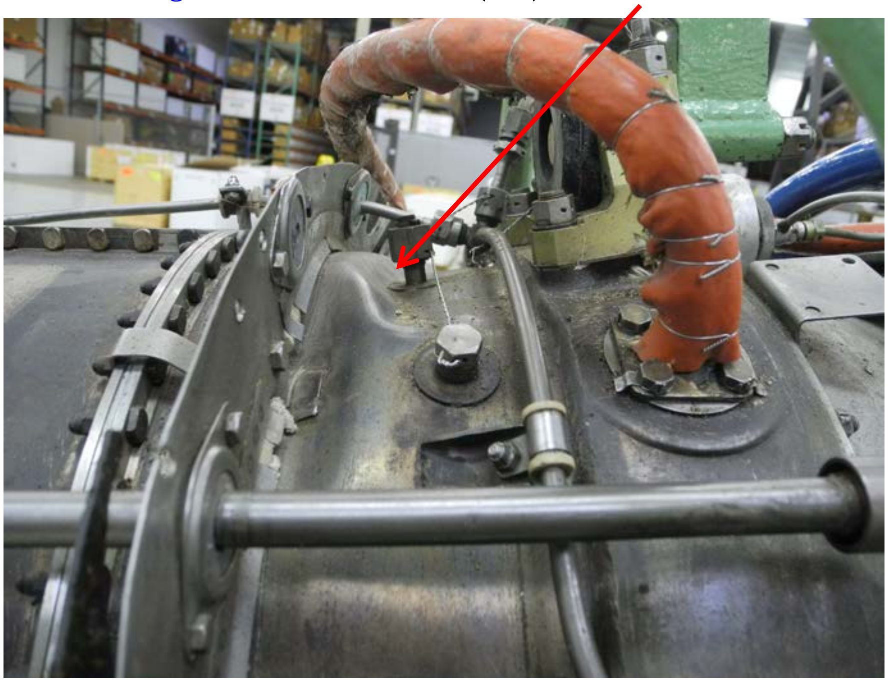
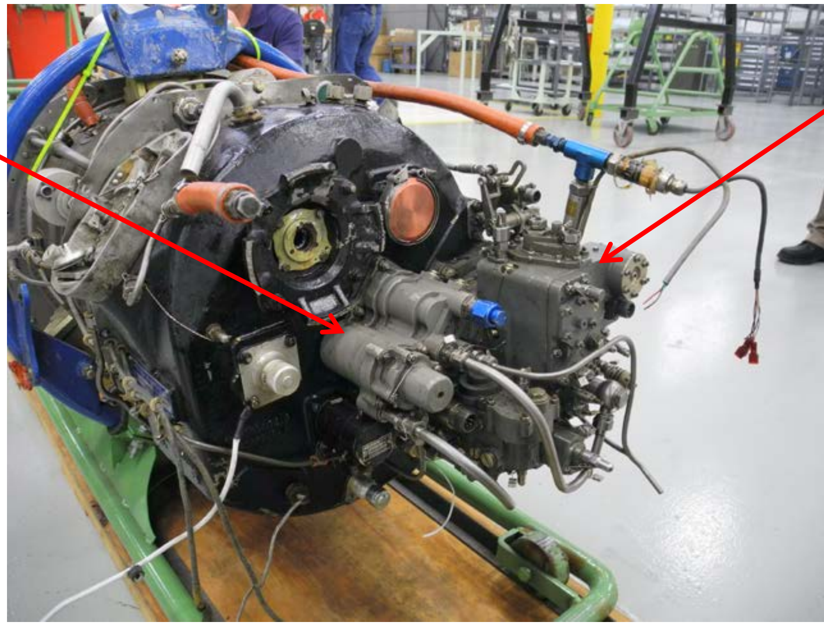


Figure 10 – Oil Fill and Check Hardware

Figure 11 – Fuel Pump & Fuel Control Unit (FCU) – As Received



Fuel Pump

Fuel Control Unit (FCU)

Figure 12 – Compressor Air Bleed Valve (ABV) - Open

Figure 13 – RGB Scavenge and Pressure Oil Filters

Figure 14 – RGB Chip Detector – Water Contaminated

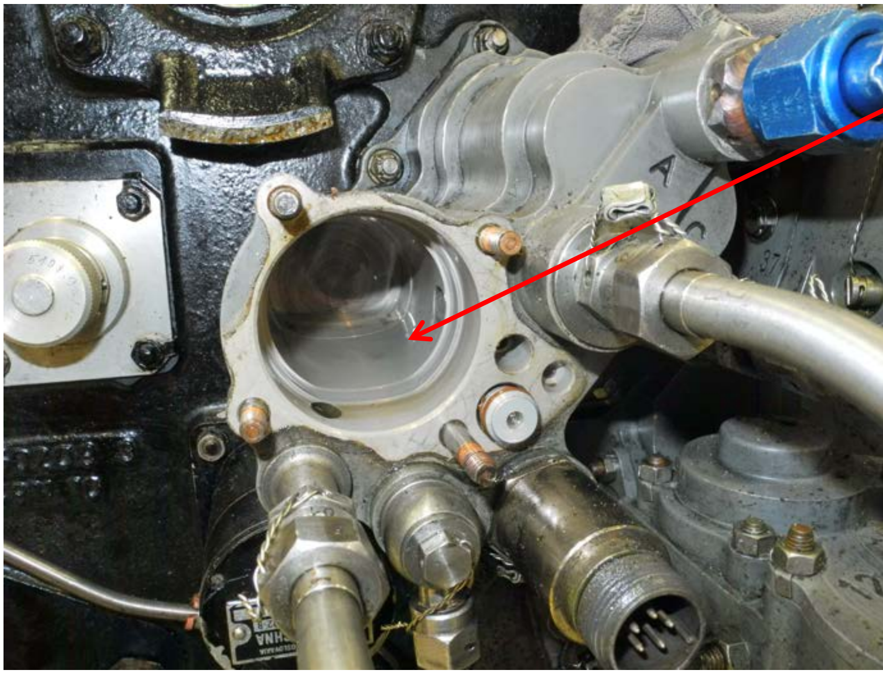
Figure 15 – AGB/Oil Tank Magnetic Drain Plug

Figure 16 – AGB/Oil Tank Chip Detector

Figure 17 – Oil Filter – Free of Metallic Particles

Figure 18 – Fuel Filter - Clean

Figure 19 – Fuel Filter Cavity – Fuel Filled



Fuel Level After Removal of Filter

Figure 20 – Fuel Drained from Filter Cavity

Fuel Filter Housing

Figure 21 – Fuel Draining From FCU

Figure 22 – Fuel Collected from FCU and Associated Tubing

Figure 23 – Power Turbine (PT) Support Cone

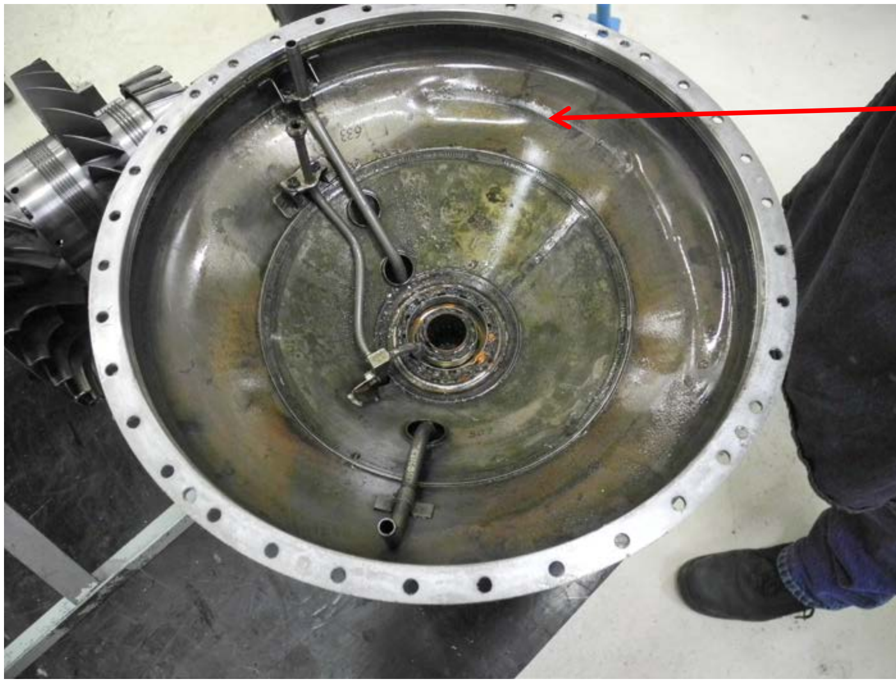
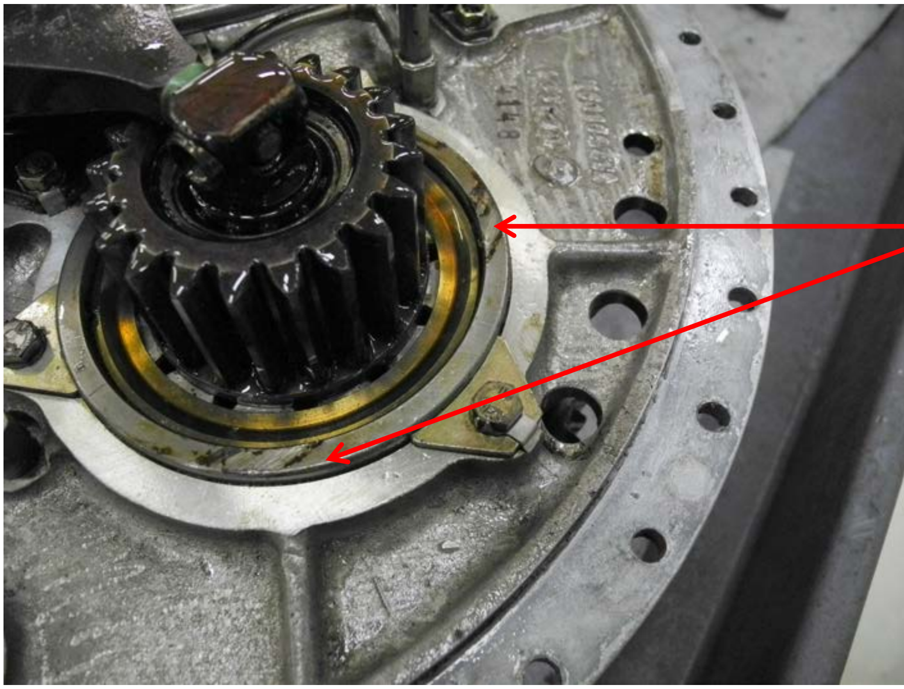


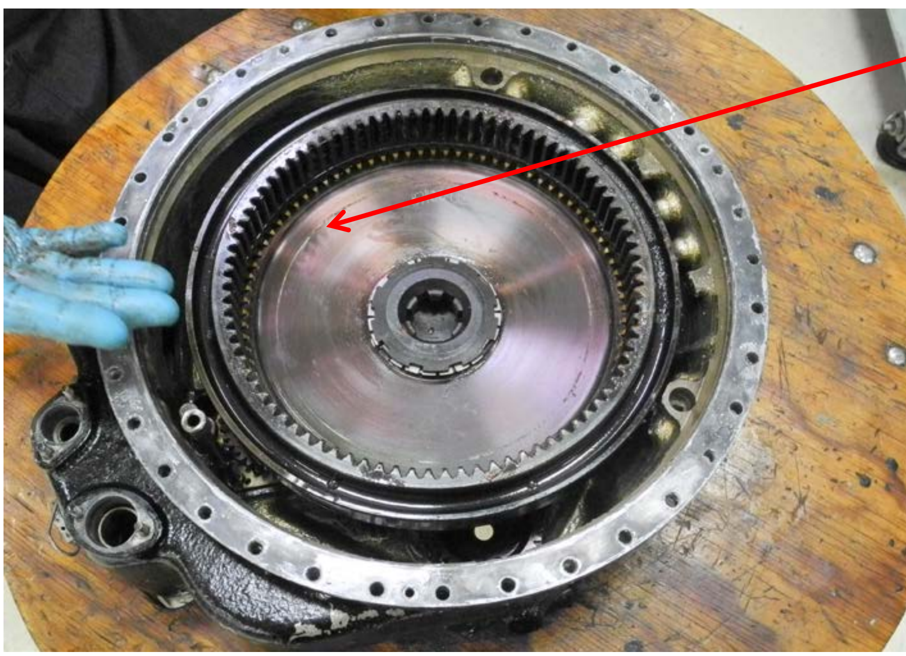
Figure 24 – Reduction Gear Support Diaphragm

Figure 25 – Rotational Score Marks on Bearing Sleeve



Rotational Score Marks Consistent with Contact Against Propeller Ring Gear

Figure 26 – Propeller Ring Gear – Rotational Scoring



Rotational Scoring, Consistent with Contact Against the Tripod Gear Shaft Ends

Figure 27 - Tripod Gear Shaft Ends

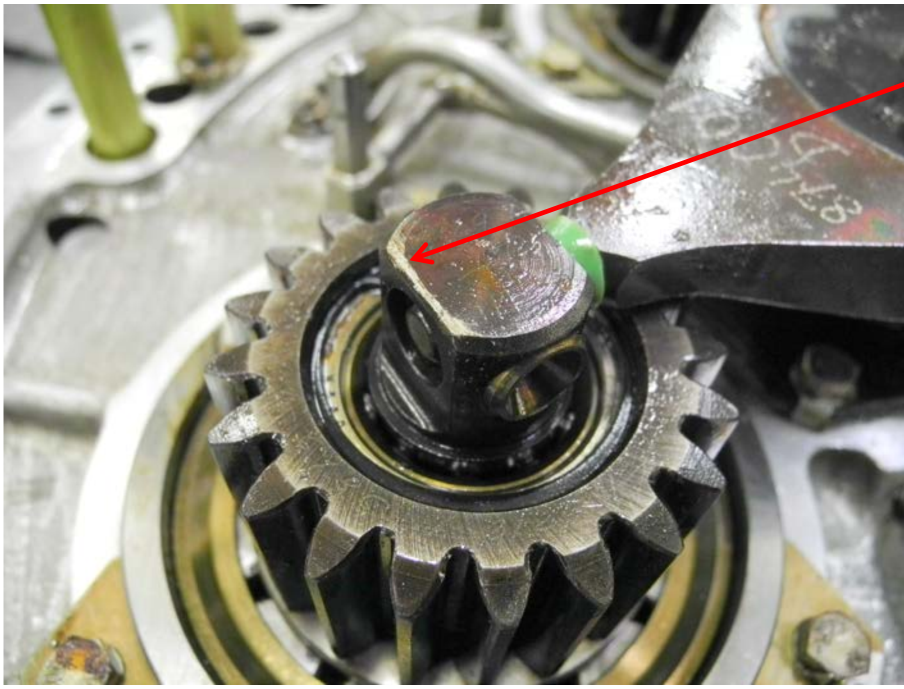


Figure 28 – Magnetic Sliver in Ring Gear Teeth

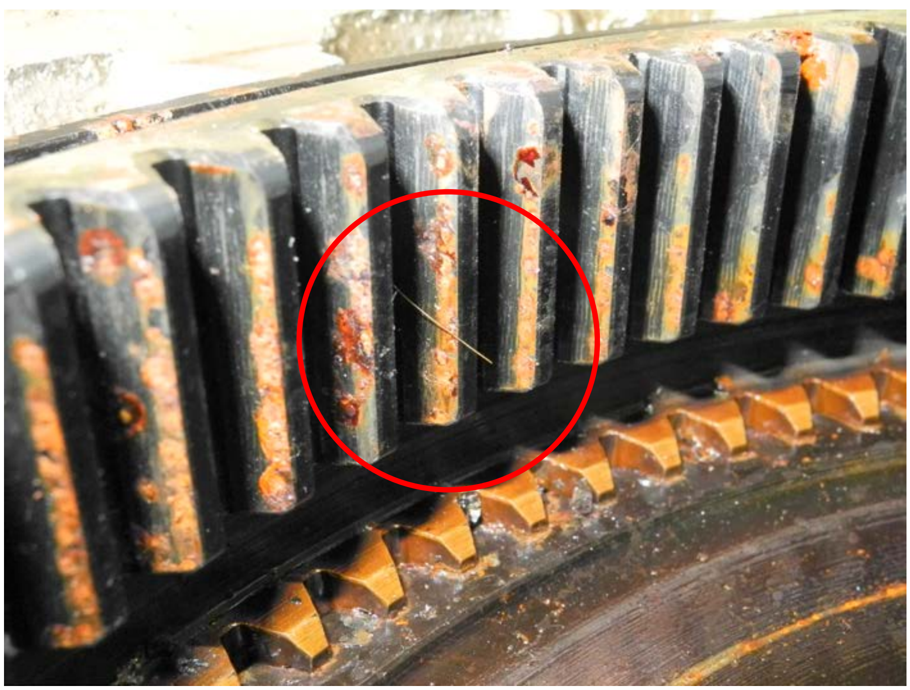


Figure 29 – Power Turbine - Hub Rotationally Scored on Forward Face

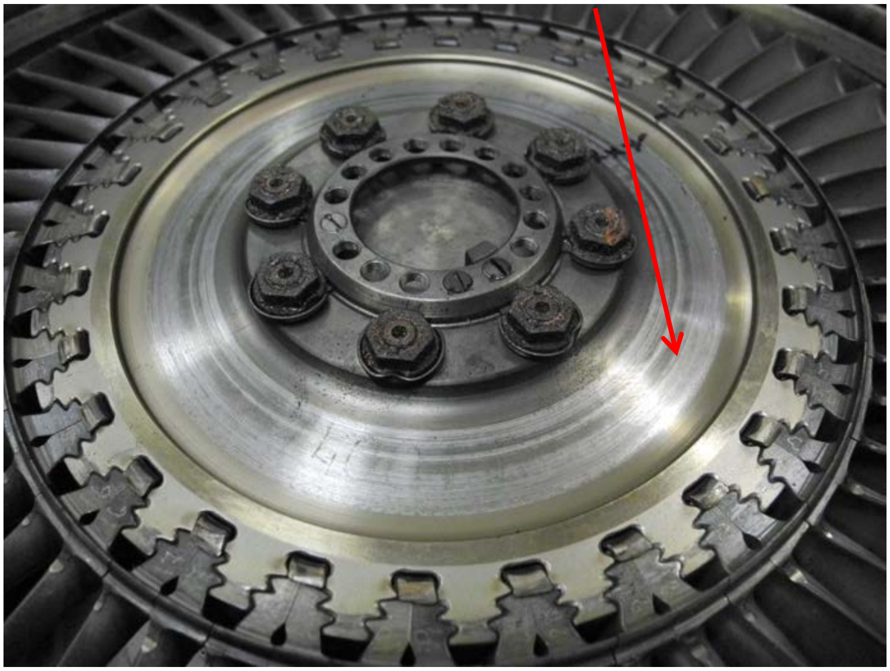
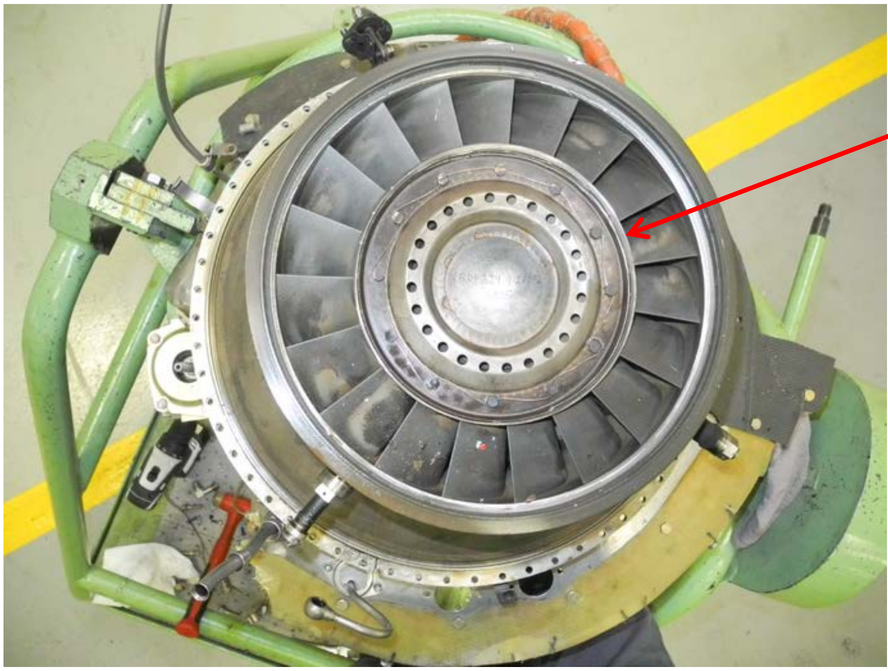


Figure 30 - Power Turbine - Rotationally Scored Near Blade Root

Figure 31 - Power Turbine Nozzle Guide Vane Ring



Rotational Scoring

Figure 32 - Gas Generator Turbine (GGT) - Undamaged

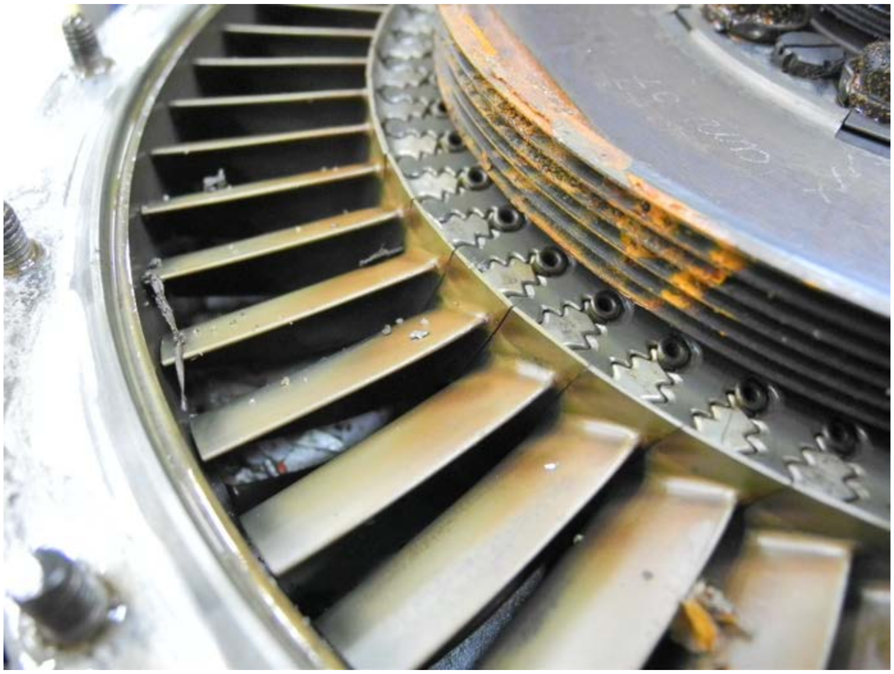


Figure 33 – N205 Roller Bearing & Cage

Figure 34 – Gas Generator Turbine Nozzle Guide Vane Ring – Leading Edge View

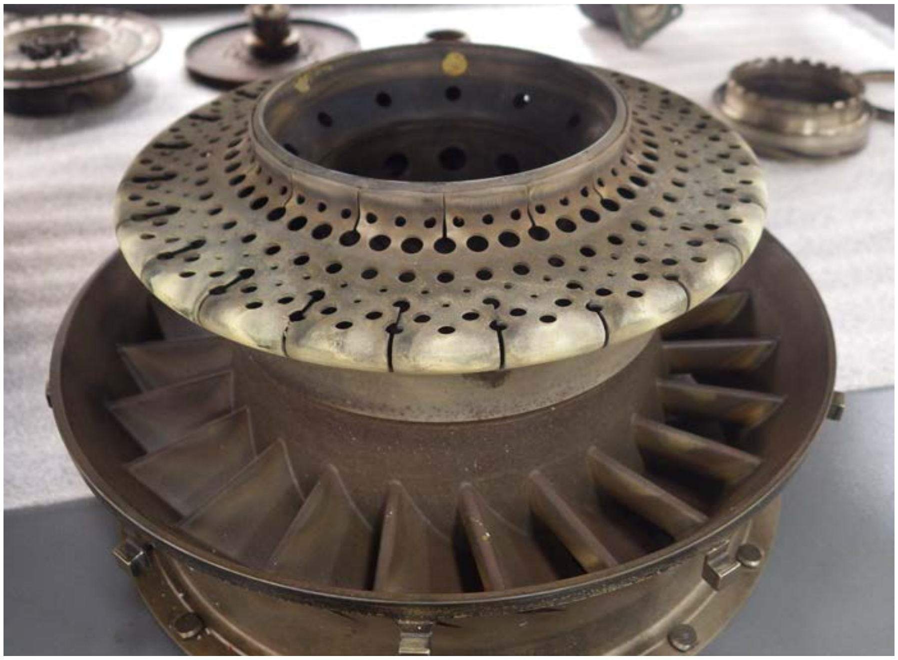


Figure 35 - Gas Generator Turbine Nozzle Guide Vane Ring – Trailing Edge View

Figure 36 – 1st Stage Compressor Rotor

Figure 37 - 1st Stage Axial Compressor Shroud

Scored Near the Trailing Edges of the 1st Stage Compressor Blades

Figure 38 – 2nd Stage Axial Compressor Shroud

Scored Near the Leading Edges of the 2nd Stage Compressor Rotor

Figure 39 - Impeller Vanes - Detail

Figure 40 – Accessory Gearbox Cavity- Interior

Figure 41 - Ignitor P/N 2201.03-8, S/N 297-8

Figure 42 - Ignitor P/N 2201.03-8, S/N 1168-0

Figure 43 - Ignitor Plugs

Figure 44 - Fuel Pump - Jihostroj, P/N LUN6290.03.8, S/N 873 026

Figure 45 - Fuel Pump Input Drive Spline - Undamaged

Figure 46 - Fuel Pump – Cover & Pump Elements

Figure 47 - Brass Gear Side-Sealing Plates

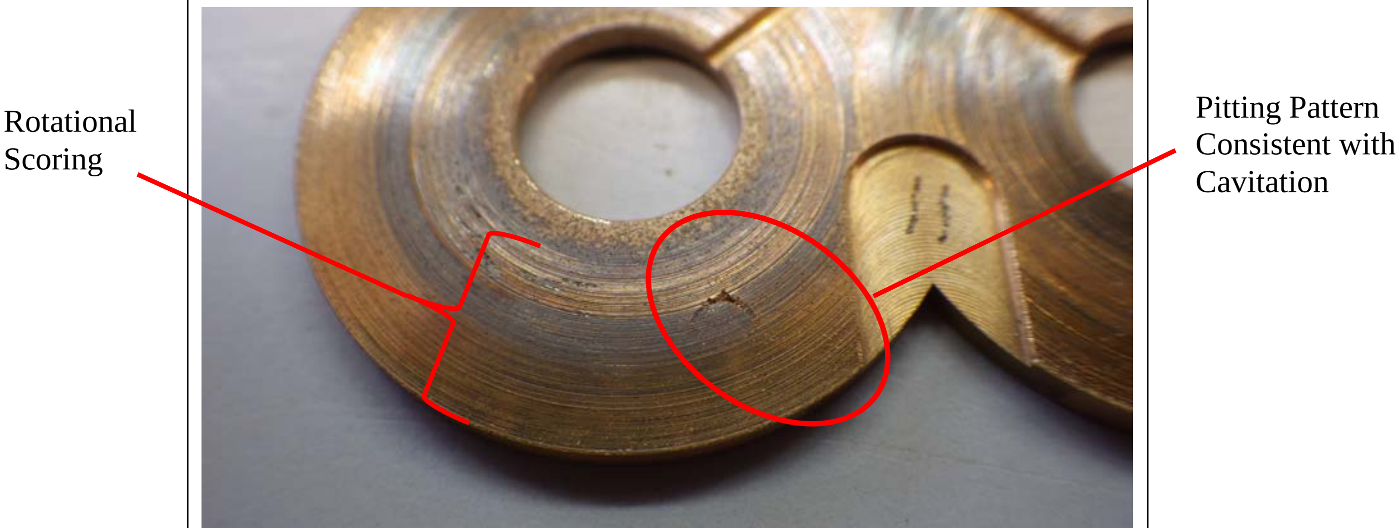


Figure 48 - Cavitation On Pump Gear Housing Inlet Edges

Figure 49 – FCU - Jihostroj, P/N LUN6590.03.8, S/N 873 030

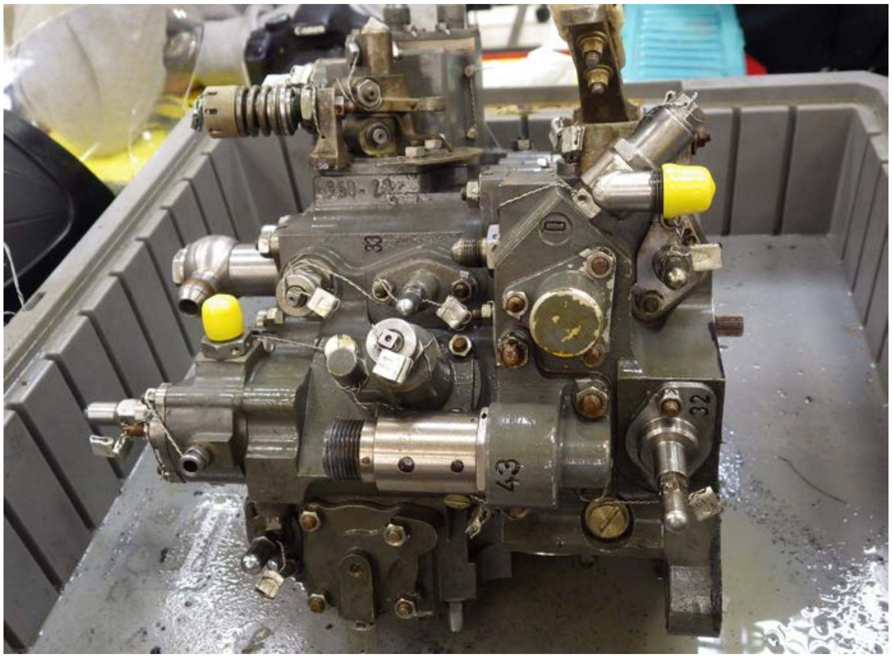


Figure 50 – Fuel Control Unit Input Drive Spline - Undamaged

Figure 51 – FCU as Received at Jihostroj Factory

Figure 52 – FCU in Final Stage of Dis-assembly

Figure 53 – Main Metering Valve - Undamaged

Figure 54 - Main Metering Valve Bearing Sleeve Seal - Undamaged

Figure 55 – Flyweights and Associated Mechanisms - Undamaged

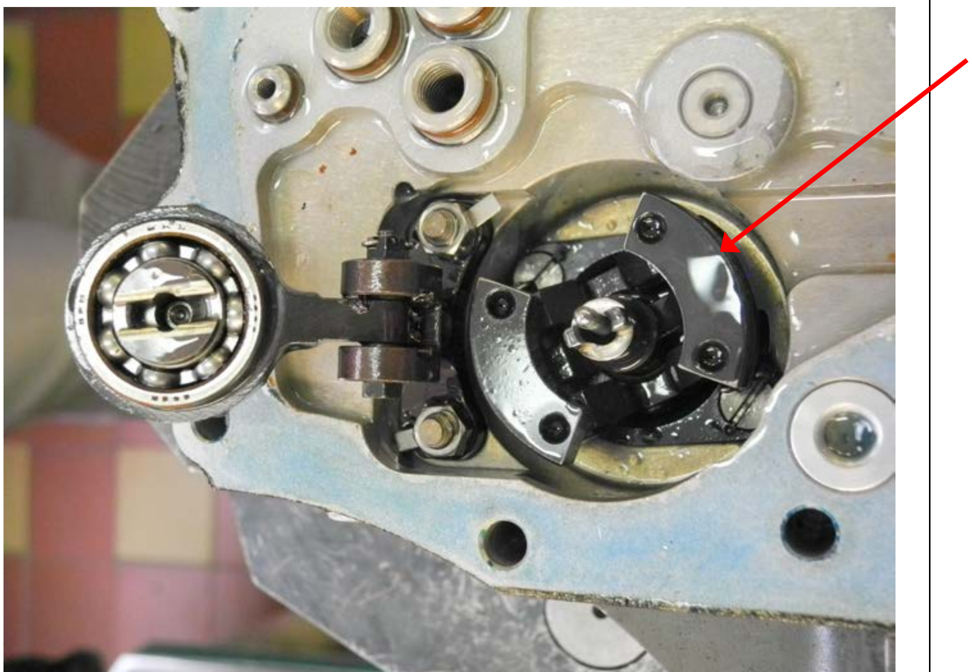


Figure 56 – PCU - Jihostroj, P/N LUN7815.02-8, S/N 873 024

Figure 57 – Propeller Control Unit – Bottom View – Note Deformation

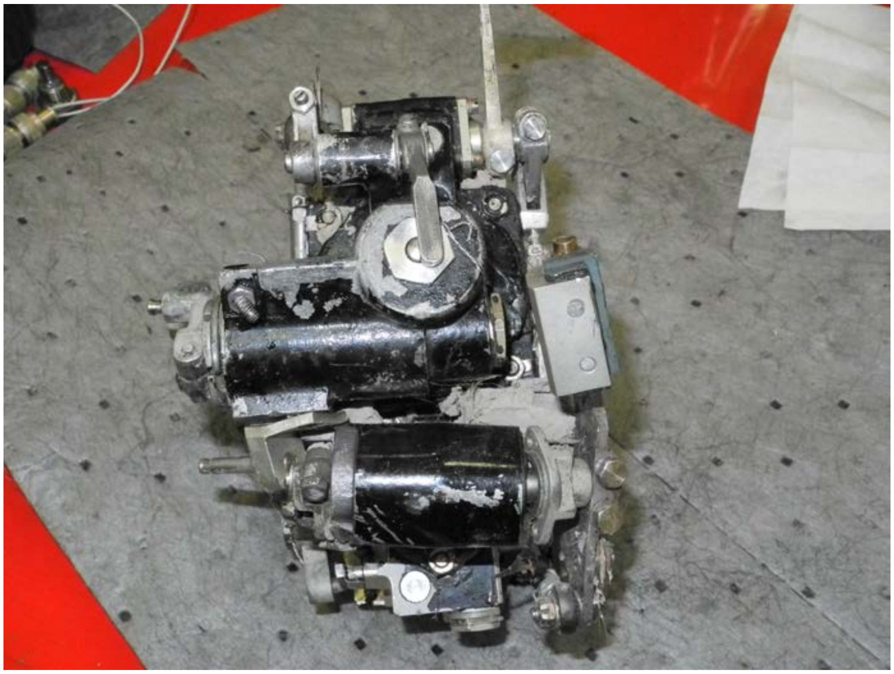


Figure 58 – Propeller Control Unit Input Drive Spline - Undamaged

Figure 59 – PCU Involute Gears and Side Seals - Undamaged

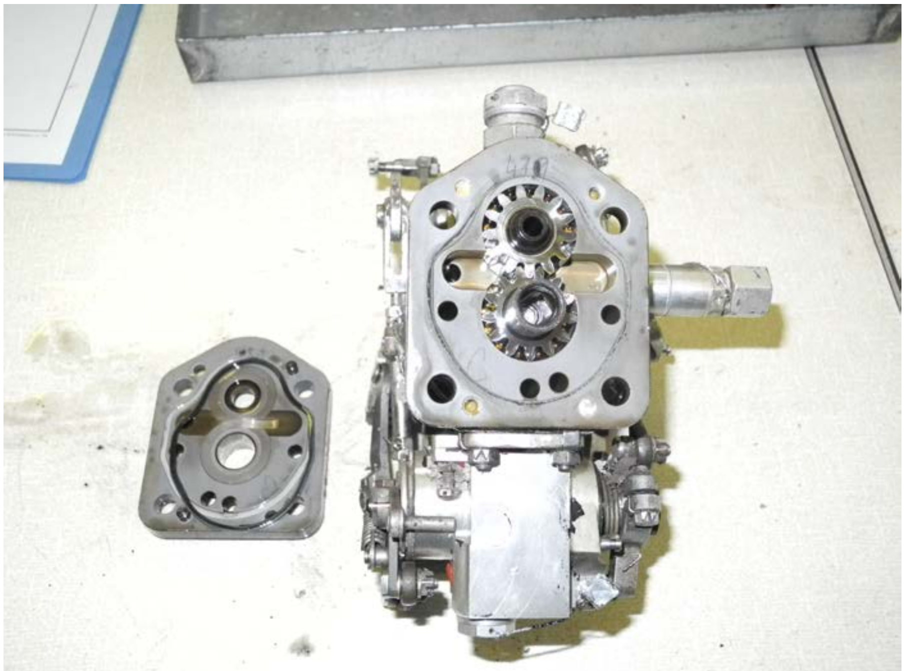


Figure 60 – Pilot Valve & Speeder Spring - Undamaged

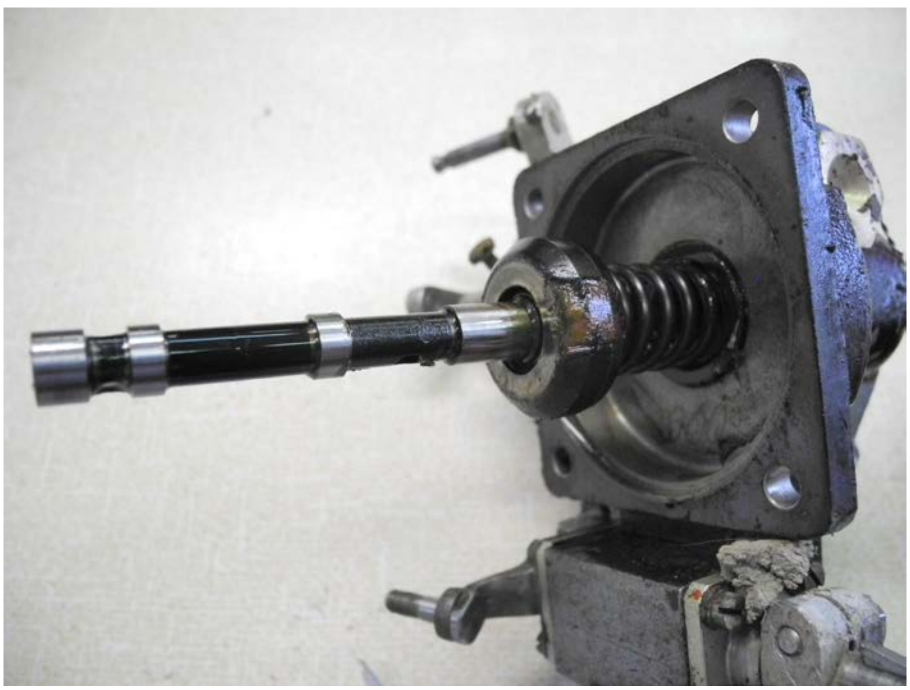


Figure 61 – PCU Flyweights – Undamaged and Free to Operate

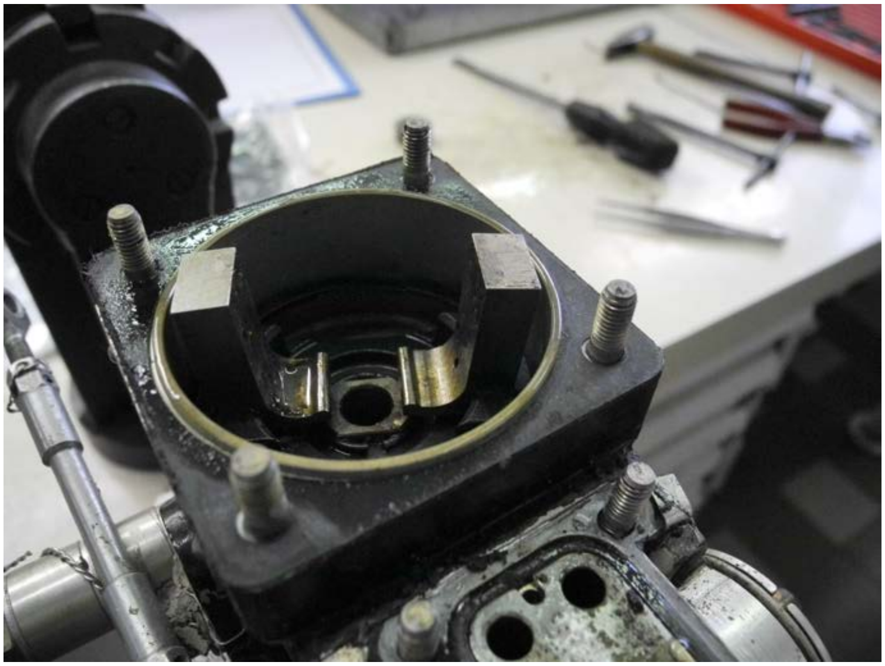
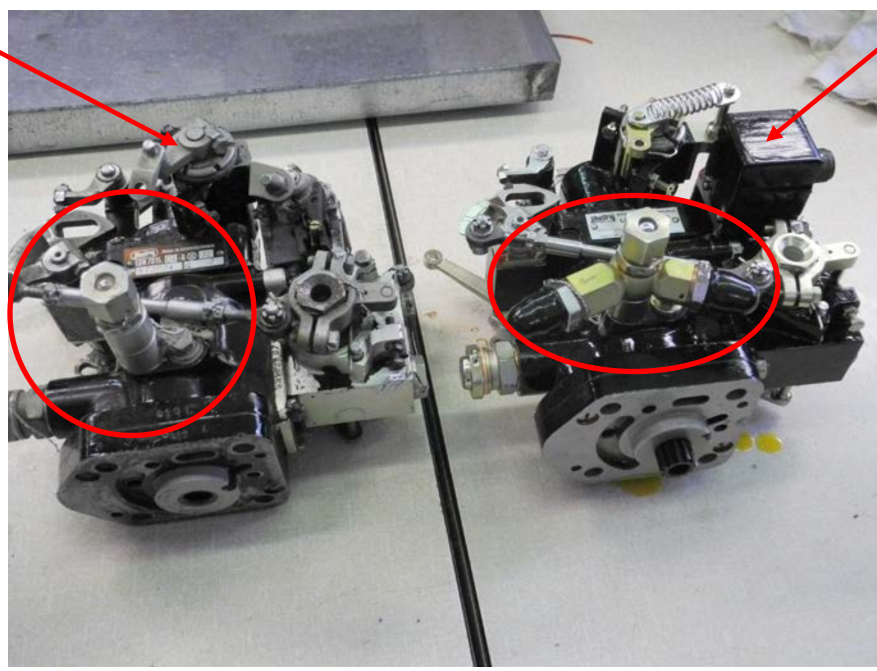


Figure 62 – Emergency Electric Feathering Pump Oil Pressure Port - Blocked

Event PCU S/N 873024 with Blocked Emergency Electric Feathering Pump Fitting



Exemplar PCU With Standard Fittings for Emergency Electric Feathering Pump

Figure 63 – Propeller

Figure 64 – Blade – No Impact or Scoring Damage

Figure 65 – Propeller – Front View – Depicting Counterweight Position During Impact

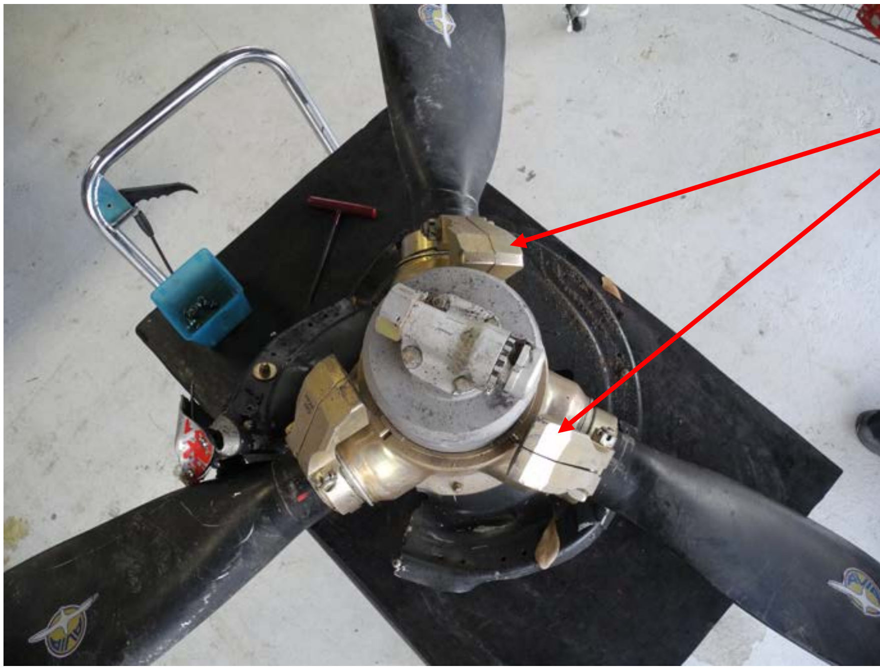
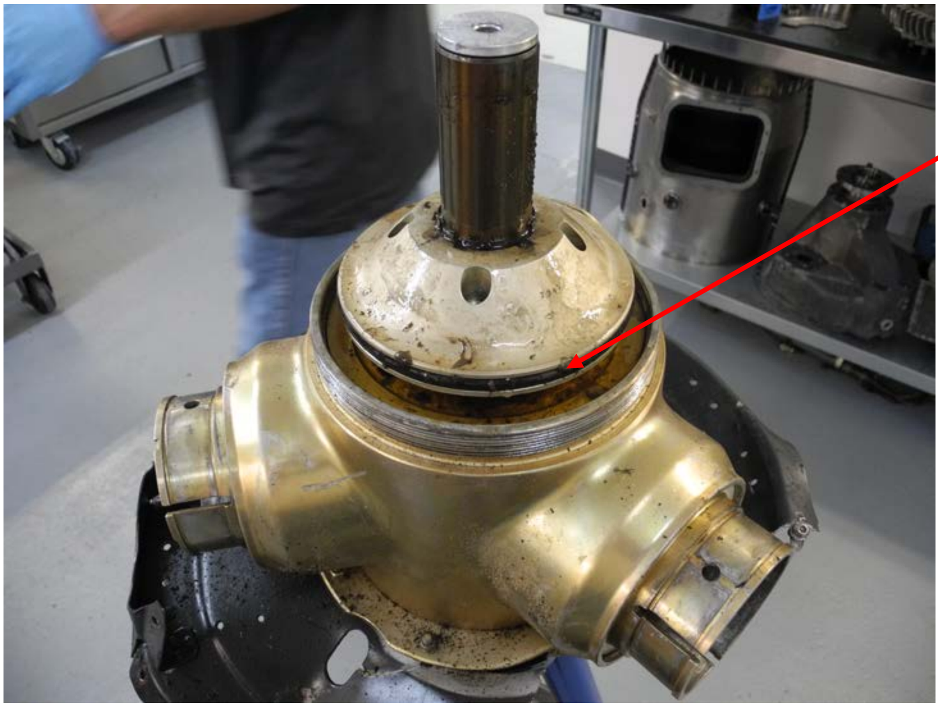


Figure 66 – Blade Counterweight Locating Key - Undamaged

Figure 67 – Blade Bushing - Undamaged

Figure 68 – Cylinder - Undamaged

Figure 69 – Piston and Ring - Undamaged



Piston Ring

Figure 70 – Main Fork and Tube

Figure 71 – Impact Dent from Contact Against Pitch Change Block

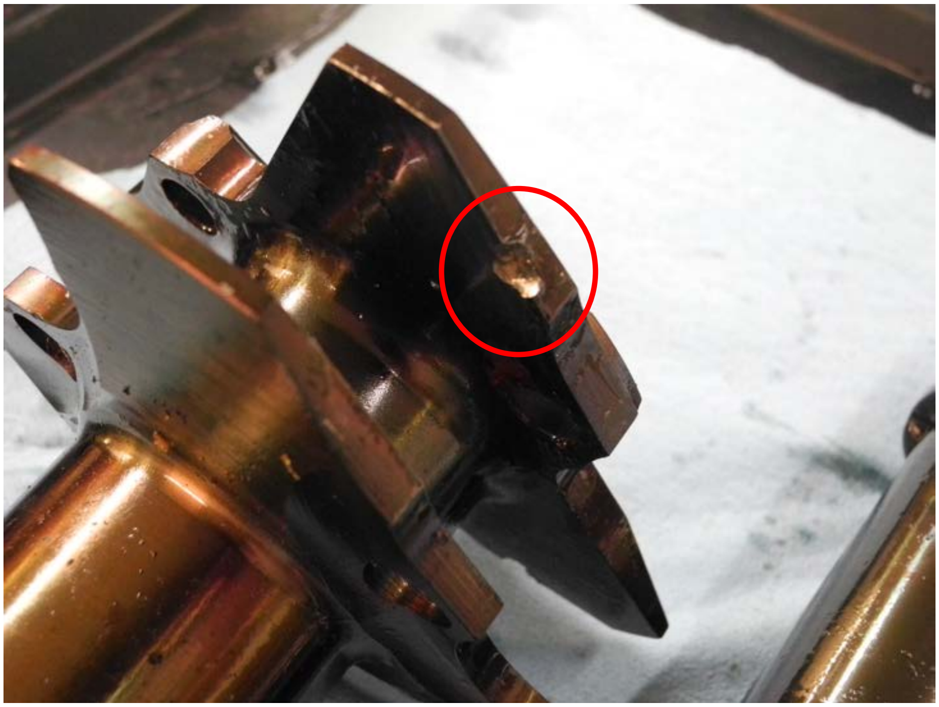


Figure 72 – Blade Bushings & Pitch Change Blocks

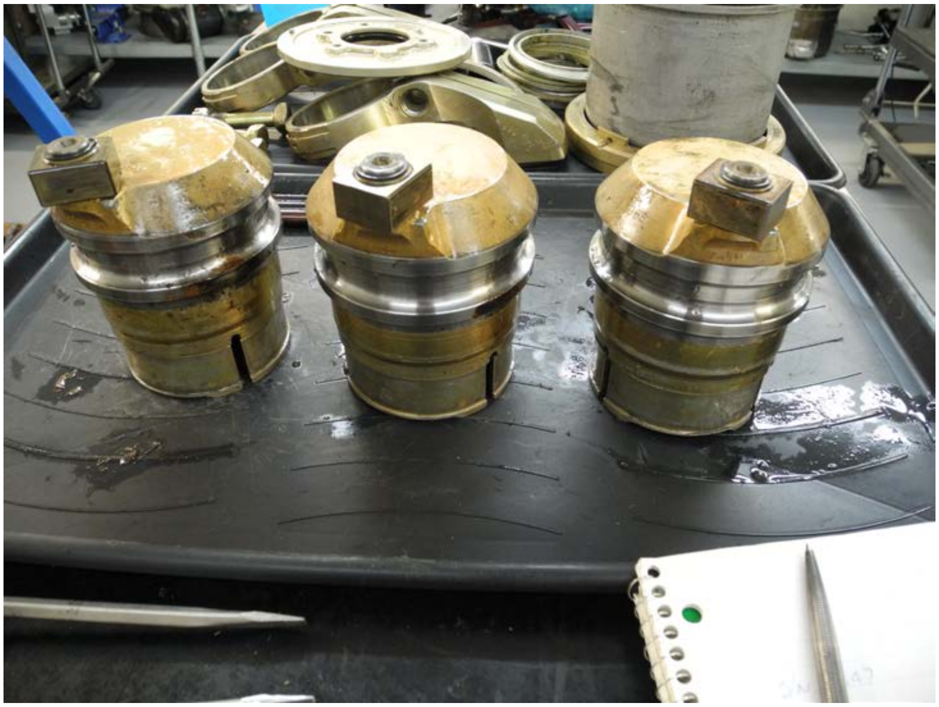


Figure 73 – Blade Bushing Ball Bearings - Intact

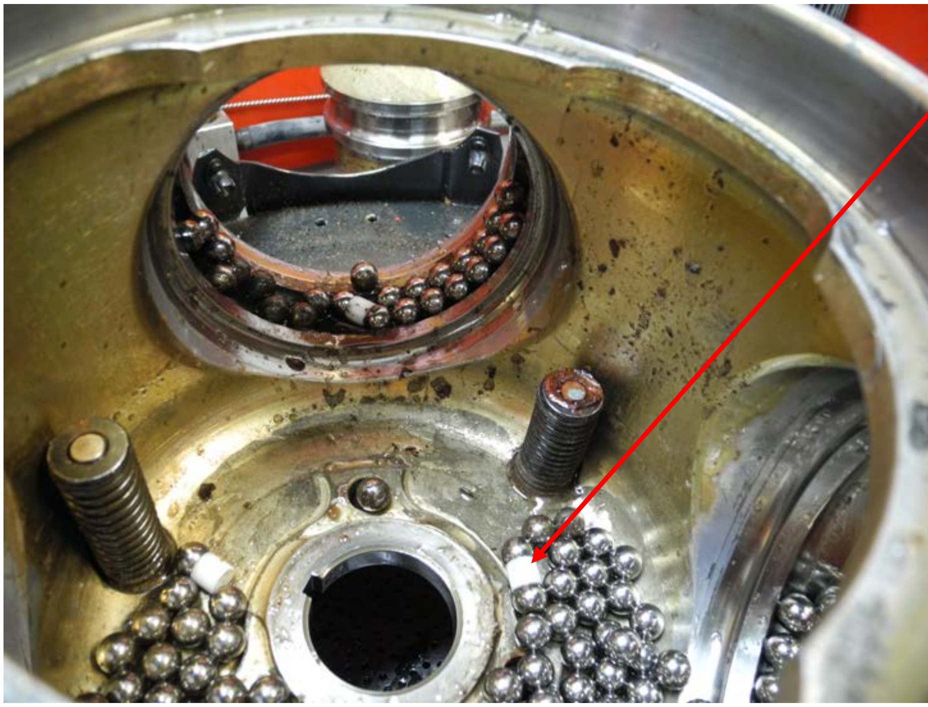


Figure 74 – Blade Bushing Sleeve – Fractured

Figure 75 – Indentations on Aft Side of Outer Race from Ball Bearing