



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

July 31, 2023

POWERPLANTS GROUPCHAIRMAN'S FACTUAL REPORT

NTSB No: CEN21LA287

A. ACCIDENT

Location: Sedgwick, Arkansas

Date: June 20, 2021

Time: 0700 central daylight time

Aircraft: Grumman G-164B airplane, registration number N62375

B. POWERPLANT GROUP

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C. SUMMARY

On June 20, 2021, about 0700 central daylight time, a Grumman G-164B airplane, N62375, was substantially damaged when it was involved in an accident near Sedgwick, Arkansas. The pilot was not injured. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 137 aerial-application flight.

The pilot stated that he did not observe any anomalies during his preflight inspection, there was no contamination observed in fuel samples obtained from both airframe fuel filter canisters, and that he departed on the local flight with about 60 gallons of Jet-A aviation fuel and 2,300 pounds of dry urea fertilizer. The pilot reported that he had completed 5-6 aerial-application passes over the intended rice field when the airplane had a total loss of engine power while in level flight. The pilot remarked that the sound of the engine went from normal to silent in conjunction with the total loss of engine power. The airplane impacted a levee and nosed over during the forced landing. The airplane's empennage, aft fuselage, and engine mounts were substantially damaged during the accident.

The engine was subsequently removed from the airframe and shipped to the Honeywell facility in Phoenix Arizona where a detailed examination was conducted on March 3-4, 2022. Disassembly of the engine found that the torque sensor assembly front spur gear (also referred to as the second direct drive fuel control gear) was loose and had disengaged from the splined shouldered shaft on which it was installed. Furthermore, the self-locking nut that secures the front spur gear to the splined shouldered shaft was loose and had back off allowing the front spur gear to disengage from the splined shouldered shaft. Disassembly of the torque sensor assembly found that the internal spline teeth of the front spur gear and the corresponding external forward spline teeth of the splined shouldered shaft were heavily damaged, smeared over, and exhibited loss of teeth material. Metallurgical evaluation of the splined shouldered shaft found stepped wear and deformation in the clockwise direction along the axial length of the external forward spline teeth consistent with meshing with the fretted internal spline teeth of the front spur gear. Wear and deformation were also observed on the last (rearward) threads of the splined shouldered shaft consistent with contact with the worn threads of the self-locking nut. The internal spline teeth of the front spur gear exhibited wear and deformation in the counterclockwise direction (forward looking aft) about $\frac{2}{3}$ of the axial length near the aft end consistent with meshing with the fretted external forward spline teeth of the splined shouldered shaft. Dimensional inspection of the splined shouldered shaft away from the damaged region showed it to be consistent within the manufacturing drawing; the average hardness was also with the specified drawing range. The average hardness of the front spur gear was also with the specified drawing range. The self-locking nut exhibited: 1) wear marks on one side of each wrenching flat consistent with contact from the installation/torque tool, 2) wear marks on the aft face of the nut consistent with contact with the mating washer, and 3) wear of the internal threads through the silver plating predominately on the forward/pressure face/loaded flank side of the threads consistent with engagement with the splined shouldered shaft. Like the front spur gear and splined shouldered shaft, average hardness of the self-locking nut met the minimum hardness requirement. Through a series of gears in the accessory gearbox, including the front spur gear, the engine-driven fuel pump assembly and fuel control unit are driven; any

failure in the gear train that drives the fuel pump and fuel control may result in an uncommanded engine shutdown depending on the operating condition.

Honeywell conducted a series of tests to determine if the front spur gear self-locking nut had been properly torqued during installation or if it had come loose during operation due to a loss of retention. Based on the repair shop's invoice for the last overhaul of the event torque sensor assembly, the front spur gear self-locking nut had been replaced with a new nut. Thus, the tests conducted by Honeywell included repetitive installation and untorquing of several new self-locking nuts and accessing their thread condition in comparison with the event self-locking nut that was found loose. Additionally, tests were performed to see, if and by how much, repetitive torquing and untorquing of the self-locking nut would affect its retaining feature and discernably alter it dimensionally. The self-locking nut threads are slightly ovalized so that the nut must elastically deformed to mate with the threads of the splined shouldered shaft causing increased surface friction that resists loosening when fully and properly torqued.

The testing was inconclusive if the front spur gear self-locking nut had been properly torqued at installation or if had come loose during operation due a loss of retention. What the tests did show was that run-on (installation) torque values for the new self-locking nuts were generally the best and most consistent and that repetitive torquing/untorquing operations generally lowers the self-locking nut's retaining feature when compared to new ones.

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TABLE OF ACRONYMS

°C	TEMPERATURE IN DEGREES CELSIUS
°F	TEMPERATURE IN DEGREES FAHRENHEIT
AD	AIRWORTHINESS DIRECTIVE
ALF	AFT LOOKING FORWARD
BTU	BRITISH THERMAL UNIT
DDFC	DIRECT DRIVE FUEL CONTROL
EDS	ENERGY DISPERSIVE SPECTROSCOPY
ESHP	EQUIVALENT SHAFT HORSEPOWER
ESN	ENGINE SERIAL NUMBER
FAA	FEDERAL AVIATION ADMINISTRATION
ft	FEET
GP	GAS PRODUCER
HP	HORSEPOWER
in. Hg	INCHES OF MERCURY
ISA	INTERNATIONAL STANDARD ATMOSPHERE
lb.-ft.	POUND-FOOT-
MCD	MAGNETIC CHIP DETECTOR
MoS ₂	MOLYBDENUM DISULFIDE
NTSB	NATIONAL TRANSPORTATION SAFETY BOARD
PN	PART NUMBER
R&O	REPAIR AND OVERHAUL
RPM	REVOLUTIONS PER MINUTE
SEM	SCANNING ELECTRON MICROSCOPE
SHP	SHAFT HORSEPOWER
SN	SERIAL NUMBER
TCDS	TYPE CERTIFICATE DATA SHEET
TSN	TIME SINCE NEW
ATP	ACCEPTANCE TEST PROCEDURE

D. DETAILS OF THE INVESTIGATION

1.0 ENGINE AND AIRPLANE INFORMATION

1.1 ENGINE DESCRIPTION

The accident airplane was powered by one Honeywell (formerly AlliedSignal, Garrett, and AiResearch) model number TPE331-1-151G turbo-propeller engine, (**FIGURE 1**). The TPE331-1-151G is a single-shaft engine with a two-stage centrifugal compressor, an annular combustion chamber, and three-stage axial turbine that drives the compressor (gas generator section) (**FIGURE 2**) and the reduction/accessory gearbox; sometimes the reduction gearbox is also referred to the output gearbox (gear reduction section) (**FIGURE 3**). The model number identification is broken down as follows:

TPE331-1-151G

TPE means turboprop engine

331 is the series number assigned by Honeywell

-1 identifies the FAA power class certification

The engine may be installed inlet up or down. The letter "U" after the model dash number indicates that the engine air inlet is located above the propeller shaft centerline. Omission of the letter "U" after the model dash number indicates that the engine air inlet is located below the propeller shaft centerline.

-151 indicates the engine configuration in that specific components may be identified
G indicates the customer code for this engine model – Originally installed on Fairchild Aircraft

According to the Federal Aviation Administration (FAA) Type Certificate Data Sheet (TCDS) E3WE, revision 8, dated February 1, 2000, the TPE331-1 turbo-propeller engine has a maximum continuous shaft horsepower power (SHP) of 665; 705 Equivalent Shaft Horsepower (ESHP); and output shaft rotation speed of 2,000 revolutions per minute (RPM). The takeoff (5 minute) limit is as follows: 665 SHP, 705 ESHP, and output shaft rotation speed of 2,000 RPM. The maximum exhaust gas temperature is 1047°F (564°C) for maximum continuous and 1072°F (578°C) for takeoff.¹ Maximum allowable propeller shaft torque as sensed by the torque sensor, in pound-feet (lb.-ft.), is 1,890 for 5 minute torque limit and 1,746 lb.-ft. for maximum continuous.

The TPE 331-1-151G is a clockwise rotating propeller installation. The gearbox incorporates a fixed planetary gear carrier assembly. The bull gear/sun gear assembly drives the planet gears, which drive the rotating ring gear. The ring gear is attached to the propeller

¹ Engine power rating is based on the following: 1) International Standard Atmosphere (ISA), Sea Level Static Conditions, 2) fuel with lower heating value of 18,400 British Thermal Unit (BTU) per pound, 3) no bleed-air extraction, 4) no external accessory loads, and 5) zero inlet loss. ESHP is for a static condition and is based on the following equation: $ESHP = (\text{Net Thrust (pounds)} / 2.5) + SHP$

shaft with a splined hub. With the ring and propeller shaft rotating as one assembly, this produces clockwise rotation. The gearbox ratio is 20.865 to 1, with a 2,000 RPM propeller speed at 100% engine speed (**FIGURE 3**).

TYPICAL TPE 331 CONFIGURATION

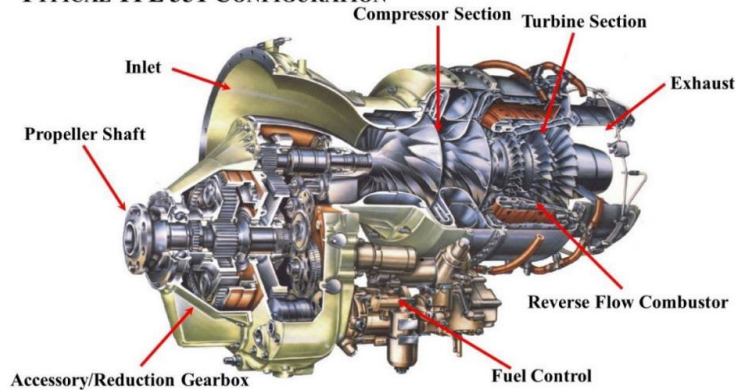


FIGURE 1: GENERIC TPE331 TURBO-PROPELLER ENGINE CROSS-SECTION

FIGURE COURTESY OF HONEYWELL (MODIFIED BY NTSB)

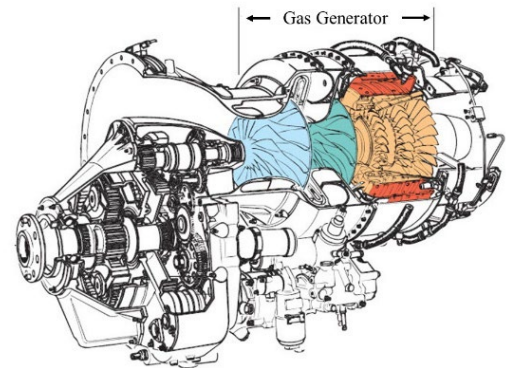


FIGURE 2: GENERIC TPE331 TURBO-PROPELLER ENGINE CROSS-SECTION

FIGURE COURTESY OF HONEYWELL

All directional references to front and rear; left and right; top and bottom; and clockwise and counterclockwise are made aft looking forward (ALF), as is the convention. All numbering is in the circumferential direction starting with the No. 1 position at the 12:00 o'clock position or immediately clockwise from the 12:00 o'clock position and progressing sequentially clockwise ALF. The direction of rotation of the engine compressor and turbine is clockwise, and the propeller shaft is clockwise as well. Since the TPE331 may be installed either with the inlet up or the inlet down based on the type of airplane installation, references to top and bottom are as the engine is installed in the airplane.

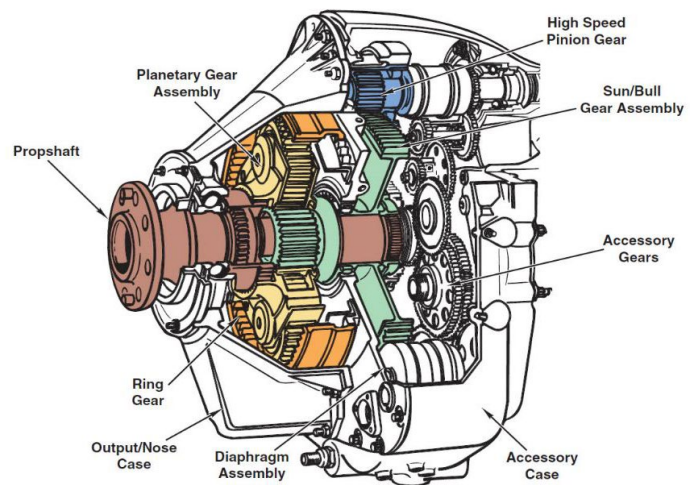


FIGURE 3: ACCESSORY/REDUCTION GEARBOX - GEAR REDUCTION SECTION

FIGURE COURTESY OF HONEYWELL

1.2 ENGINE HISTORY

According to the data plate, which is affixed to the engine's accessory case, the engine serial number (ESN) was P-92122C (**PHOTO 1**). Based on the maintenance records and the Hobbs meter in the airplane, the calculated time since new (TSN) and time since overhaul (TSO) of the engine at the time of the accident was 21,012.5 hours and 18,452.5 hours respectively.

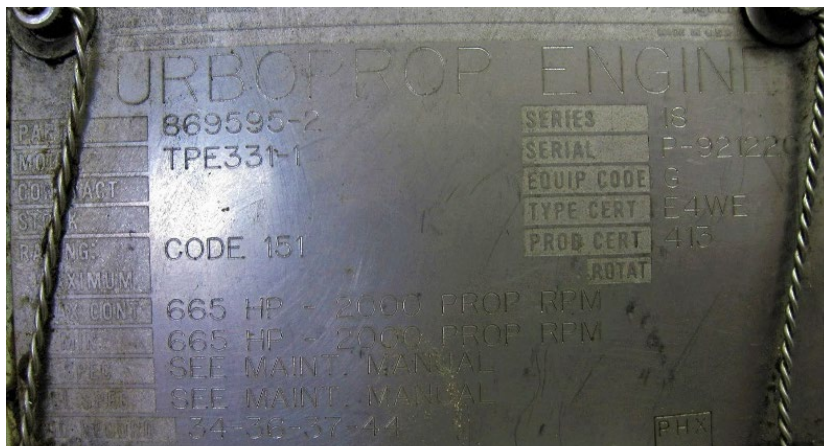


PHOTO 1: ENGINE DATA PLATE

1.3 TORQUE SENSOR HISTORY

The engine logbook indicated that torque sensor assembly part number (PN) 3101726-3, serial number (SN) P-4184C, series 2, was installed on the incident engine on February 11, 2015 (**PHOTO 2**); the data plate from the accident torque sensor confirms that this is the same torque sensor assembly as reference in the engine logbook (**PHOTO 3**).

ENGINE ☐ MODULE ☐ SERIAL NUMBER <u>P-92122</u>				SERVICE RECORD				PAGE _____	
DESCRIPTION OF INSPECTIONS, REPAIRS AND OVERHAULS ENDORSE ALL INSPECTIONS AND REPAIRS WITH NAME, RATING AND CERTIFICATE NUMBER.									
DATE	HOURS THIS FLIGHT	CYCLES THIS FLIGHT	ACCUMULATIVE TOTALS				DESCRIPTION OF WORK PERFORMED		
			HOURS		CYCLES				
			SINCE NEW	SINCE O/H	SINCE NEW	SINCE O/H			
			TOTALS BROUGHT FORWARD						
2/11/2015 S/N P-92122 Hobbs 4748 Disassembled gearbox per Honeywell M/M 72-00-92 and installed torque sensor P/N 3101726-3 S/N P-4184. Reassembled gearbox and reset trip pressure. Complied with S/B 72-0416 by installation of new gearshaft P/N 3103192-3 and new seal P/N 3103872-1 and new adaptor P/N 3103828-1. Complied with AD 2006-15-08 1000 Hr FCU spline check. Splines are within acceptable limits. Next inspection due in 1000 engine operating Hrs. Installed cleaned and flow checked fuel nozzle set. Installed engine on test cell and performed leakdown. Adjusted torque compensator and made new graph. Performed vibration analysis. Vibration is within acceptable limits. Operational check and leak check OK. All work performed in accordance with current regulations of the Federal Aviation administration and is approved for return to service with respect to work performed. NOTE : SOAP sample due in 10 Engine operating Hrs.									

PHOTO 2: TORQUE SENSOR ASSEMBLY LOGBOOK ENTRY



PHOTO 3: TORQUE SENSOR ASSEMBLY ON ACCIDENT ENGINE

An Authorized Release Certificate FAA form 8130-3 Airworthiness Approval Tag was issued by National Flight Services Inc. Holland, Ohio, on October 3, 2013, for the same torque sensor assembly (**PHOTO 4**). Based on the maintenance records and the Hobbs meter in the airplane, the calculated time that the torque sensor assembly had accumulated since its last overhaul/repair was 2,541.5 hours. According to the torque sensor assembly FAA form 8130-3, it was inspected, overhauled, and tested per the Honeywell torque sensor gear assembly overhaul manual with illustrated parts list, 72-00-17 revision No. 9 (July 20, 1992).²

National Flight Services Inc. did not retain the hard copies of the work order and test data sheet for this event torque sensor assembly so it was not possible to review all the overhaul/repairs tasks that were performed; it should be noted that the FAA only requires that certified repair stations retain hard copies of the maintenance records for a period of two years in accordance with 12 CFR 145.219 (c).³ Since the torque sensor was overhauled/repaired in 2013, National Flight Services Inc. was under no obligation to retain the maintenance records past October 2015. National Flight Service Inc. was able to provide a copy of the invoice for the event torque

1. Approving National Aviation Authority/Country: FAA/UNITED STATES		2. AUTHORIZED RELEASE CERTIFICATE FAA Form 8130-3, AIRWORTHINESS APPROVAL TAG National Flight Services, Inc. 1640 COMMERCIAL ROAD HOLLAND, OH 43028 CRS DSCR311D				3. Form Tracking Number: TOC-2854	
4. Organization Name and Address:		5. Work Order/Contract/Invoice Number: 1053531					
6. Item:	7. Description:	8. Part Number:	9. Eligibility:	10. Quantity:	11. Serial/Batch Number:	12. Status/Work:	
1	TORQUE SENSOR	3101726-3	N/A	1	P-4184C	OVERHAULED	
13. Remarks: INSPECTED, OVERHAULED, AND TESTED TORQUE SENSOR PER THE HONEYWELL TYPE 311 COMPONENT OVERHAUL MANUAL 72-00-17 R9 (JUL 20 1992) COMPLIED WITH SERVICE BULLETIN: N/A							
14. Certifies that the work specified in Block 12/13 was carried out in accordance with EASA 145 and with respect to that work the aircraft component is considered ready for release to service and/or EASA Acceptance Certificate Number: EASA 145 4695							
15. Authorized Signature:		16. Approved/Authorized Signature:		17. Certified that unless otherwise specified in Block 13, the work identified in Block 12 and described in Block 13 was accomplished in accordance with Title 14, Code of Federal Regulations, part 43 and in respect to that work, the items are approved for return to service.		18. Other regulation specified in Block 13	
19. Name (Typed or Printed):		20. Date:		21. Name (Typed or Printed):		22. Date (mm/dd/yyyy):	
NATE COUSINO		OCT 3, 2013		DSCR311D		OCT 3, 2013	
User/Installer Responsibilities It is important to understand that the existence of this document alone does not automatically constitute authority to install the part/component/assembly. Where the user/installer performs work in accordance with the national regulations of an airworthiness authority different than the airworthiness authority of the country specified in Block 1, it is essential that the user/installer ensures that the airworthiness approval part/component/assembly from the airworthiness authority of the country specified in Block 1. Statements in Blocks 14 and 15 do not constitute installation certification. In all cases, aircraft maintenance records must contain an installation certification issued in accordance with the national regulations of the country before the aircraft may be flown.							
FAA Form 8130-3 (4-01)		*Installer must cross-check eligibility with applicable technical data.				N/A (002-00-012-9003)	

PHOTO 4: TORQUE SENSOR SN P-4184C FAA FORM 8130-3

National Flight Services		Telephone: [REDACTED] Fax: [REDACTED]			
10971 East Airport Service Road Swanton, OH 43558 USA		Invoice			
Bill To: SEATTLE TURBINE PARTS		WO #: TOC-2854 Invoice Number: INV13-03710			
Item: 1. TORQUE SENSOR		Part/Model #: 3101726-3 Item Serial Number: P-4184C Registration Number: N/A Aircraft Serial Number: N/A			
Discrepancy: 1.1. Torque sensor requires overhaul.					
Resolution: Overhauled and tested per the Honeywell report 72-00-17 Rev 9					
		Time & Materials	Flat Rate		
Labor:		[REDACTED]	[REDACTED]		
Parts:		[REDACTED]	[REDACTED]		
Total:		[REDACTED]	[REDACTED]		
Part:					
Ref. No.	Part number	Description	Quantity	Sell price	Extended
1.1 #1	3103583-3	TORQUE SENSOR HOUSING	1	-	0.00
1.1 #2	3103589-1	GEAR	1	-	0.00
1.1 #3	3103599-2	GEAR	1	-	0.00
1.1 #4	3103406-2	Serial Number(s) 13P56392	1	-	0.00
1.1 #5	5103585-1	IDLER GEAR	1	-	0.00
1.1 #6	5103585-1	BEARING	1	-	0.00
1.1 #7	S9413-017	Serial Number(s) 13-151725-04671	1	-	0.00
1.1 #8	S8157N46-072	Serial Number(s) 13-151725-04670	3	-	0.00
1.1 #9	3102243-1	PACKING (O-RING)	1	-	0.00
1.1 #10	3102243-1	WASHER	1	-	0.00
1.1 #11	MS21043-3	BEARING	1	-	0.00
1.1 #12	MS21043-4	Serial Number(s) 09-151725-03278	1	-	0.00
1.1 #13	MS21043-5	BEARING	1	-	0.00
1.1 #14	MS21043-88	Serial Number(s) 09-151725-03288	2	-	0.00
1.1 #15	626-606-9012	NUT, 10-32 SELF LOCKING	1	-	0.00
		HIGH TEMP			
		NUT	1	-	0.00
		NUT	1	-	0.00
		NUT	1	-	0.00
		SNAP RING	1	-	0.00

PHOTO 5: INVOICE FOR TORQUE SENSOR SN P-4184C

² Honeywell issued revision 10 to torque sensor gear assembly overhaul manual 72-00-17 on October 31, 2013, 28 days after the accident torque sensor was overhauled/repaired.

³ § 145.219 Recordkeeping

(a) A certificated repair station must retain records in English that demonstrate compliance with the requirements of part 43. The records must be retained in a format acceptable to the FAA.

(b) A certificated repair station must provide a copy of the maintenance release to the owner or operator of the article on which the maintenance, preventive maintenance, or alteration was performed.

(c) A certificated repair station must retain the records required by this section for at least 2 years from the date the article was approved for return to service.

sensor assembly that provided a list of parts replaced (**PHOTO 5**).

1.4 TORQUE SENSOR AIRWORTHINESS DIRECTIVE

The FAA issued Airworthiness Directive (AD) 2018-13-05 with an effective date of July 26, 2018, to address reports of failures of the direct drive fuel control gears and bearings in the hydraulic torque sensor gear assembly, P/N 3101726-3; the AD is to prevent failure of the hydraulic torque sensor gear assembly. The unsafe condition, if not addressed, could result in failure of the hydraulic torque sensor gear assembly, in-flight shutdown, and reduced control of the airplane. The accident engine and the torque sensor assembly PN were applicable to the AD. The AD required: 1) an initial and repetitive oil filter sample and analysis for wear material every 150 hours in service after the effective date of this AD and 2) do not use the Honeywell torque sensor gear assembly overhaul manual with illustrated parts list, 72-00-17, Revision No. 9, dated, July 20, 1992, or earlier versions, to overhaul TPE331 or TSE331 hydraulic torque sensor gear assemblies, P/Ns 3101726-1, -2, or -3. The repair/overhaul performed by National Flight Services Inc. in 2013 was before the AD was issued, so the torque sensor gear assembly overhaul manual version requirement was not applicable. **PHOTOS 4** and **5** (the FAA 8130 Form and the parts invoice for the event torque sensor) showed that torque sensor was repaired in accordance with the Honeywell/Allied-Signal Aerospace Company Overhaul manual 72-00-17 Revision 19 (July 20, 1992).

In accordance with the AD, the initial and repetitive oil filter sample and analysis did apply to this engine and torque sensor assembly. According to the engine logbooks, the repetitive oil filter sample and analysis was performed on March 18, 2019 (19,451 hours TSN), April 1, 2020 (19,948 hours TSN), March 1, 2021 (20,465 hours TSN), and May 17, 2021 (20,523 hours TSN)⁴ with no findings.

(d) A certificated repair station must make all required records available for inspection by the FAA and the National Transportation Safety Board.

⁴ All times are engine total times.

2.0 ENGINE EXAMINATION AND DISASSEMBLY - ENGINE SERIAL NUMBER P-92122C

The accident engine was examined and disassembled at the Honeywell facility in Phoenix, Arizona with persons from Honeywell, FAA, and the National Transportation Safety Board (NTSB) in attendance. The examination commenced on March 3, 2022, and was completed on March 4, 2022.

The engine was removed from its shipping container (**PHOTOS 6, 7, and 8**). The engine was received in essentially two separate sections: the gear reduction section and the gas generator section (compressor-through-turbine). No sign of an engine fire or uncontainment was noted.



PHOTO 6: ENTIRE ENGINE



PHOTO 7: GEAR REDUCTION



PHOTO 8: GAS GENERATOR

Looking through the exhaust, the stage 3 turbine blades were visible; they all appeared intact, full length, and undamaged (**PHOTO 9**). Looking through the air inlet, the stage 1 compressor impeller blades were visible with no sign of significant impact or ingestion damage; however, debris/dirt was noted in the impeller. The stage 1 impeller shroud exhibited what appeared to be static impact marks (**PHOTO 10** red arrows).

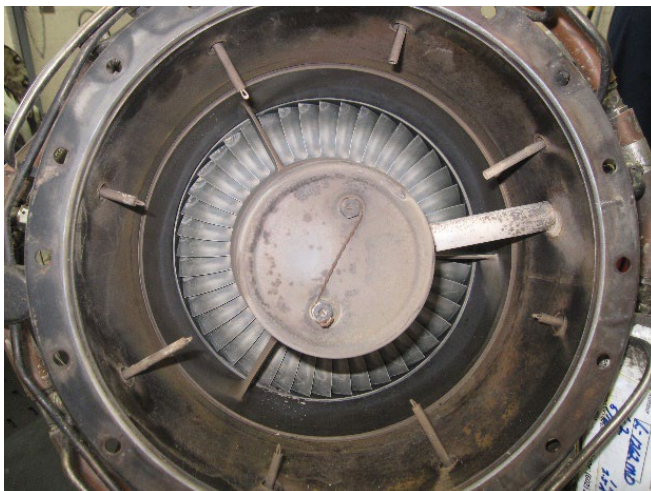


PHOTO 9: STAGE 3 TURBINE BLADES INTACT

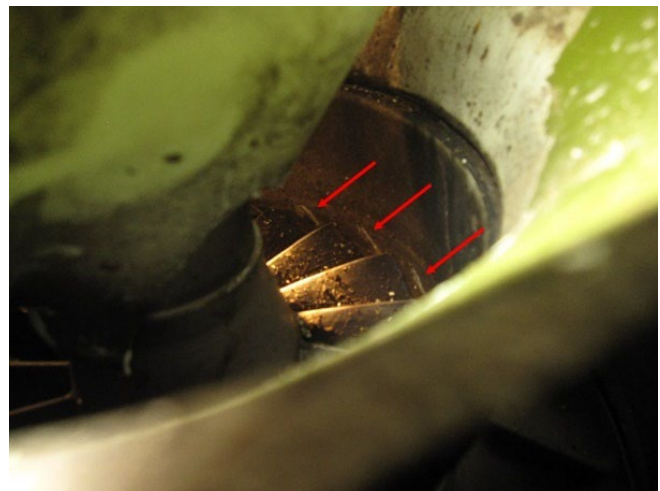


PHOTO 10: STAGE 1 COMPRESSOR BLADES INTACT

The gas generator section was placed on a table exhaust end down. The air inlet duct was fractured into multiple pieces and a portion of the torque sensor assembly remained still attached (**PHOTO 11**); the other half of the torque sensor assembly remained attached to the accessory case. The fuel nozzle and ignitor, along with their respective bosses, were pulled out from the combustion plenum at the 12:00 o'clock position. What remained of the torque sensor assembly was removed; the helical gear exhibited damage/smearing to the tops of teeth but was otherwise intact (**PHOTO 12**). The compressor bearing was visible, it appeared undamaged, and the ball bearings were shiny and round. The compressor bearing rotated by hand with some drag. A wrench was placed on the compressor bearing retaining nut and the compressor and turbine rotated in unison, confirming continuity of the gas generator section. The gas generator section was not disassembled further based on the finding that: 1) no damage was observed to the stage 1 impeller blades and stage 3 turbine blades, 2) the compressor and turbine bearing rotated freely, and 3) compressor and turbine rotated in unison.

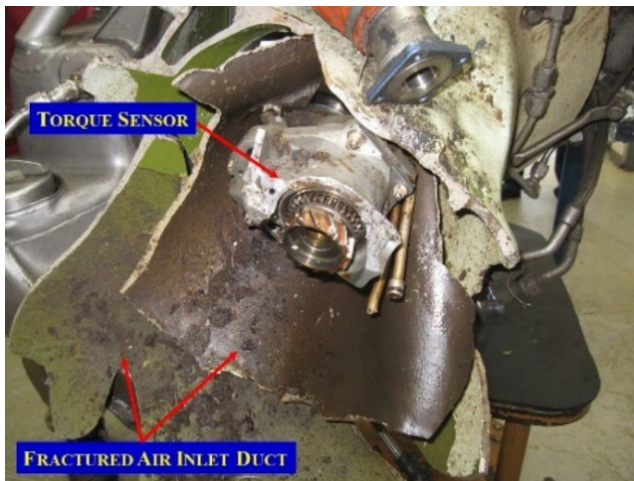


PHOTO 11: TORQUE SENSOR INSTALLED

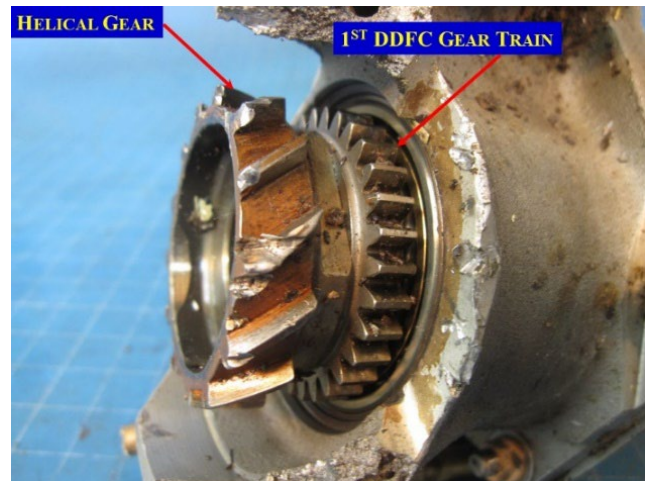
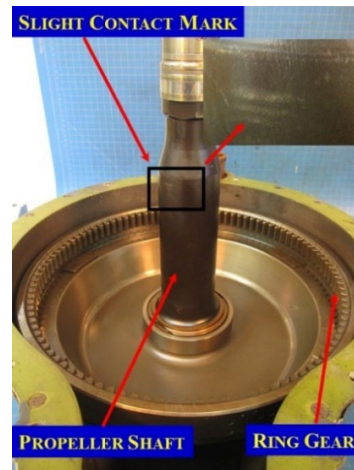


PHOTO 12: HELICAL GEAR TEETH DAMAGE

The gear reduction section was placed in a disassembly stand. The propeller front flange was intact and undamaged, the propeller locating pins were still present, and the output/nose cone assembly was intact and undamaged (**PHOTO 13**). The output/nose cone assembly was removed to expose the propeller shaft, the planetary gear, the sun gear front splines, the ring gear/hub, and the propeller shaft thrust bearing. The propeller shaft thrust ball bearing outer race is secured to the output/nose cone and the propeller shaft spun freely within the output/nose cone assembly; no further disassembly was performed to access the propeller shaft thrust bearing condition. The propeller shaft was intact, in good condition, and exhibited a very slight and small visual (no depth to the mark) rotational mark; the mark was localized and not circumferentially around the entire shaft (**PHOTO 14**). The ring gear/hub was intact, in good condition, and did not exhibit any distinguishing marks. The planetary gear set was intact, in good condition, all the gears spun freely, and did not exhibit any distinguishing marks.

**PHOTO 13: PROPELLER AND OUTPUT/NOSE CONE****PHOTO 14: PROPELLER SHAFT**

The diaphragm assembly was removed, and all the accessory gears that were mounted on the aft side of the diaphragm were intact and appeared to be in good condition, and their respective support bearings were intact, shiny, and appeared undamaged. The accessory gears did not rotate by hand; however, using a wrench the gear set did rotate with some resistance. The sun/bull gear assembly appeared to be intact and in good condition. The accessory gearbox oil scavenge tube was damaged; this was consistent with the location where the accessory case was fractured and missing.

Fuel flows from the aircraft system to the fuel pump assembly to the fuel control unit, where fuel is metered to the engine for all operating conditions. The engine-driven fuel pump assembly and fuel control unit are driven by a quill shaft coupling that is splined into the back of the oil pressure pump in the accessory gearbox (**FIGURE 4** and **PHOTO 15**). The oil pressure pump, fuel pump and fuel control are all driven by the gas generator through a gear train in the accessory gearbox. Should the quill shaft fail, or any of the gears that make up the gear train that drive the fuel pump and fuel control, the operational effect is an uncommanded engine shutdown or an engine overspeed depending on the operating condition.

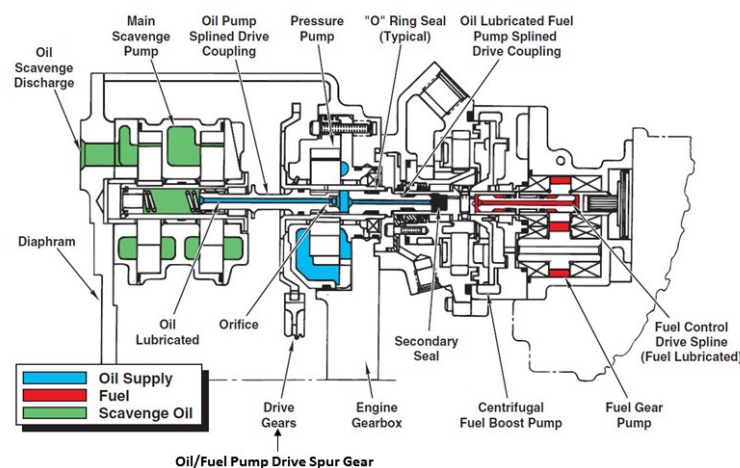
**FIGURE 4: EXPLODED VIEW OF ACCESSORY GEARBOX FUEL PUMP/FUEL CONTROL DRIVE GEAR**

FIGURE COURTESY OF HONEYWELL (MODIFIED BY NTSB)

The bottom portion of the accessory case was fractured and missing; the fracture location was coincident with where the torque sensor assembly was located (**PHOTO 15**)⁵. The 2nd direct drive fuel control (DDFC) is comprised of a front and rear spur gear supported by a duplex bearing and a splined shouldered shaft (PN 3103405-3) with a forward threaded end to accept an ovalized self-locking nut (**FIGURE 5** and **PHOTO 16**). The front 2nd DDFC spur gear was found loose and disengaged from the splined shouldered shaft and therefore disengaged from rear 2nd DDFC gear; they both should rotate together but when one was rotated the other did not. Both the front and rear 2nd DDFC spur gears were intact, and their gear teeth were in good condition; the self-locking nut that secures the front spur gear to the splined shouldered shaft was found loose with no torque (See **PHOTO 15**, yellow box, item 70). Comparing the self-locking nut from the event torque sensory assembly with that of an exemplar one revealed that the number of exposed threads on the splined shouldered shaft were not the same. On the event torque sensor assembly, no threads were exposed⁶ indicating that the self-locking nut was at the very end of the splined shouldered shaft threads (**PHOTO 17**, left side) while on the exemplar torque sensor assembly, several exposed threads were observed (**PHOTO 17**, right side).



PHOTO 15: FRACTURED PORTION OF TORQUE SENSOR ASSEMBLY AND ACCESSORY CASE

⁵ The yellow numbers in **PHOTOS 15-18** are reference numbers related to the blue numbers in **FIGURE 5** schematic of the torque sensor.

⁶ Typically, for threaded fasteners, after they are installed and torqued to the proper requirements, they should protrude at distance of a least one thread past the nut. A good rule of thumb to have between 2 to 3 full threads exposed. In some applications, the exposed thread is specified; however, according to the torque sensor assembly overhaul manual, no exposed thread number or length requirement is provided. Instead, the self-locking nut should be torqued to 200 inch-pounds (22.6 Newton meters)

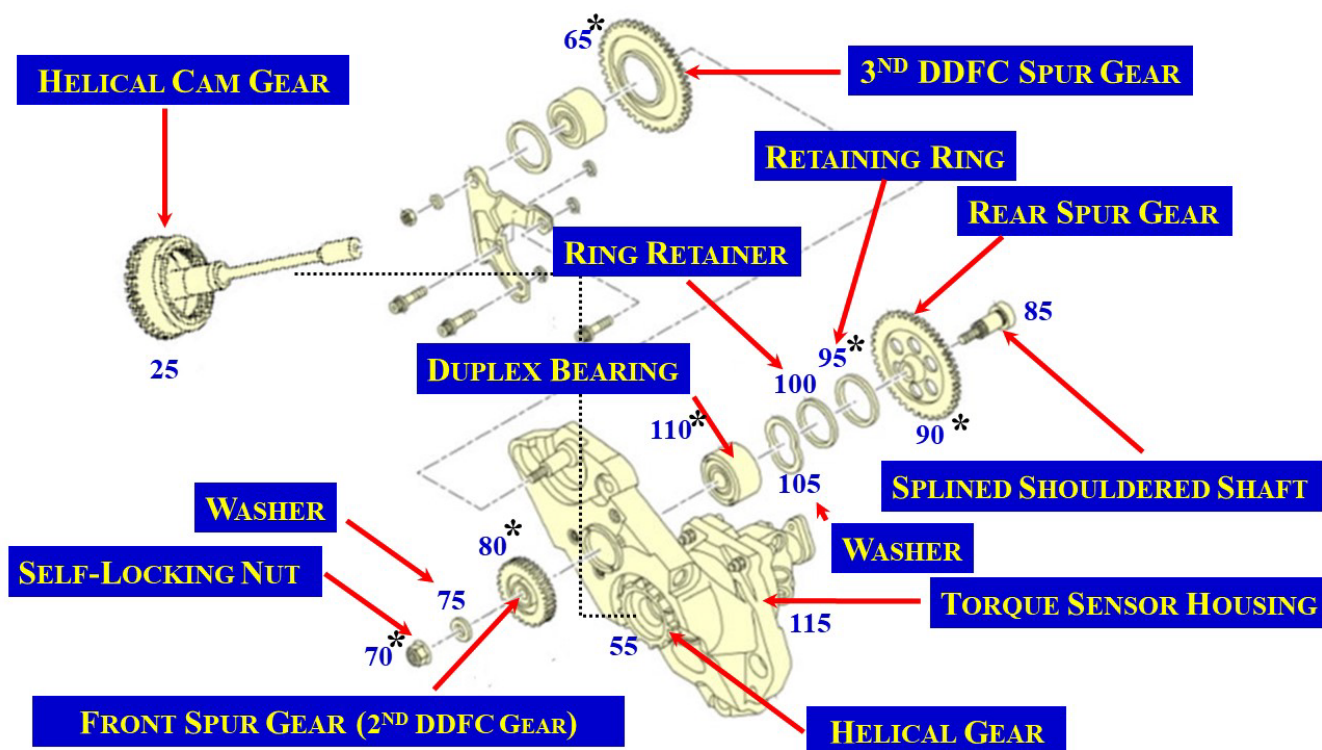


FIGURE 5: TORQUE SENSOR ASSEMBLY EXPLODED VIEW

FIGURE COURTESY OF HONEYWELL (MODIFIED BY NTSB)

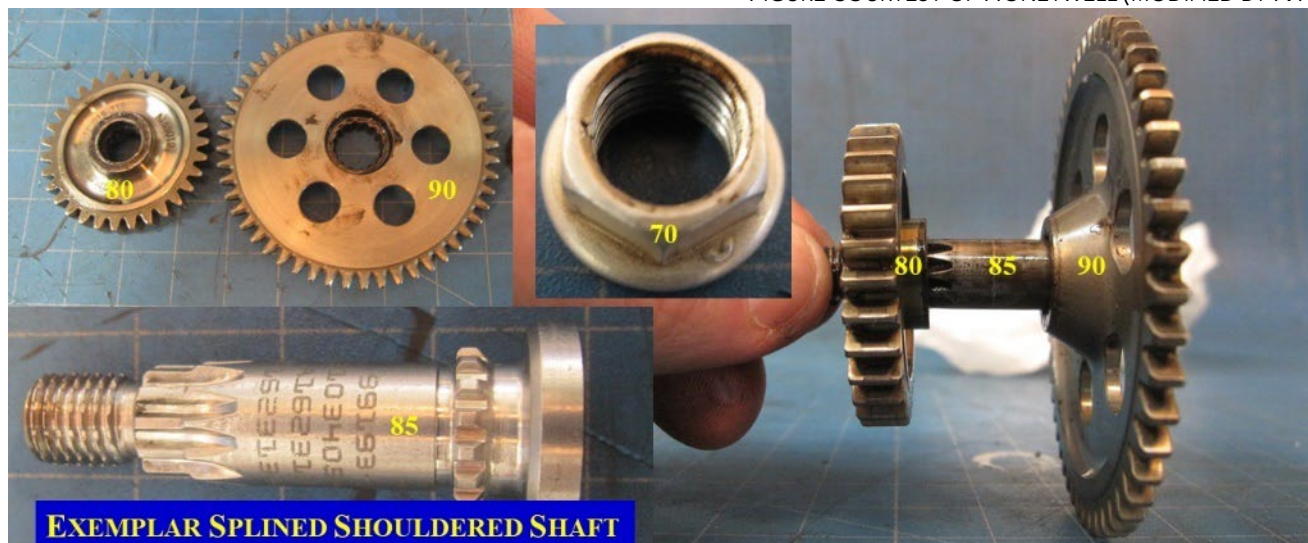


PHOTO 16: 2ND DIRECT DRIVE FUEL CONTROL COMPONENTS

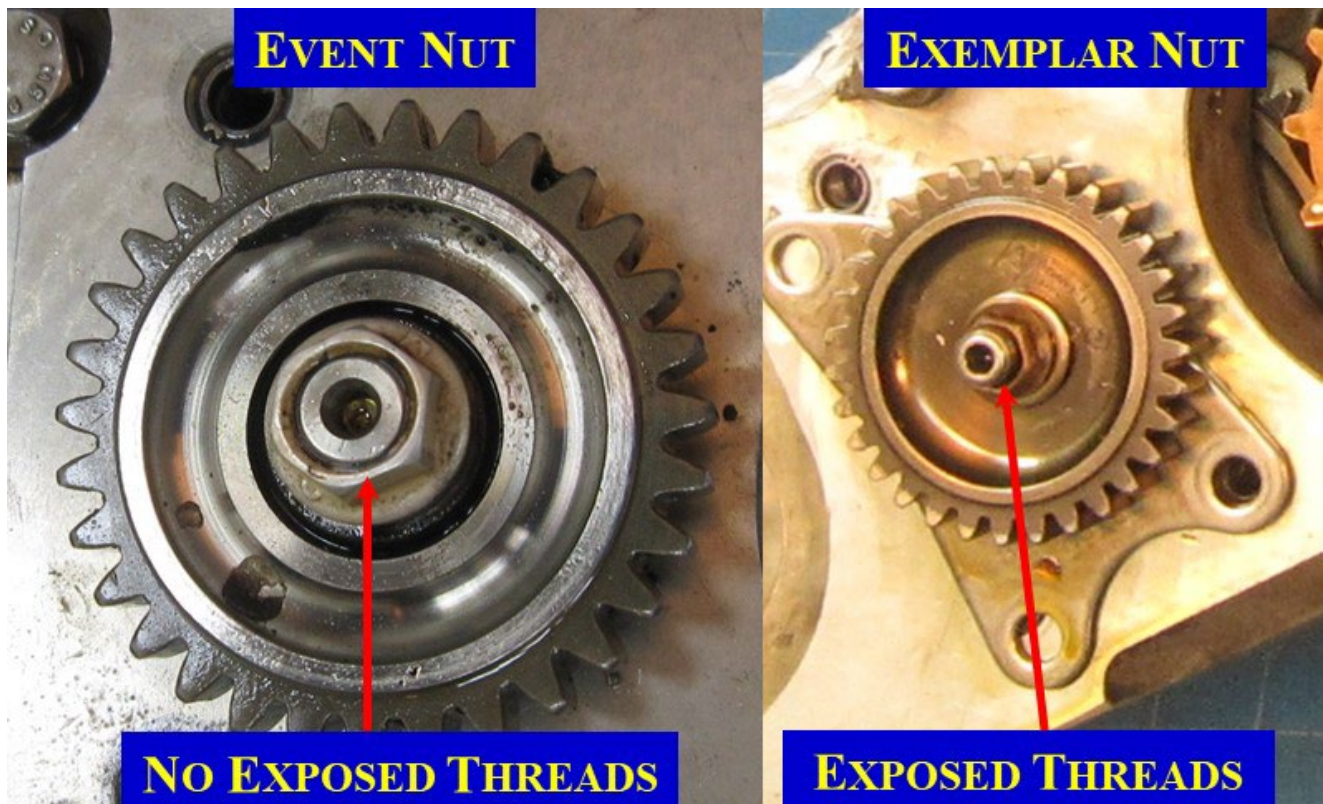


PHOTO 17: SPLINED SHOULDERED SHAFT EXPOSED THREADS WITH SELF-LOCKING NUT INSTALLED

When rotating the 2nd, 3rd, and 4th DDFC spur gears the oil /fuel pump drive gear rotated slightly in both direction but were essentially bound. When the fuel control and fuel pump were removed from the back side of the accessory case, the 3rd and 4th DDFC spur gears and the fuel pump drive gear spun freely. The fuel pump drive shaft was intact and in good condition. The fuel control drive splines were intact, in good condition, and the fuel control rotated easily by hand. The torque sensor assembly housing exhibited spur teeth impression where the helical cam gear would normally be installed (See **PHOTO 15**, upper right corner and black box).

The helical cam gear was missing from the torque sensor assembly and was not recovered (**PHOTO 18** bottom corner shows an exemplar helical cam gear installed). The 3rd DDFC was removed to facilitate removal of the remaining portion of the torque sensor assembly that was attached to the accessory case. Two bolts secured what remained of the torque sensor assembly to the accessory case. Both bolts had their anti-rotating lock-tabs installed the ends flared over; when a torque check was performed both were finger tight (no torque). The bolts were removed, and both appeared to be deformed (no longer straight). Examination of the accessory case helical inserts revealed that the insert threads appeared to be satisfactory, and the inserts had not pulled out of the case.

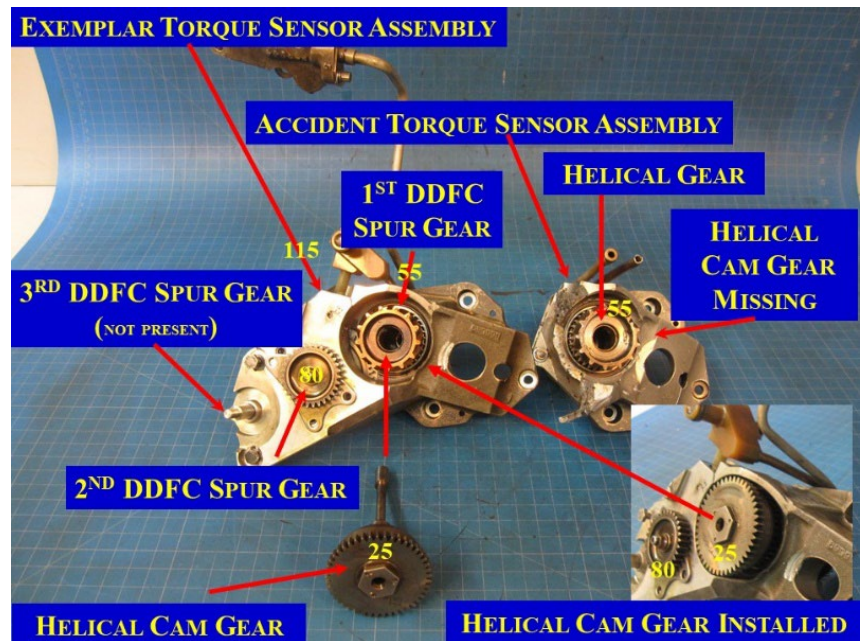


PHOTO 18: EXEMPLAR AND EVENT TORQUE SENSOR ASSEMBLY

Examination of the accessory case helical inserts revealed that the insert threads appeared to be satisfactory, and the inserts had not pulled out of the case.

Disassembly of the 2nd DDFC revealed the following: 1) gear teeth on the forward and aft spur gears appeared in good condition and undamaged, 2) the rear spur gear internal spline teeth appeared to be present and undamaged, 3) front spur gear internal splines teeth appeared to be heavily damaged (**PHOTO 19**, top row), 4) the splined shouldered shaft rear external spline teeth that engage with the rear spur gear were in good condition and undamaged (**PHOTO 19**, bottom right), and 5) the splined shouldered shaft external forward spline teeth that engage with the front spur gear were heavily damaged.

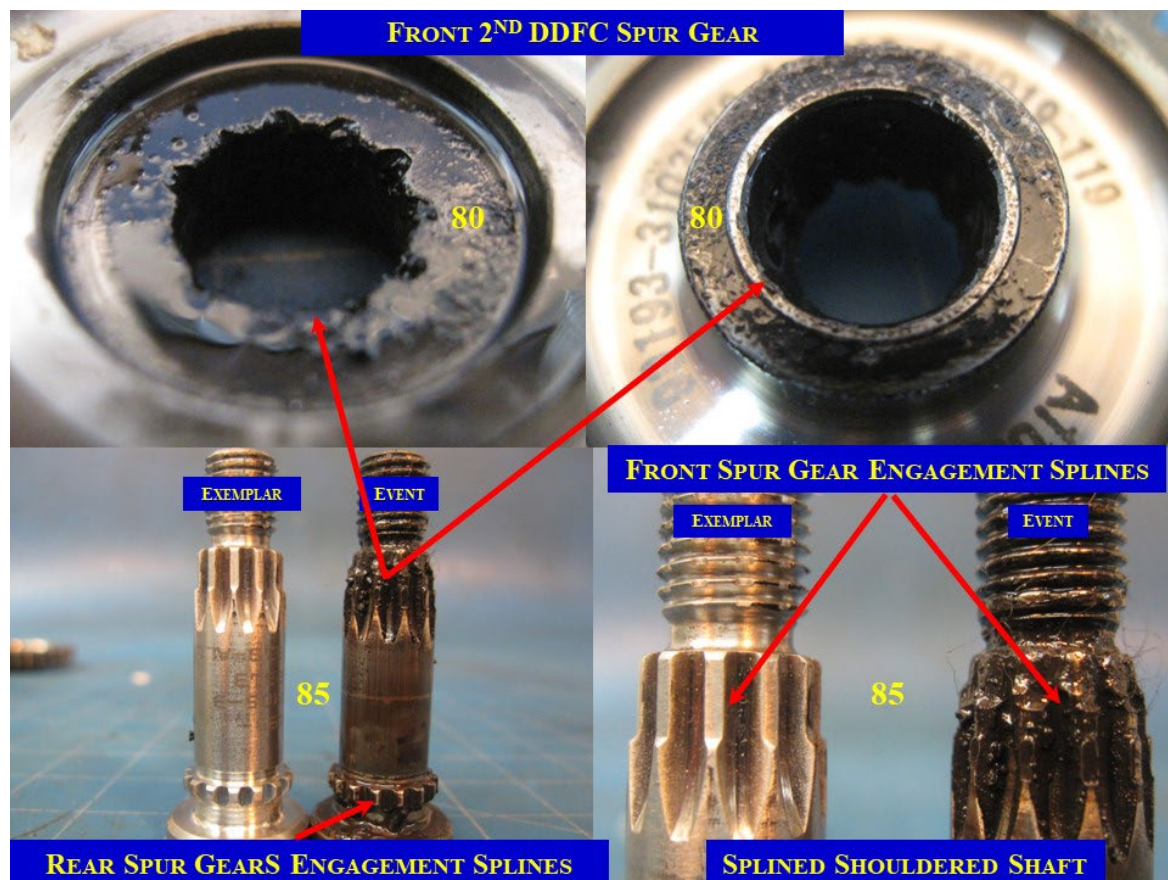


PHOTO 19: 2ND DDFC FRONT SPUR GEAR AND SPLINED SHOULDERED SHAFT DAMAGE

Comparing the invoice of the from National Flight Services Inc. for the accident torque sensor assembly, with the disassembled parts, the following parts were installed new at the last overhaul and repair (See **FIGURE 5** (numbers with asterisk were installed new at overhaul)).

- 1) front spur gear/2nd DDFC gear (PN 3103589-1) - item 80 in **PHOTOS 15-16** and **FIGURE 5**,
- 2) rear spur gear (PN 3103406-2) - item 90 in **PHOTO 16** and **FIGURE 5**,
- 3) 3rd DDFC gear (PN 3103590-2) - item 65 in **PHOTO 15** and **FIGURE 5**,
- 4) self-locking nut (PN MS21043-5) - item 70 in **PHOTOS 15-18** and **FIGURE 5**,
- 5) duplex bearing (PN 3103585-1) - item 110 (**FIGURE 5**)

The splined shouldered shaft (PN 3103405-3) - item 85 in **PHOTO 16** and **FIGURE 5** was not replaced and the torque sensor housing (PN 3103583-3) - item 115 (**PHOTO 18** and **FIGURE 5**) was provided in a serviceable condition.

The magnetic chip detector (MCD) was removed and fine hair-like ferrous material was noted on the tip (**PHOTO 20**).

The fuel pump, PN 89400-5, SN P-3352, was subjected to a run-on torque requirement as per the acceptance test procedure (ATP) step 3.12; the maximum permissible value is 18 inch-pounds (**PHOTOS 21** and **22**). The fuel pump was tested in the dry condition; the shaft was rotated in the clockwise direction facing the pad (**PHOTO 23**). The initial break away torque was around 30 inch-pounds; however, as rotation started the value settle between 15 and 20 inch-pounds. The fuel pump was partially disassembled. The low pressure circumferential boost pump rotated freely, and no debris was noted on in any of the exit ports. Both high pressure gears rotated freely in union.

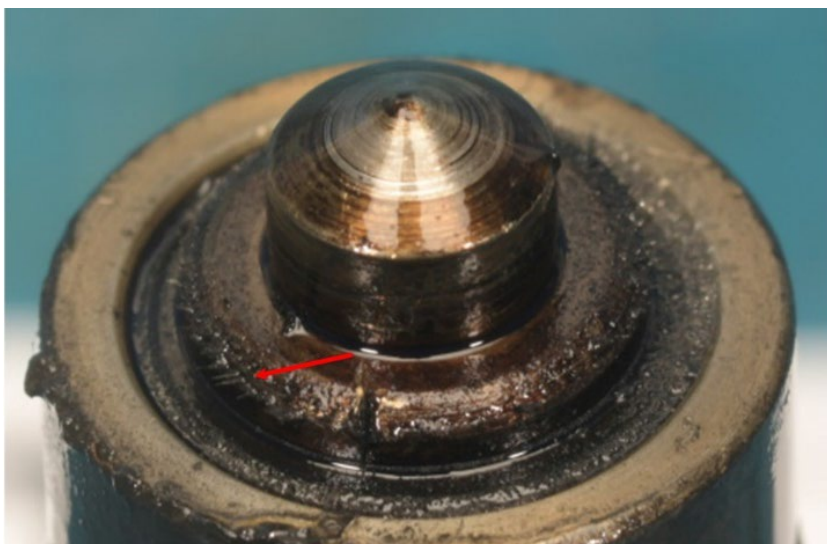


PHOTO 20: FUZZ ON THE MCD (red arrow)

PHOTO COURTESY OF HONEYWELL

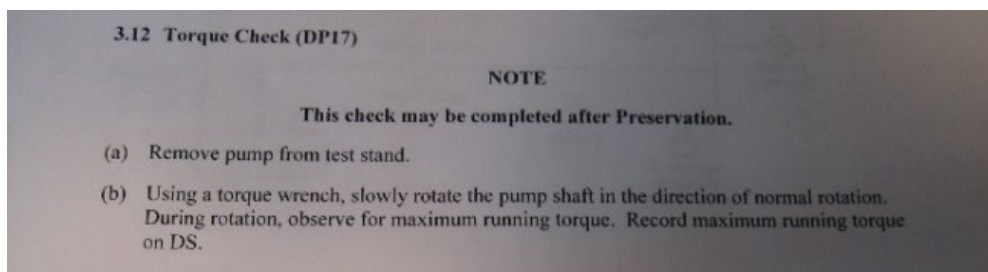


PHOTO 21: RUN-ON TORQUE PROCEDURE

PHOTO COURTESY OF HONEYWELL

Para	Points	(psig)	(psig)	(±10)	(psig)	(lb/hr)	(lb/hr)	(°F)	(°F)	(lb/hr)	(lb/hr)
3.4	1, 2, 3	Break-In	Record	Accept	Reject	(Circle One)					
3.5	4, 5	5		4536	1375 MAX			75			
3.6	6	5		4536	700		1400 MIN	75			
3.6	7	5		4536	140			75			
3.6	8	5		4000	700			75			
3.6	9	5		2500	700			75			
3.6	10	5		2500	140		120 MIN	75			
3.6	11	5		500	140			75			
3.9	12	5		4536	330			85*		15 MAX	
3.9	13	5		4536	330			49*		200 MAX	
3.9	14	5		4536	330			34*		170 MIN	
3.10	15	External Leak Record:				0 Drops Allowed					
		Shaft Leak Record:				1 Drop In 5 Minutes Allowed					
3.11	16	Filter Inspect Record:			Accept	Reject	Replace And Accept (Circle One)				
3.12	17	Run Torque Record:				18 In-Lb Max					
3.13	18	Preserve Record:			Complete	(Circle)					

PHOTO 22: RUN-ON TORQUE MAX VALUE

PHOTO COURTESY OF HONEYWELL

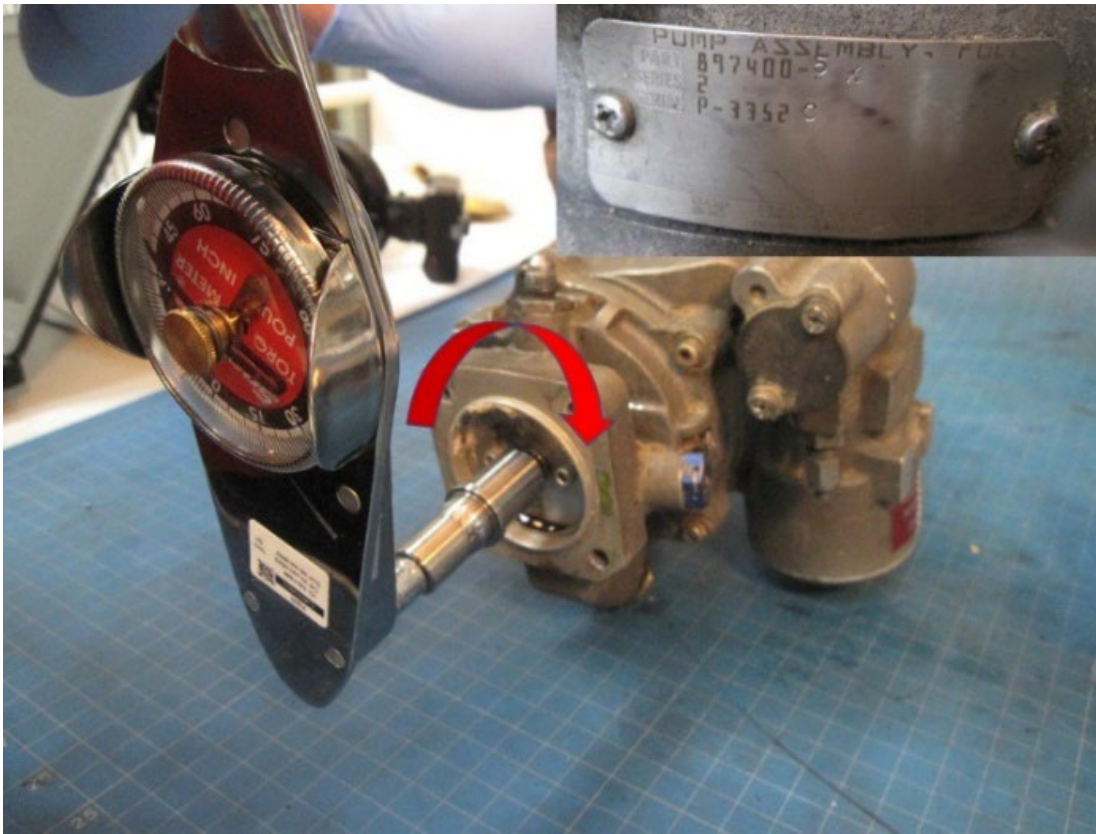


PHOTO 23: FUEL PUMP RUN-ON TEST SETUP

3.0 METALLURGICAL EVALUATION

The following parts were sent to the Honeywell Metallurgical laboratory in Phoenix, Arizona for evaluation (**Photo 24 and Figure 6**):

- 1) The 2nd DDFC spur gears (PN 3103589-1 and 3103406-2)
- 2) Splined shouldered shaft (PN 3103405-3,
- 3) Duplex bearing (PN 3103585-1)
- 4) The 3rd DDFC spur gear (PN 3103590-2)
- 5) Torque sensor housing (PN 3103583-3)
- 6) Self-locking nut (PN MS21043-5)
- 7) Swabs of the debris from the 2nd DDFC, the MCD, and the oil filter



PHOTO 24: PARTS SENT TO HONEYWELL METALLURGICAL LABORATORY FOR ADDITIONAL EVALUATION

For complete details, see Honeywell metallurgical report, ERS-ASYS-PENG-MA-0000865-B (**ATTACHMENT 1**).

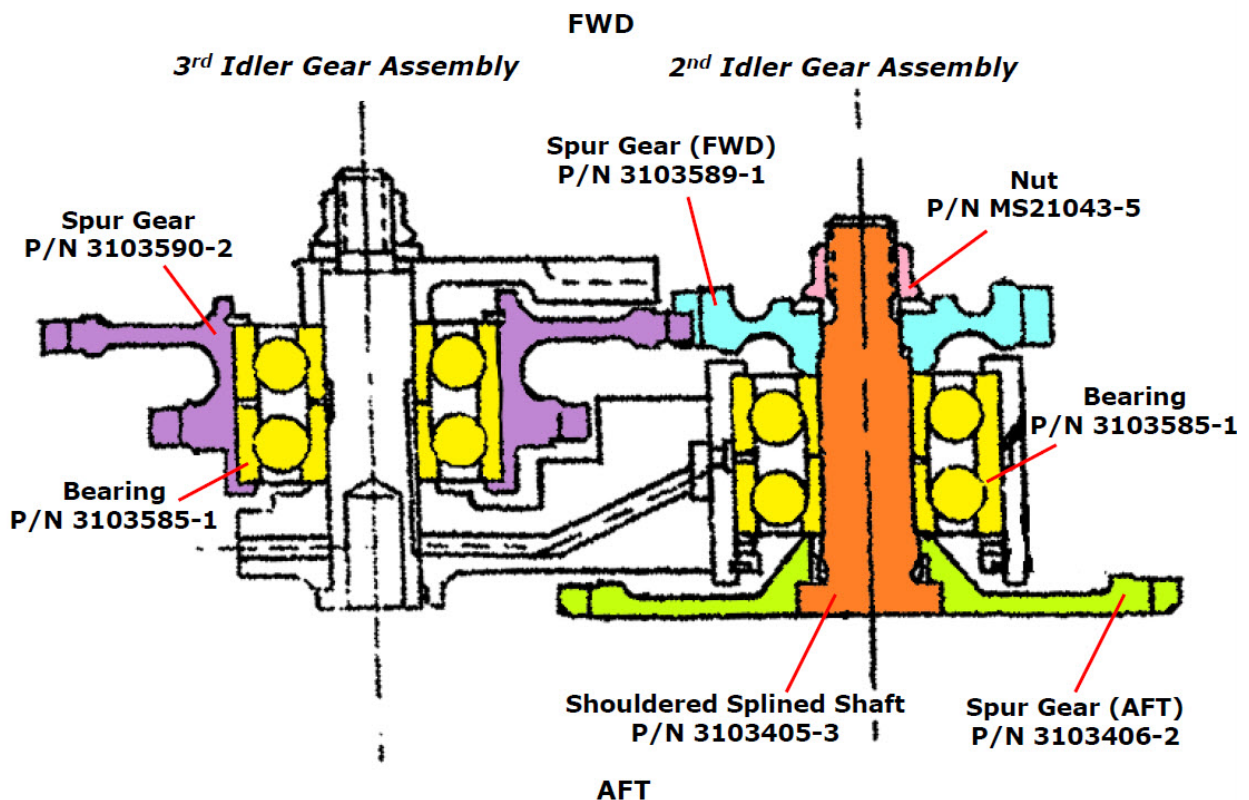
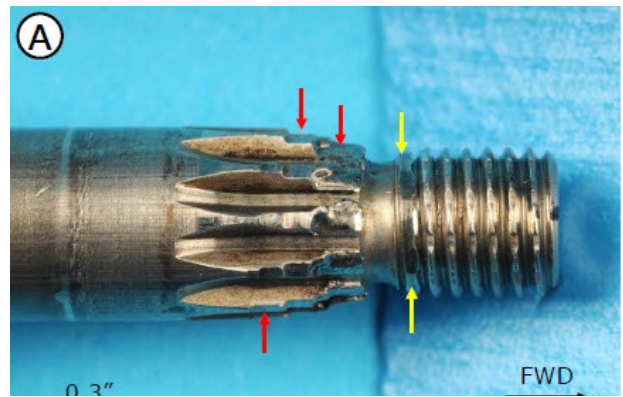


FIGURE 6: CROSS-SECTION OF TORQUE SENSOR HARDWARE SUBMITTED FOR LABORATORY ANALYSIS

Figure courtesy of Honeywell

3.1 SPLINED SHOULDERED SHAFT

The splined shouldered shaft was cleaned, and the external forward spline teeth exhibited stepped wear and deformation in the clockwise direction/loading direction (forward looking aft) about $\frac{2}{3}$ of the axial length near the front spline teeth consistent with meshing with the fretted internal spline teeth of the 2nd DDFC front spur gear (**PHOTO 25**, red arrows). Wear and deformation were also observed on the last (rearward) threads consistent with contact with the worn threads of the self-locking nut (**PHOTO 25**, yellow arrows). The external aft spline teeth were undamaged and exhibited normal meshing wear on the pressure face/loaded flank side of the spline's teeth consistent 2nd DDFC rear spur gear normal engagement. The aft face of the splined shouldered shaft face exhibited fretting consistent with contact of the rear aft face of the 2nd DDFC rear spur gear. Dimensional inspection of the splined shouldered shaft away from the damaged region showed it to be consistent within the manufacturing drawing; the average hardness was also with the specified drawing range. **PHOTO 26** shows a side-by-side comparison of an exemplar and event splined shouldered shafts highlighting the forward spline teeth. The drawing calls out a single step change in the forward splines (**PHOTO 26**, black arrows). The event splined shoulder shaft exhibited multiple step changes to various depths (**PHOTO 26**, red arrows) with the most forward part of the spline almost completely obliterated.



**PHOTO 25: SPINED SHOULDERED SHAFT
FRONT SPLINE AND THREAD DAMAGE**

Photo courtesy of Honeywell (modified by NTSB)

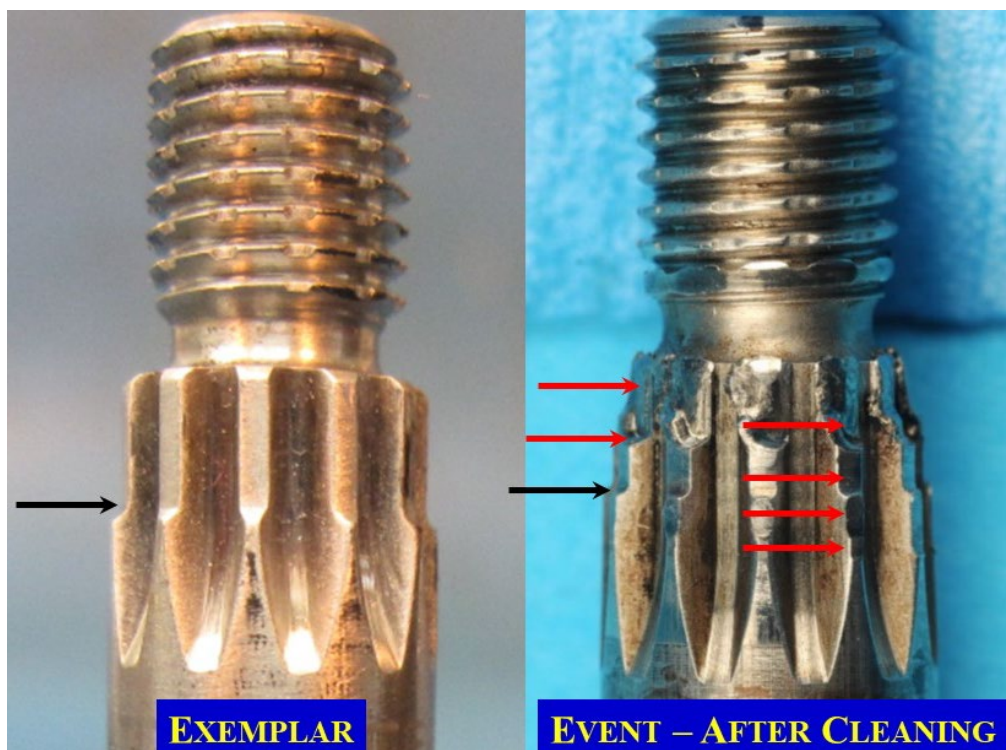


PHOTO 26: MULTIPLE STEP CHANGES IN THE EVENT FORWARD SPLINE TEETH

Right photo courtesy of Honeywell (modified by NTSB)

3.2 2ND DDFC SPUR GEARS

3.2.1 2nd DDFC Front Spur Gear

The aft side of the front spur gear exhibited fretting wear and part markings transfer consistent with contact with the duplex bearing. Wear and deformation of the external gear teeth were noted on the pressure face/loaded flank side while light contact marks were noted on the inactive/unloaded flank side; the contact marks were consistent with the gear teeth normal meshing with the 3rd DDFC spur gear teeth. The internal spline teeth exhibited wear and deformation in the counterclockwise direction/loading direction (forward looking aft) about $\frac{2}{3}$ of the axial length near the aft end consistent with meshing with the fretted external spline teeth of the splined shouldered shaft (**PHOTO 27** - red arrows). Contact marks on the inner diameter (ID) of the front spur gear were consistent with contact with the splined shouldered shaft (**PHOTO 27** - yellow arrows); the splined shouldered shaft exhibited similar marks. The forward side of the front spur gear exhibited fret wear consistent with contact from the self-locking nut washer. The average hardness of the front spur gear was within the specified drawing range.

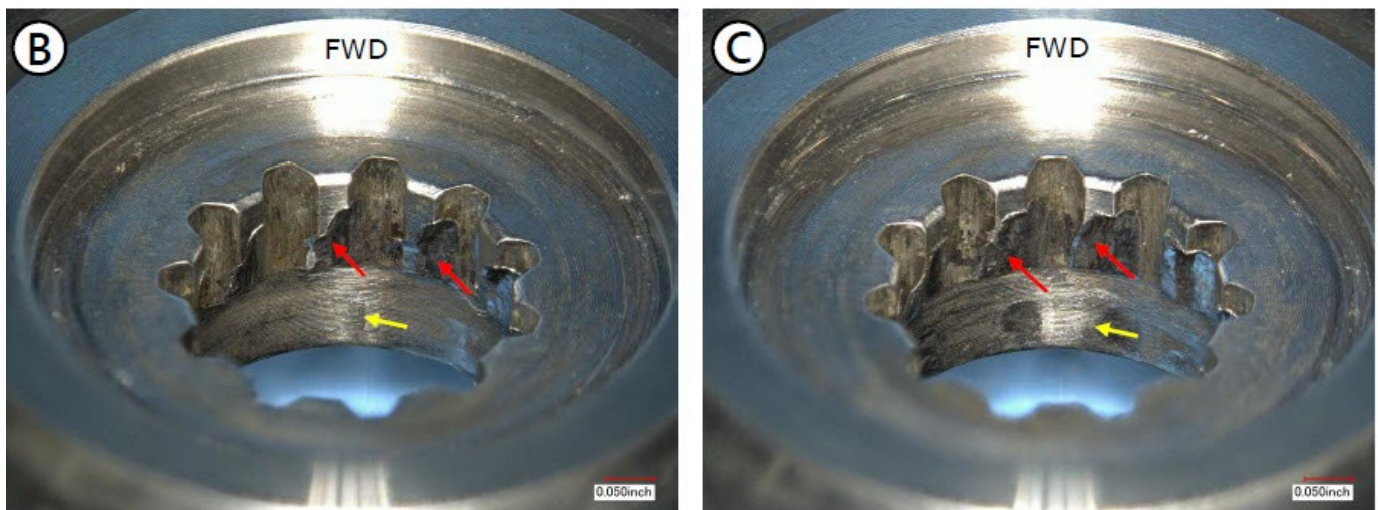


PHOTO 27: 2ND DDFC FRONT SPUR GEAR INTERNAL SPLINE TEETH DAMAGE

Photos courtesy of Honeywell

3.2.2 2nd DDFC Rear Spur Gear

The forward and aft sides of the rear spur gear exhibited fretting wear consistent with contact from the duplex bearing and the splined shouldered shaft. The internal spline teeth exhibited wear/contact marks on the pressure face/loaded flank sides of the teeth consistent with meshing with the splined shouldered shaft external spline teeth; the wear spanned about half the spline tooth length.

3.3 SELF-LOCKING NUT

The invoice (**PHOTO 5**) lists that self-locking nuts PNs MS21043-3, MS21043-4, and MS21043-5 were replaced during the repair; PN MS21043-5 is the self-locking nut specified to be installed on the splined shouldered shaft to retain the front spur gear. Self-locking nut, PN

MS21043-5, is a fine pitch corrosion resistant silver plated all metal nut that fits nominal thread size $\frac{5}{16}$ inch with 24 threads per inch. The nut threads are slightly ovalized so that the nut must elastically deformed to mate with the threads of the splined shouldered shaft causing increased surface friction that resists loosening when fully and properly torqued. PNs MS21043-5 and MS21043-6 both have 24 thread per inch pitch and differ in nominal thread size. PN MS21043-5 has a nominal thread size $\frac{5}{16}$ inch, while PN MS21043-6 nominal thread size $\frac{3}{8}$ inch. Honeywell was able to confirm that the event self-locking nut used to secure the front spur gear was in fact PN MS21043-5.

The self-locking nut exhibited distinctive marks on two of the wrenching flats consistent with tool locking imprint marks as specified. An exemplar new self-locking nut showed the same tool locking imprint marks (**PHOTO 28** - yellow arrows). Wear marks were observed on one side of each (**PHOTO 28** - top row red arrow) wrenching flat consistent with contact with installation/torque tool. Wear marks were observed on the aft face of the self-locking nut consistent with contact with the mating washer (**FIGURE 5**, item 75).

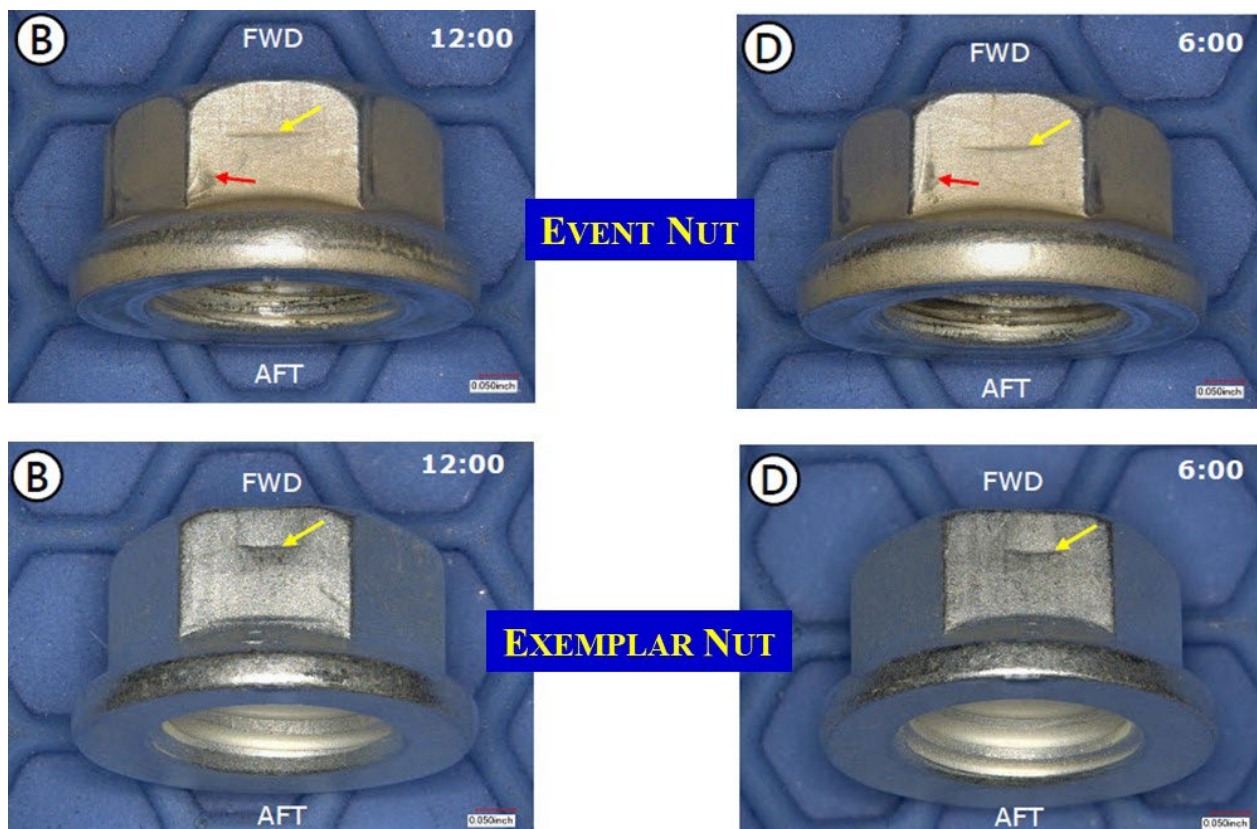


PHOTO 28: EVENT AND EXEMPLAR SELF-LOCKING NUTS WITH LOCKING TOOL MARKS

Photos Courtesy of Honeywell

The internal threads of the self-locking nut exhibited wear that penetrated through the silver plating predominately on the forward/pressure face/loaded flank side of the threads in the areas aligned with the locking tool mark. The aft/inactive/unloaded flank side of the threads exhibited non-uniform wear that had penetrated through the silver plating with some areas of little to no wear (nickel plating intact) observed at multiple locations. The

average hardness of the nut met the minimum hardness requirement; the silver plating was removed from the area where the hardness measurements were taken.

3.4 DUPLEX BEARINGS, 3RD DDFC SPUR GEAR, AND TORQUE SENSOR HOUSING ASSEMBLY

The duplex bearings were undamaged and rotated freely by hand; no other significant findings were noted. The teeth of the 3rd DDFC forward and aft spur gear exhibited wear consistent with contact from the 2nd DDFC and the 4th DDFC spur gears; no other significant findings were noted. No additional significant findings were noted on the fractured torque sensor housing assembly.

3.5 DEBRIS ANALYSIS

A Scanning Electron Microscope (SEM) equipped with an energy dispersive spectroscopy (EDS) system was used to analysis the debris found the on the splined shouldered shaft, the MCD, and the oil filter. The debris from the splined shouldered shaft was identified predominantly to be stainless steel similar to A286, a wrought heat resistant precipitation hardened iron base alloy that is the specified material for the splined shouldered shaft and self-locking nut, and a low alloy steel similar to 9310, a carburized steel that is the specified material for the spur gears. From the MCD, stainless steel, copper, silver, and M50 material were identified; M50 is a high speed wrought alloy tool steel with elevated levels of molybdenum typically used in bearing material and copper is type of bearing cage material. The oil filter had much of the same material that was found on the MDC. Most of the debris was consistent with material from the splined shouldered shaft, spurs gears, and bearing material.

4.0 SELF-LOCK NUT TORQUE AND DIMENSIONAL TEST RESULTS

4.1 BACKGROUND INFORMATION

Section 1.4 discussed that an AD was issued to stop using Honeywell torque sensor gear assembly overhaul manual with illustrated parts list, 72-00-17, Revision No. 9, dated, July 20, 1992, or earlier versions, to overhaul TPE331 or TSE331 hydraulic torque sensor gear assemblies. The current torque sensor gear assembly overhaul manual with illustrated parts list is Revision No. 10, dated, October 31, 2013. A comparison of the parts list and assembly procedures from Revisions 9 and 10 for the parts that make up the stack-up for the front spur gear (2nd DDFC Gear) to the splined shouldered shaft (**FIGURE 5**, items 70, 75,80, 85, 90, 95,100, 105, and 110) revealed that all the parts numbers were identical as well as the installation torque for the self-locking nut (item 70) of 200 inch-pounds.

4.2 TORQUE ASSEMBLY WEAR AND DEFORMATION RESULTS

Five new self-locking nuts, PN MS21043-5 nuts, were used by the Honeywell laboratory to test different assembly scenarios; each new nut had the locking tool mark on two of the nut faces and the threads were plated and undamaged (See **ATTACHMENT 1** for details). **TABLE 1** provides the various assembly conditions.

TABLE 1: NEW NUT ASSEMBLY/DISASSEMBLY CONDITIONS

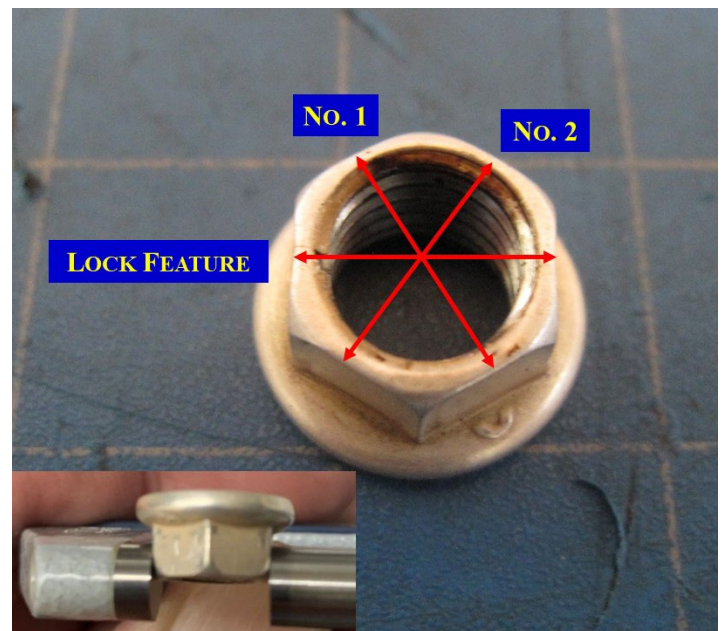
Nut Number	Torque (Y/N)	Lubricant Used (Y/N) Molybdenum Disulfide (MoS ₂) ⁷	Times Assembly/Disassembly Point Socket Used
1 (MA)	Yes	No	6 assembled/12 disassembled
2 (MA)	No	Yes	12
3 (MA)	Yes	No	12
4 (MA)	Yes	Yes	12
5 (MA)	No	No	6

A comparison of the new self-locking nut condition after the multiple assembly and disassembly procedures with the event self-locking number from ESN P92122C revealed the following: 1) wear was predominately observed on the forward/pressure face/loaded flank side of the threads for the new self-locking nuts 1, 3, and 4 (all torqued) and the event self-locking nut, 2) wear was non-form on the aft/inactive/unloaded flank side of the threads of the new self-locking nuts 1, 3, and 4 (all torqued) and the event nut, 3) all the self-locking nuts exhibited some amount of wear on the wrenching flats, and 4) none of the new self-locking nuts exhibited any notable wear on the aft side of the end where it contacts the washer; whereas the event nut exhibited distinctive wears marks on the aft face of the nut.

The average hardness of the nut met the minimum hardness requirement; the silver plating was removed from the area where the hardness measurements were taken.

4.3 TORQUE ASSEMBLY TORQUE RETENTION AND DIMENSIONAL RESULTS

The five torque nuts used for the torque assembly wear and deformation assessment (Section 4.2, **TABLE 1**) were the same as for this test; also included were the event and two new self-locking nuts that were sourced from the Honeywell repair and overhaul (R&O) shop. A micrometer gage was used to measure across the distance across the wrenching nut flats (**PHOTO 29**) and calibrated torque wrench was used for the run-on (installation) torque. For the run-on torque, the nut was installed with a least 1 thread visible protruding through the so that the torque measurement would only be that of the self-locking nut and threads and not any additional torque build-up to overcome frictional forces between the self-locking

**PHOTO 29: NUT DIMENSIONAL LOCATIONS**

Inset photo courtesy of Honeywell

⁷ No notable difference was observed between the nuts torques with MoS₂ lubricant and those without.

nut and gear. Due to variability in the measured distance between the flats, the data was evaluated for trends and not absolute values. **TABLE 2** provides the results of the measurements.

TABLE 2: NUT DIMENSIONAL CHANGE DUE TO TORQUE				
Nut	Run-On (Installation) Torque (inch-pounds)	Measure at lock feature (inch)	No lock feature No. 1 (inch)	No lock feature No. 2 (inch)
Event	9	0.3683	0.3727	0.3732
1 (MA)	22	0.3764	0.3795	0.3804
2 (MA)	15	0.3695	0.3742	0.3744
3 (MA)	14	0.3706	0.3762	0.3757
4 (MA)	13	0.3703	0.3759	0.3754
5 (MA)	19	0.3692	0.3759	0.3760
6 (R&O)	22	0.3661	0.3767	0.3755
7 (R&O)	24	0.3688	0.3760	0.3766

Based on the data, several general observations were noted:

- 1) The MA self-locking nuts were installed and uninstalled several times during the course of the wear and deformation study conducted by Honeywell (See Section 4.2). The run-on (installation) torque values for the MA self-locking nuts from **TABLE 2** seems to show that the repetitive torquing/untorquing operation generally lowers the self-locking nut's retaining feature when compared to new (R&O) self-locking nuts.
- 2) The run-on (installation) torque values for the new R&O self-locking nuts were generally the best and most consistent. According to the invoice, a new self-locking nut was purchased for the event torque sensor at the overhaul.
- 3) The data indicates that the repetitive torquing and untorquing of the self-locking nut can lead to some loss of the nut's retaining feature. Statically, the data also showed that there is not a disenable difference in the self-locking nut outer flat dimension between the event, the MA, and the new R&O self-locking nut. Thus, the loss of the self-locking nut's retaining feature due to repetitive torquing and untorquing did not correlate with/to a noticeable change in outer dimension of the nut flats.

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Powerplant Lead