

BACKGROUND

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.

Upon disassembly of the engine, the torque sensor nut was found to be loose on the shouldered splined shaft.

PROBLEM STATEMENT

Review and document all components of the torque sensor assembly. Analyze the debris of the submitted samples, oil filter, and magnetic chip detector.

SUMMARY/CONCLUSIONS

- Wear was observed on the splines and threads of the shouldered splined shaft from contact with the mating components.
- The 2nd idler gear assembly nut exhibited wear on one side of each of the nut faces. Wear was observed on the threads of the nut.
- The two 2nd idler spur gears exhibited wear on the internal splines and gear teeth.
- The 3rd idler spur gear exhibited wear on the loaded sides of the gear teeth.
- The 2nd idler duplex ball bearing exhibited wear on the forward and aft faces of the inner rings. No notable damage was observed on the cage and the bearing was free to rotate.
- The self-locking nut exhibited wear on one side of each of the nut faces and internal threads.

PART NAME:	Torque Sensor Assembly
PART NUMBER:	3101726-3
PART S/N:	P-4184C
OPERATING TIME:	2,559 Hours (TSO)
MODEL/PROGRAM:	TPE331
MODEL/PROGRAM S/N:	P92122C
OPERATING TIME:	20,523 Hours (Total Time)
OPERATING CYCLES:	Not Reported
MATERIAL:	See Table 1
MATERIAL SPEC:	See Table 1

- Scanning electron microscope (SEM)/energy dispersive X-ray (EDX) analysis of the debris samples revealed that most of the particles were indicative of A286 (specified shouldered splined shaft material) and 9310 (specified spur gear materials).
- See Findings.

Findings

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 lbs. 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 had 20,523 hours (total time) and 1,598 hours (time since hot section inspection (HSI)). The torque sensor had 2,559 hours since it was overhauled (TSO).

Upon disassembly of the engine, the nut was found to be loose on the shouldered splined shaft.

A schematic showing the submitted components in the 2nd and 3rd idler gear assemblies from a TPE331 engine is shown in Diagram 1. The corresponding part

information of the submitted components is shown in Table 1.

Shouldered Splined Shaft (P/N 3103405-3)

The shouldered splined shaft from TPE331 engine S/N P92122C exhibited damage predominantly on the forward side of the shaft (Figures 1-2). The forward splines were worn and deformed approximately 2/3 of the axial length from contact with the mating 2nd idler forward spur gear. Damage was observed on the aft side of the shaft threads from contact with the nut.

Wear was observed on the loaded side of the aft splines of the shaft (Figure 3). The wear step on the aft splines ranged from ~0.007"-0.011" in depth. The forward side of the shaft head exhibited fret wear from contact with the mating 2nd idler aft spur gear (Figure 4C).

Dimensional analysis was performed on the shouldered splined shaft and the results are shown in Appendix A. The dimensions measured away from the damaged regions of the splines and threads were within the specified ranges.

Hardness measurements were performed on the splined shouldered shaft OD surface. The average hardness value measured was 301 HB (converted from HR15N), which was within the specified range of 277-363 HB.

2nd Idler Forward Spur Gear (P/N 3103589-1)

The as-received condition of the 2nd idler forward spur gear from TPE331 engine S/N P92122C is shown in Figure 5. Fret wear was observed on the aft face of the spur gear from contact with the mating duplex ball bearing (Figure 5E). Note that some of the

bearing markings were transposed to the spur gear surface. The internal splines of the spur gear exhibited wear and deformation spanning approximately 2/3 of the spline length near the aft end (Figure 6).

The forward spur gear exhibited wear and deformation on the loaded side of the gear teeth (Figure 7). Witness marks were observed on the unloaded side of the gear teeth.

Hardness measurements were performed on the forward face near the internal splines of the 2nd idler forward spur gear. The average core hardness measured was 36 HRC (converted from HR15N), which was within the specified range of 33-43 HRC.

2nd Idler Aft Spur Gear (P/N 3103406-2)

The as-received condition of the 2nd idler aft spur gear from TPE331 engine S/N P92122C is shown in Figure 8. Fret wear was observed on the forward and aft sides of the spur gear from contact with the duplex ball bearing and the shouldered splined shaft head, respectively.

Wear was observed on the loaded side of the internal splines from contact with the mating splines from the shouldered splined shaft (Figure 9). The wear markings spanned approximately half of the spline length near the forward end.

Contact marks were observed on the loaded side of the spur gear; however, no notable wear depth was observed (Figure 10).

Duplex Ball Bearing (P/N 3103585-1)

The as-received condition of the 2nd idler duplex ball bearing from TPE331 engine S/N P92122C is shown in Figures 11-12. Wear was observed on the inner ring faces from contact with the mating spur gears. No notable damage was observed on the cages in the assembled state. It was noted that the bearing components were free to rotate.

3rd Idler Spur Gear (P/N 3103590-2)

The as-received condition of the 3rd idler spur gear from TPE331 engine S/N P92122C is shown in Figure 13-14. Wear was observed on the forward and aft gear teeth from contact with the mating components. The wear depths on the forward and aft gear teeth were measured to be approximately 0.003" and 0.004", respectively (Figure 15).

The duplex ball bearing from the 3rd idler gear assembly was free to rotate and no notable damage was observed in the assembled state.

Torque Sensor Housing Assembly (P/N 3103583-3)

The as-received condition of the torque sensor housing from TPE331 engine S/N P92122C is shown in Figure 16. The housing had separated into two pieces. Some of the markings observed on the housing were "P/N 3101726-3 Series 2 S/N P-4184C" and "9AA11-3103583-3."

Self-Locking Nut (P/N MS21043-5)

The as-received condition of the 2nd idler gear assembly nut from TPE331 engine S/N P92122C is shown in Figure 17. Wear marks were observed on one side of each of the nut faces. Evidence of the locking tool marks were observed on two of the nut faces, as specified. Wear marks were observed on

the aft face of the nut from contact with the mating washer.

Wear was observed on the threads of the nut (Figures 18-19). The wear marks were more predominant on the forward side of the threads and in areas aligned with locking tool marks. On the forward side of the threads, wear marks were observed throughout most of the thread circumference. On the aft side of the threads, non-uniform wear marks were observed on the thread surfaces. Areas exhibiting little to no wear on the aft side of the threads were observed in multiple locations (Figure 19).

New Nuts

Images showing the condition of a new P/N MS21043-5 nut are shown in Figures 20-21.

Evidence of the locking tool marks were observed on two of the nut faces. The thread surfaces were plated, and no damage was observed.

Five new nuts were used to test and document different assembly scenarios as shown in Table 2. The nuts were labeled 1-5. Each nut exhibited two locking tool marks, which were clocked at the 12:00 and 6:00 positions for the purposes of this report. The nuts were assembled on a scrap 2nd idler gear assembly with or without torque and removed for documentation.

Nut 1 was torqued to 200 lb/in using a torque wrench and exhibited wear marks on one side of each of the nut faces in the assembled state (Figure 22). After disassembly, wear marks were observed on both sides of each nut face (Figure 23). Wear was observed predominantly on the forward side of the threads. On the aft side of the threads, non-uniform wear

marks were observed around the circumference (Figure 24).

Nut 2 was screwed into the assembly, but not torqued, and then disassembled using a torque wrench. After disassembly, wear marks were observed on both sides of each nut face (Figure 25). It was noted that the wear marks were smaller to those marks observed on Nut 1. Wear was observed predominantly on the forward side of the threads. On the aft side of the threads, wear marks were observed on three threads that aligned with the locking tool marks at the 12:00 and 6:00 positions near the forward end of the nut (Figure 26). The remaining aft side of the threads exhibited little to no wear marks.

Nuts 3 and 4 were torqued to 200 lb/in and then disassembled using a torque wrench. After disassembly, wear marks were observed on both sides of each nut face (Figures 27 and 29). Wear was observed predominantly on the forward side of the threads. On the aft side of the threads, non-uniform wear marks were observed around the circumference (Figures 28 and 30).

Nut 5 was screwed into the assembly, but not torqued and then disassembled using a torque wrench. After disassembly, wear marks were observed on both sides of each nut face (Figure 31). It was noted that the wear marks were smaller to those marks observed on Nuts 1, 3, and 4. Wear was observed predominantly on the forward side of the threads. On the aft side of the threads, wear marks were observed on three threads that aligned with the locking tool marks at the 12:00 and 6:00 positions near the forward end of the

nut (Figure 32). The remaining aft side of the threads exhibited little to no wear marks.

No notable differences were observed between the nuts torqued with molybdenum disulfide (MoS₂) lubricant and without it.

Comparison of Nut Condition

The condition of the threads of the nut from TPE331 engine S/N P92122C appeared to be similar to Nuts 1, 3, and 4, which were torqued nuts.

No notable wear was observed on the aft side of Nuts 1-5 compared to the nut from TPE331 engine S/N P92122C (Figure 33). Elemental dot maps produced from analysis of the aft sides of the submitted nuts revealed that the silver plating on Nuts 1-5 was present throughout the surface (Figure 34). For the nut from TPE331 engine S/N P92122C, the element dot map revealed regions where the silver plating had worn away (Figure 34A). Scanning electron microscope (SEM) examination of the worn regions of the nut revealed a matted appearance with no clear wear directionality (Figure 35).

Hardness measurements were performed on the aft surfaces of the nut from TPE331 engine S/N P92122C and a new nut. Note that the silver plating was removed/ground from the aft surface before conducting hardness testing. The average hardness measured on the nut from TPE331 S/N P92122C was 42 HRC (converted from HR15N), which met the minimum requirement of 32 HRC specified under AMS5853. The average hardness measured on the new nut was 33 HRC (converted from HR15N), which met the specified hardness ranges under AMS5731, AMS5732, and AMS5737. Note that the nut drawing

(P/N NASM21043-5) identifies five different AMS specifications for material properties, any of which are considered acceptable (AMS5525, AMS5731, AMS5732, AMS5737, or AMS5853).

Debris Analysis

Images of the submitted debris collected from the splined shaft tip and the 2nd idler forward gear splines are shown in Figures 36A-B, respectively. The as-received condition of the magnetic chip detector and the oil filter from TPE331 engine S/N P92122C are shown in Figures 36C-D, respectively. Representative debris particles were removed from each sample/component for SEM and energy dispersive X-ray (EDX) analysis.

The following materials were observed from the debris collected from the splined shaft tip and the 2nd idler forward gear spline (Figures 37-38):

- stainless steel similar to A286 (the specified material for the shouldered splined shaft and nut),
- a low alloy steel (LAS) similar to 9310 (the specified material for the spur gears),
- and an oxidized stainless steel or low alloy steel.

The following materials were observed from the debris collected from the submitted magnetic chip detector (Figures 39-40):

- stainless steel with aluminum oxide,
- debris suggestive of dirt,
- copper (possible bearing cage material),
- silver (typical plating material),
- and M50 (typical bearing material).

The oil filter was backflushed, and debris was captured on filter paper. The weight of the debris

was measured to be 36 mg. The following materials were observed from the debris collected from the oil filter (Figure 41):

- oxidized stainless or low alloy steel,
- a low alloy steel (LAS) similar to 9310 (the specified material for the spur gears),
- copper (possible bearing cage material),
- silver (typical plating material),
- and M50 (typical bearing material).

Most of the debris particles observed consisted of A286 and 9310 materials, which were consistent with the worn shaft and spur gear components.

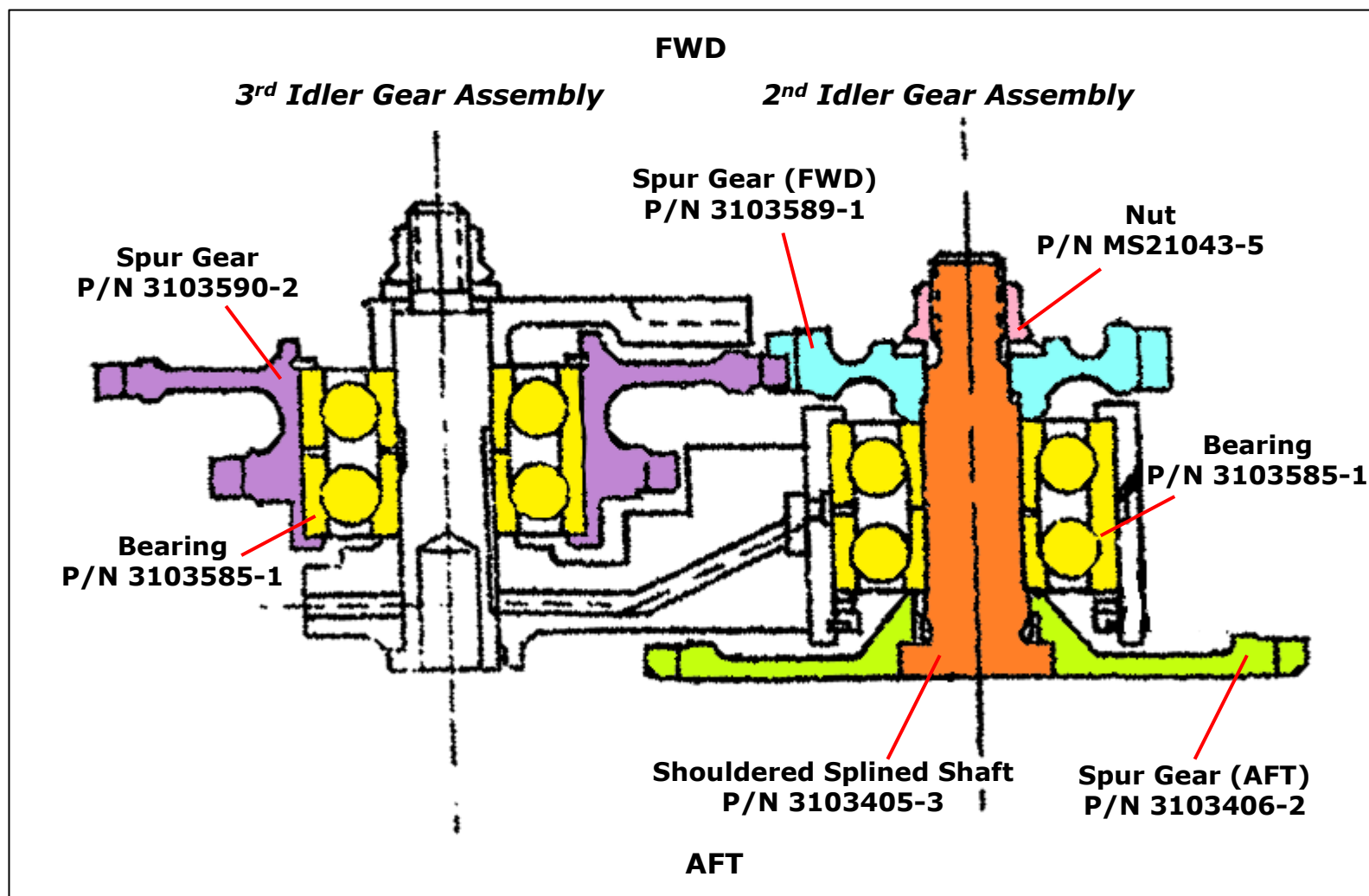


Diagram 1.

Cross sectional diagram showing the submitted components in the 2nd and 3rd idler gear assemblies from a TPE331 engine.

Table 1. Hardware Submitted

Part Name	Part Number	Serial Number	Material	Material Spec
Shaft, Shouldered, Splined	3103405-3	N/A	A286	AMS5737
Gear, Spur	3103406-2	N/A	9310	EMS56280
Gear, Spur	3103589-1	N/A	9310	EMS56280
Bearing, Ball, Duplex	3103585-1	13-151725-04670	M50/Bronze	AMS6491/AMS4616
Gear, Spur	3103590-2	13P56392	9310	EMS56280
Nut, Self-locking	MS21043-5	N/A	A286	Various
Housing Assembly, Torque Sensor	3103583-3	N/A	A356-T6	EMS54028
Torque Sensor Gear Assembly	3101726-3	P-4184C	Various	Various

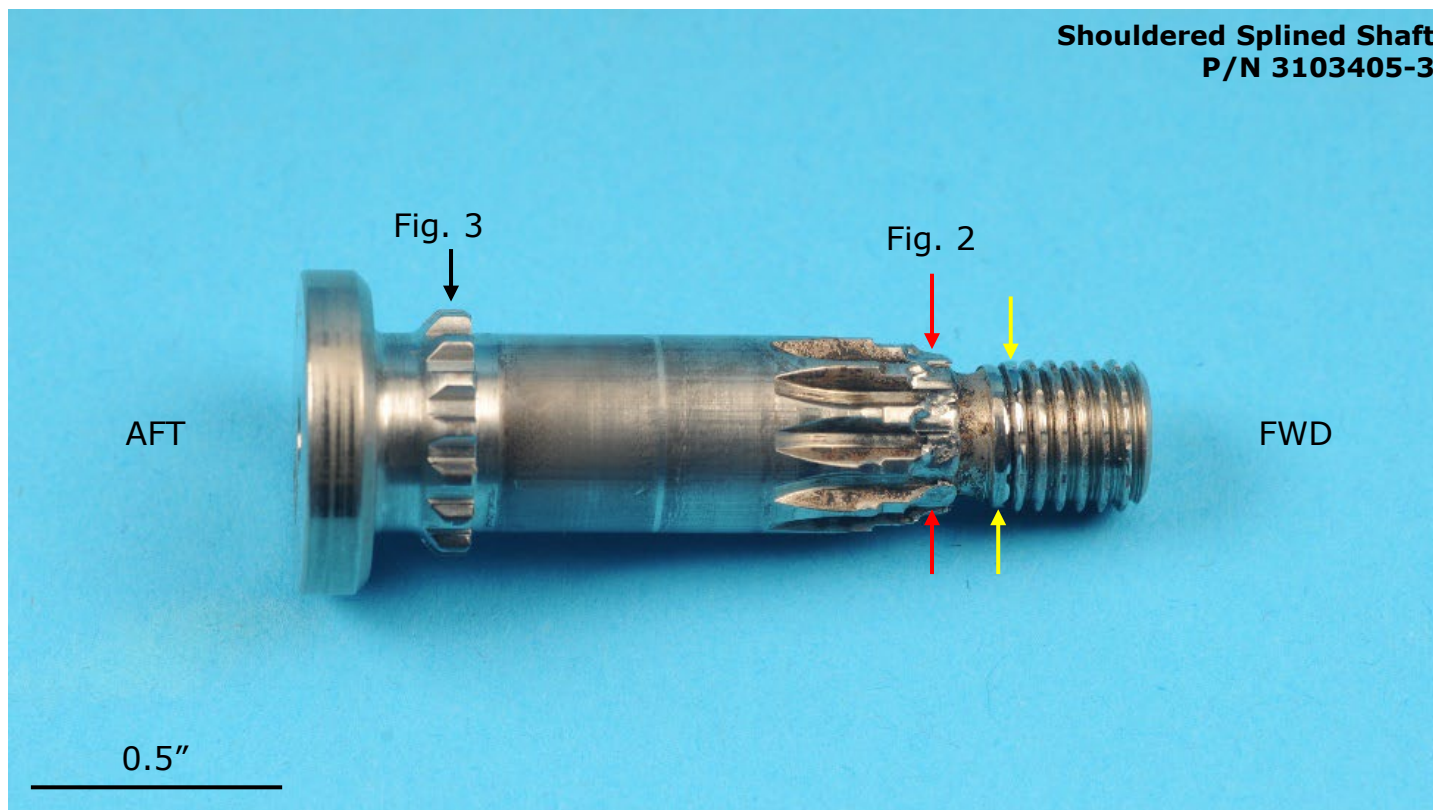


Figure 1.

Image showing the shouldered splined shaft (P/N 3103405-3) from TPE331 engine S/N P92122C after cleaning with acetone. Damage was observed on the forward splines (red arrows) and threads (yellow arrows). Close-up images of the areas identified are shown in Figures 2-3.

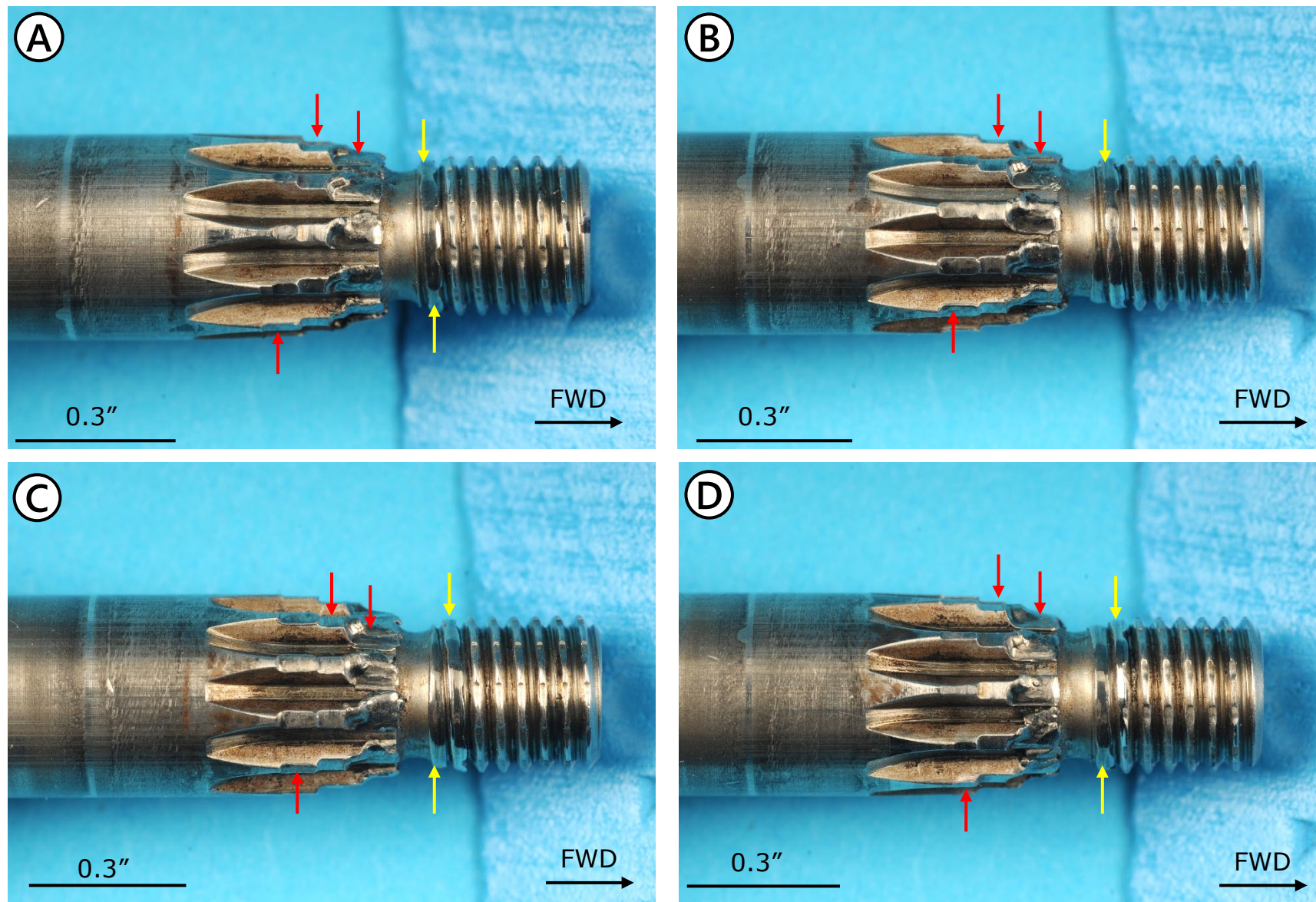


Figure 2.

(A-D) Digital microscope images showing the condition of the forward end of the shouldered spline shaft at 90° intervals. Wear and deformation were observed on the threads (yellow arrows) and splines (red arrows).

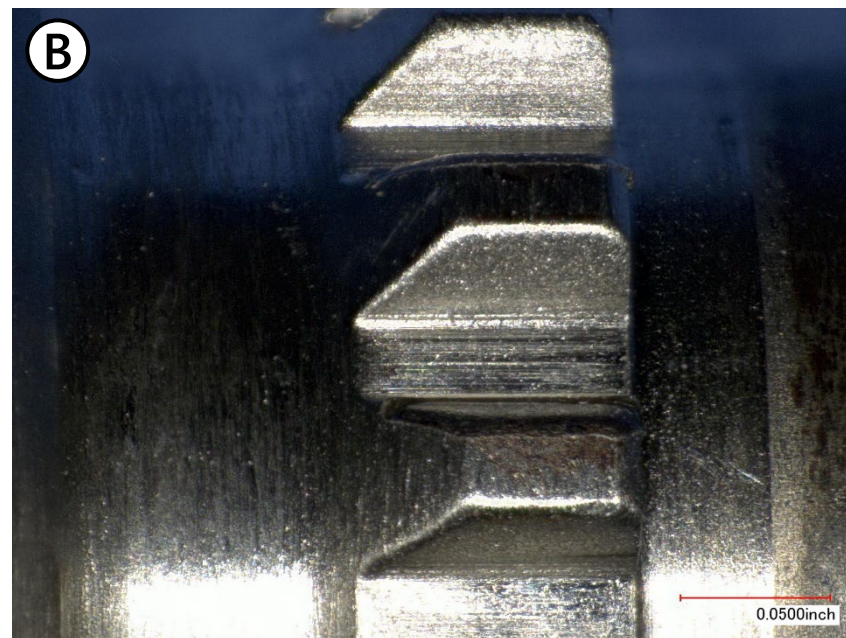
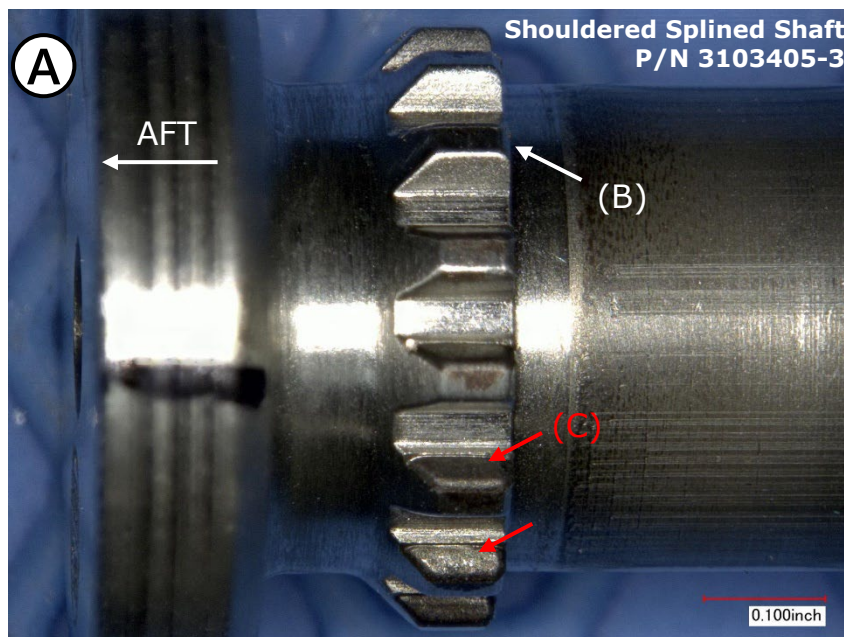
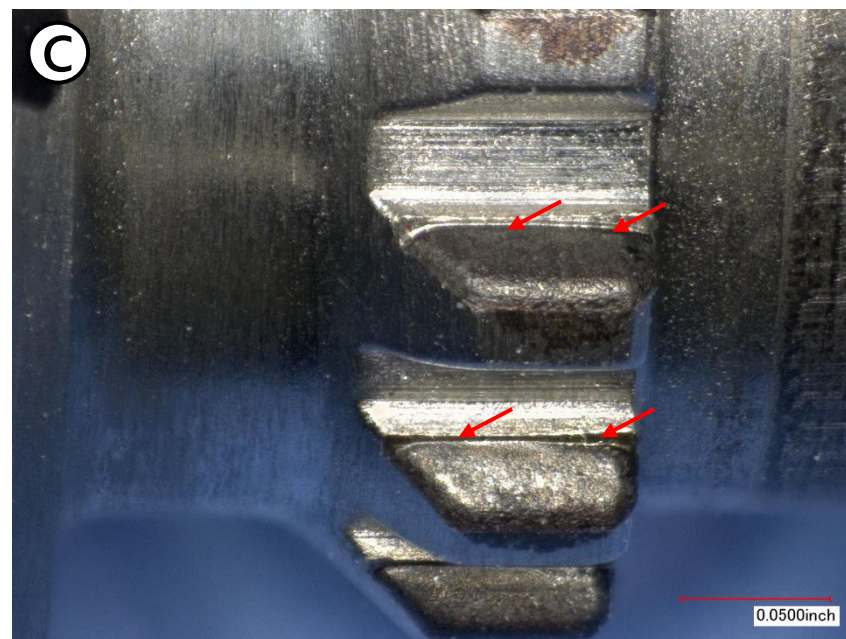


Figure 3.
(A-C) Digital microscope images showing the condition of the aft spline of the shouldered splined shaft (reference Figure 1). Wear was observed predominantly on the loaded side of the spline teeth (red arrows in (A) and (C)).



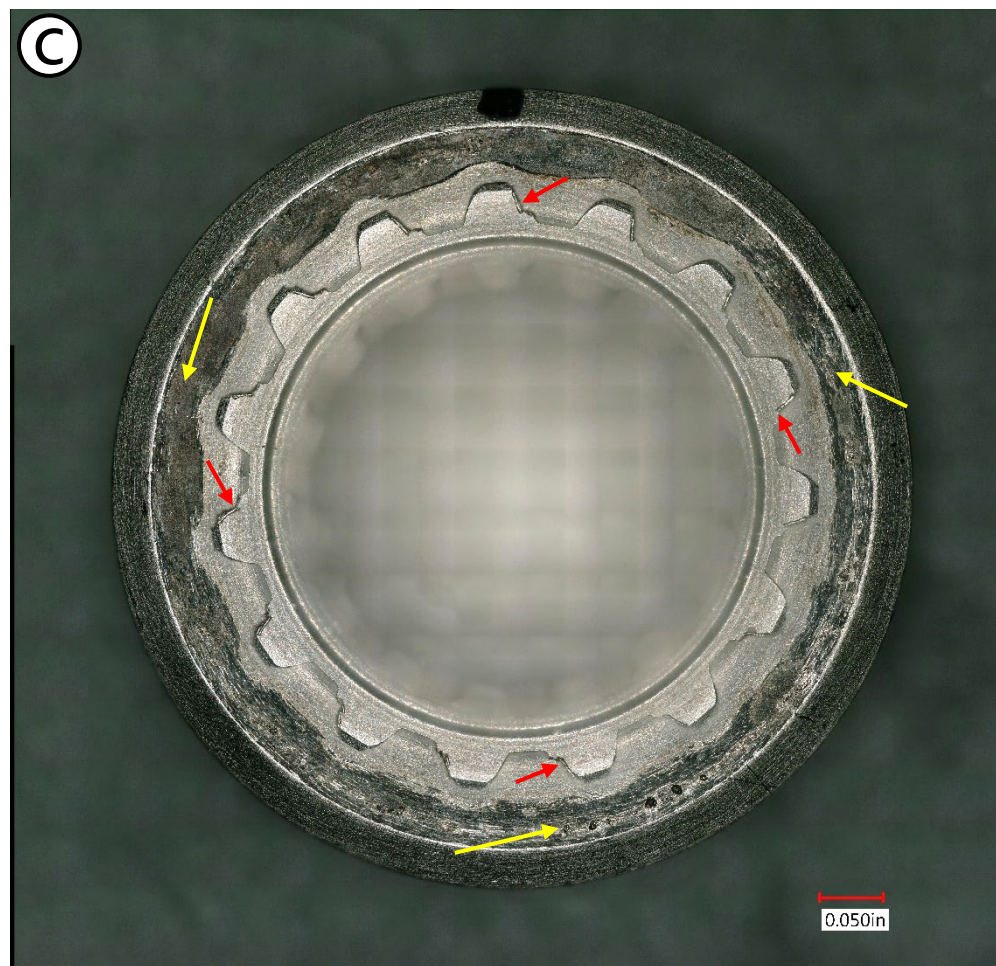
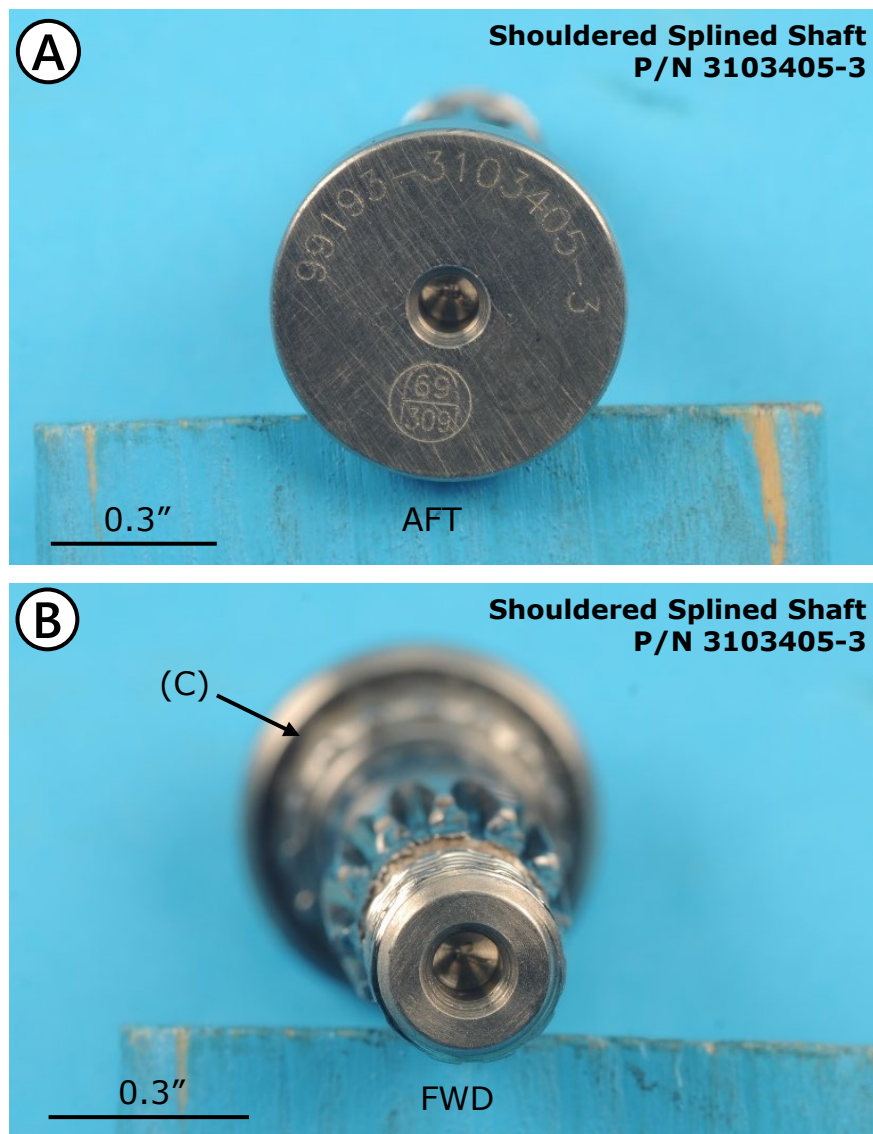


Figure 4.

(A-B) Close-up images showing the aft and forward ends, respectively, of the splined shaft. (C) Digital microscope image showing fret wear on the shaft head (yellow arrows) and on the aft splines (red arrows) from contact with the mating 2nd idler aft spur gear (P/N 3103406-2). The wear step on the aft splines ranged from ~0.007"-0.011" in depth.

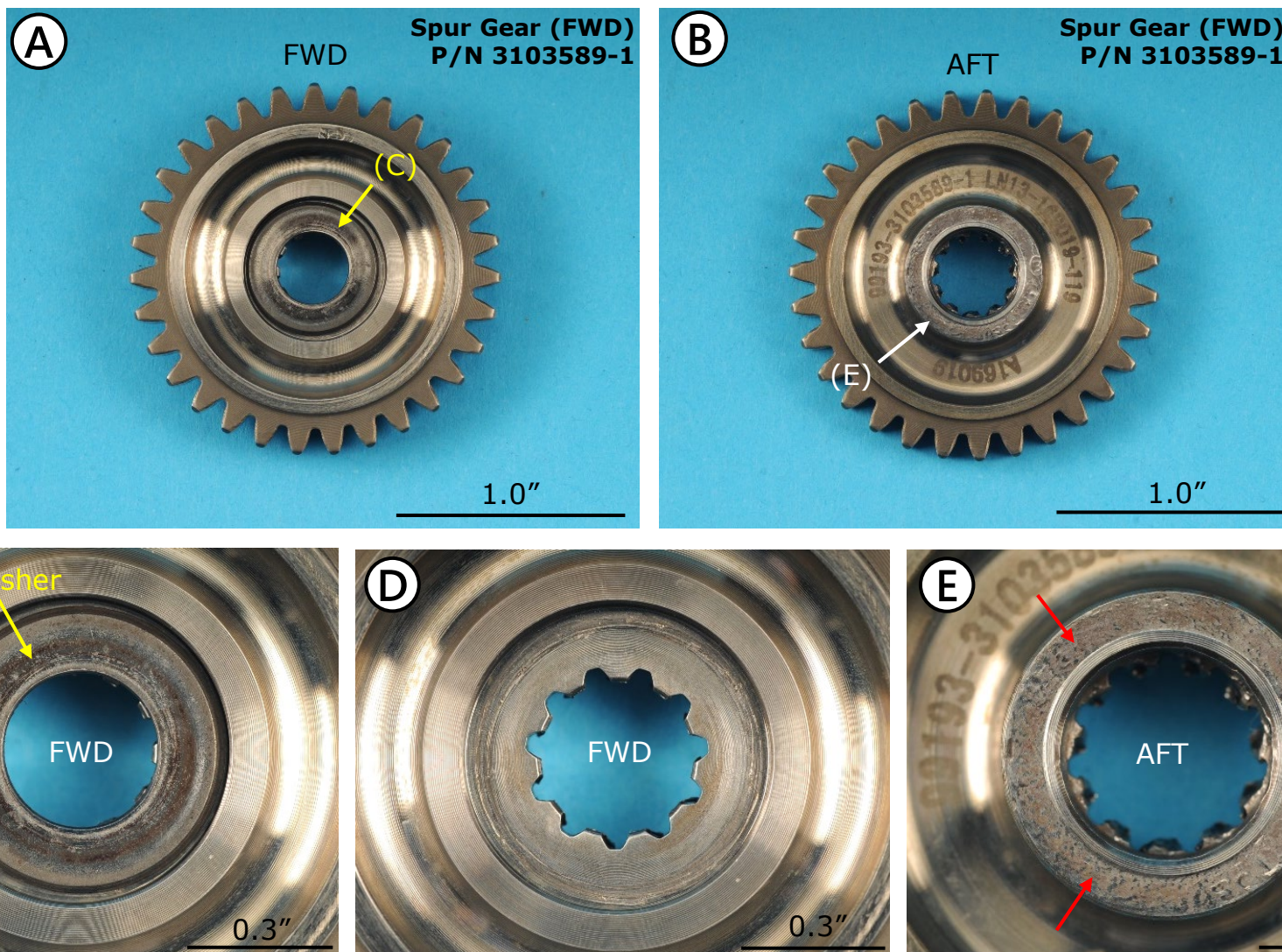
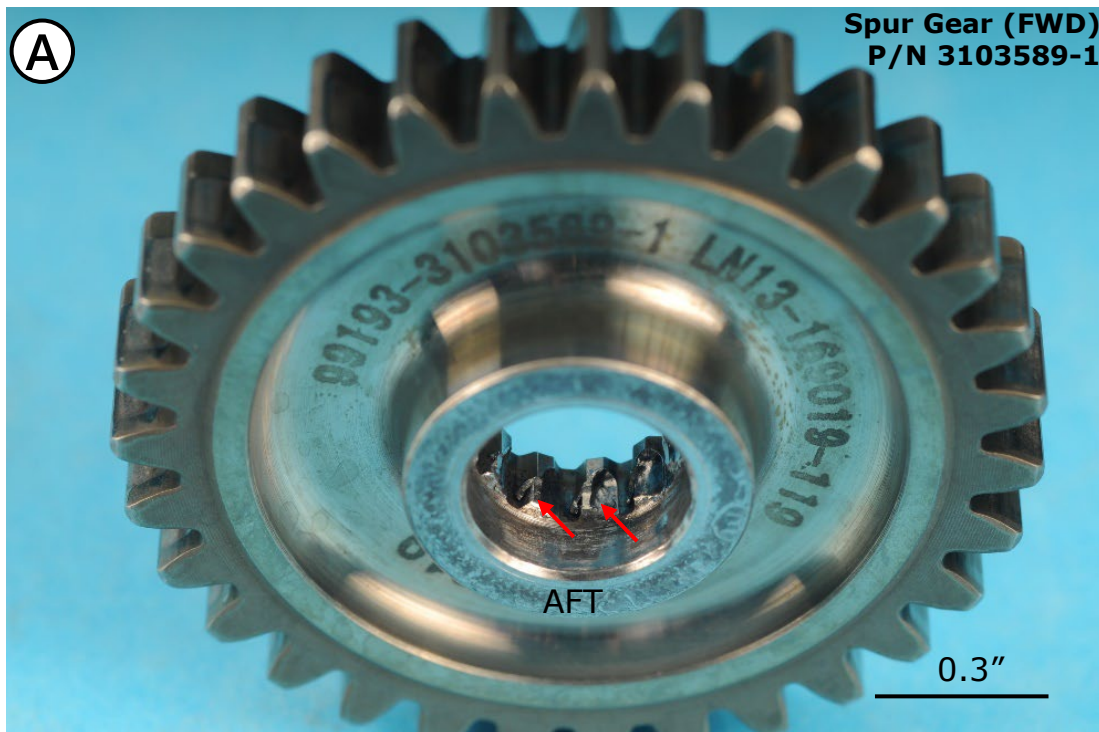
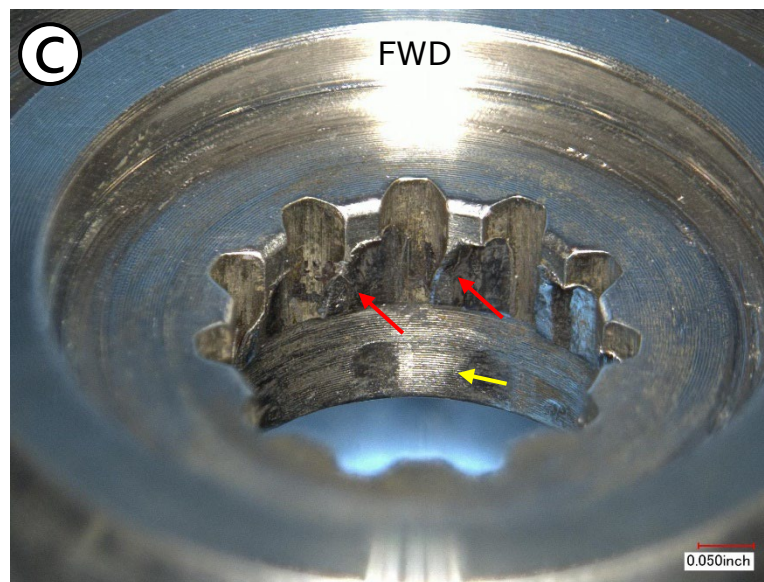
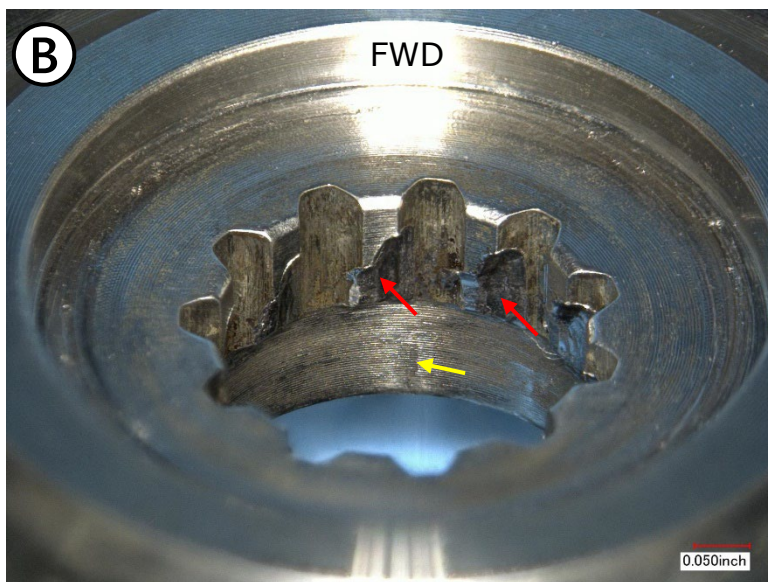


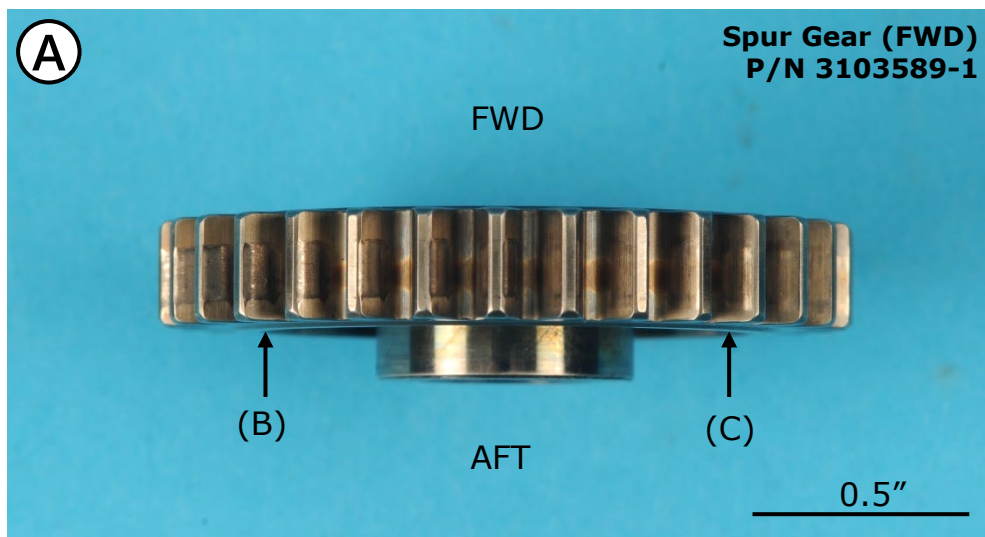
Figure 5.

(A-E) Image showing the as-received condition of the 2nd idler forward spur gear (P/N 3103589-1) from TPE331 engine S/N P92122C. The yellow arrows in (A) and (C) identify the washer between the spur gear and the nut. View (D) shows the forward spur gear with the washer removed. Fret wear (red arrows in (E)) was observed on the aft side of the spur gear from contact with the duplex ball bearing. Note that some of the bearing markings were transposed to the spur gear surface.

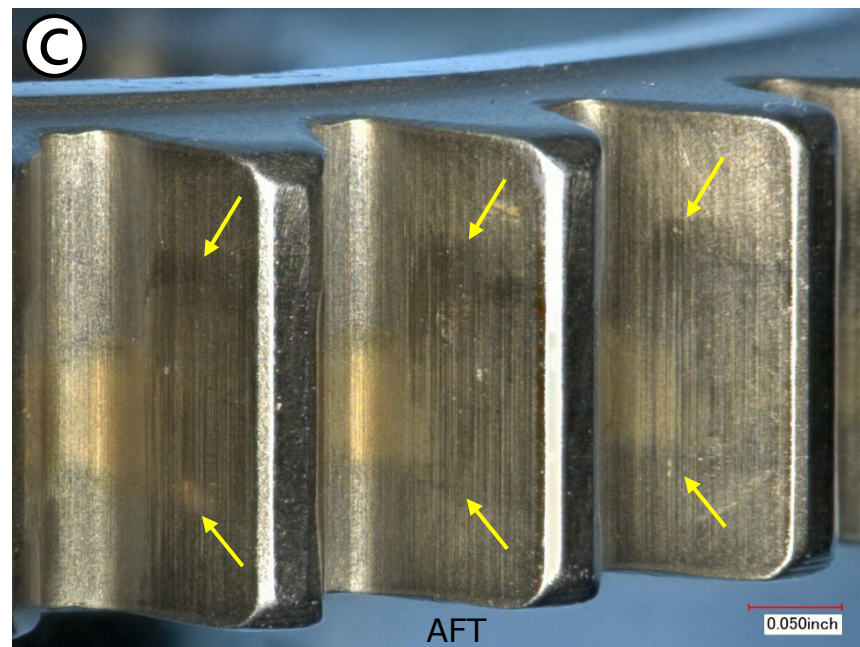
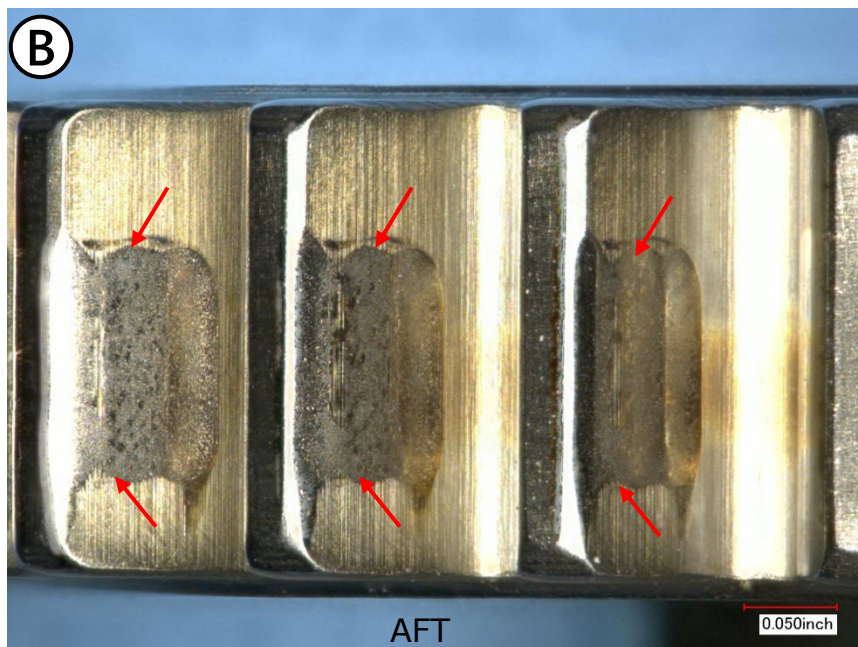
**Figure 6.**

(A-C) Images showing the condition of internal splines of the 2nd idler forward spur gear. Wear and deformation was observed on the loaded side of the splines (red arrows) from contact with the mating shouldered splined shaft. Yellow arrows in (B-C) identify wear from contact with the shaft OD.



**Figure 7.**

(A-C) Images showing the condition of gear teeth of the 2nd idler forward spur gear. Wear and deformation was observed on the loaded side of the gear teeth (red arrows) from contact with the mating 3rd idler spur gear (P/N 3103590-2). Witness marks (yellow arrows in (C)) were observed on the unloaded side of the gear teeth.



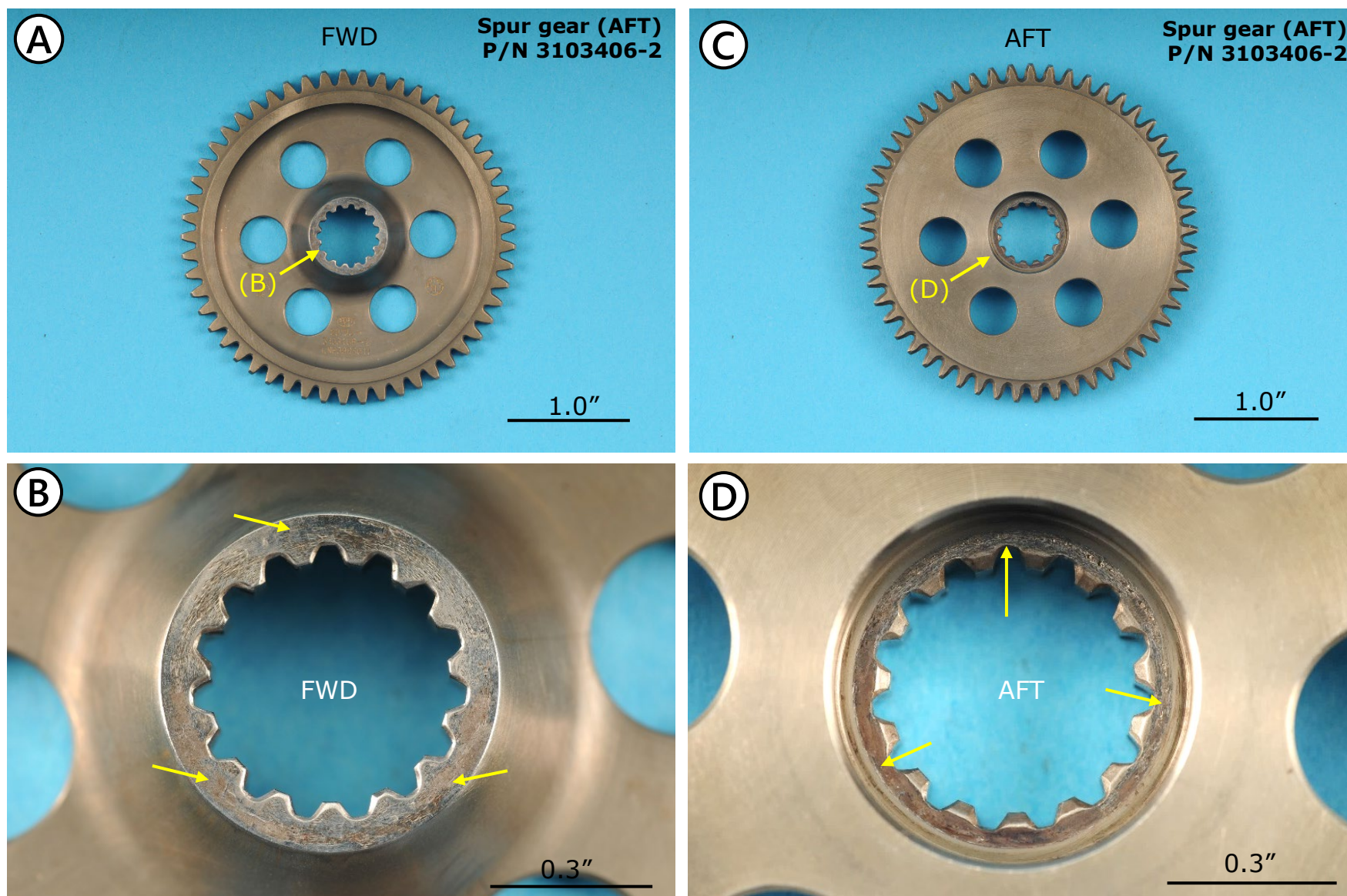
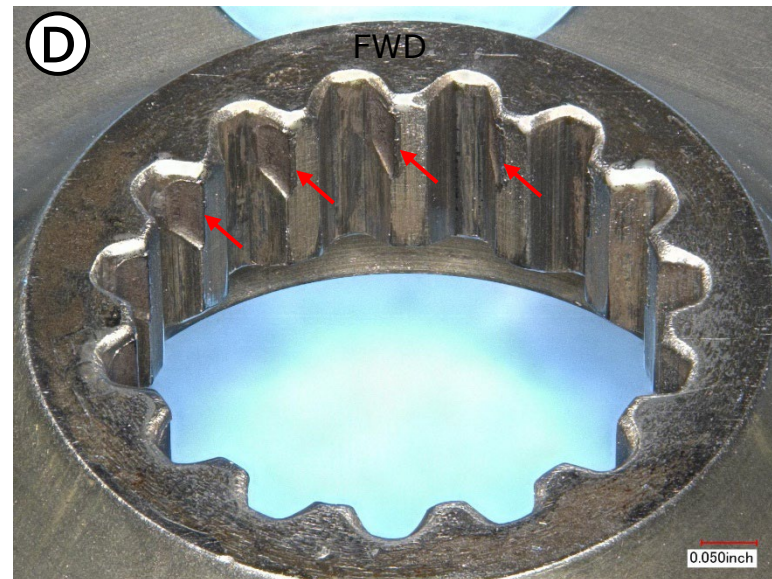
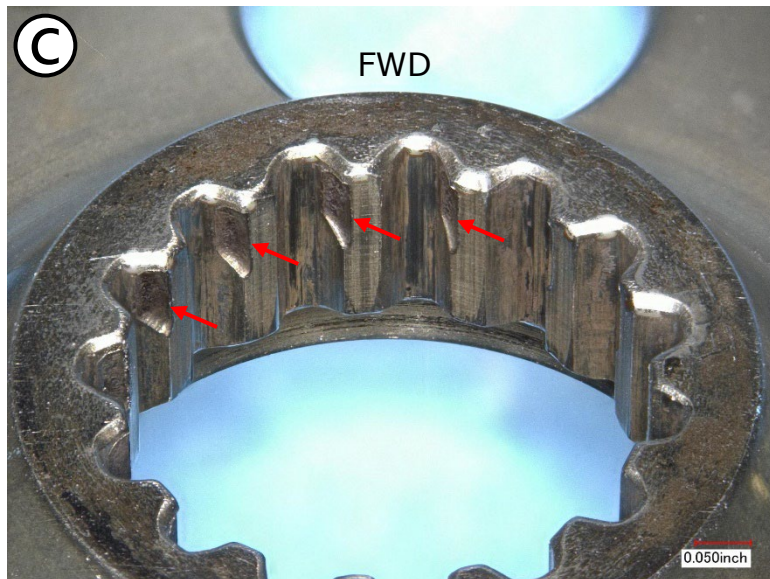
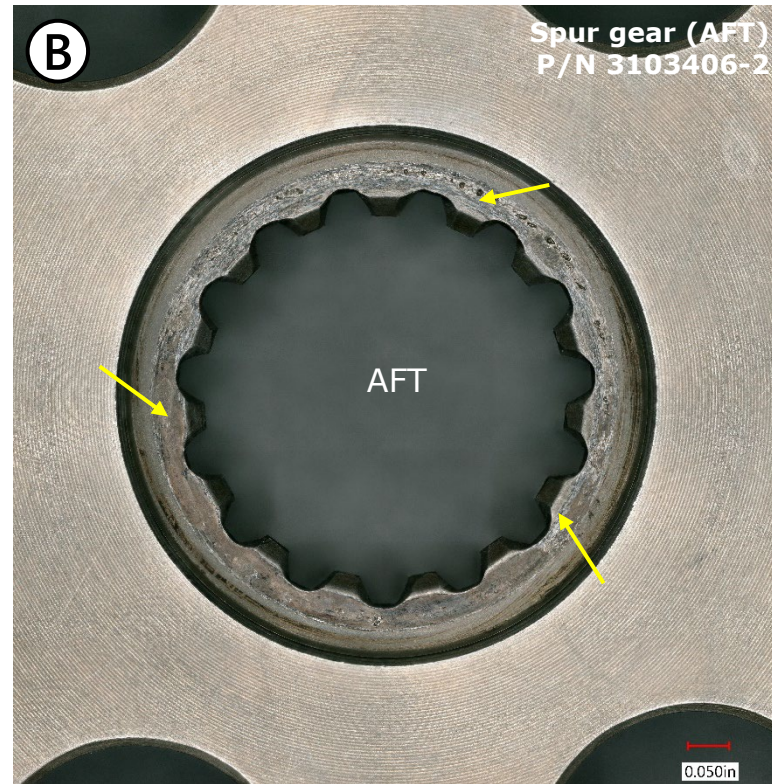
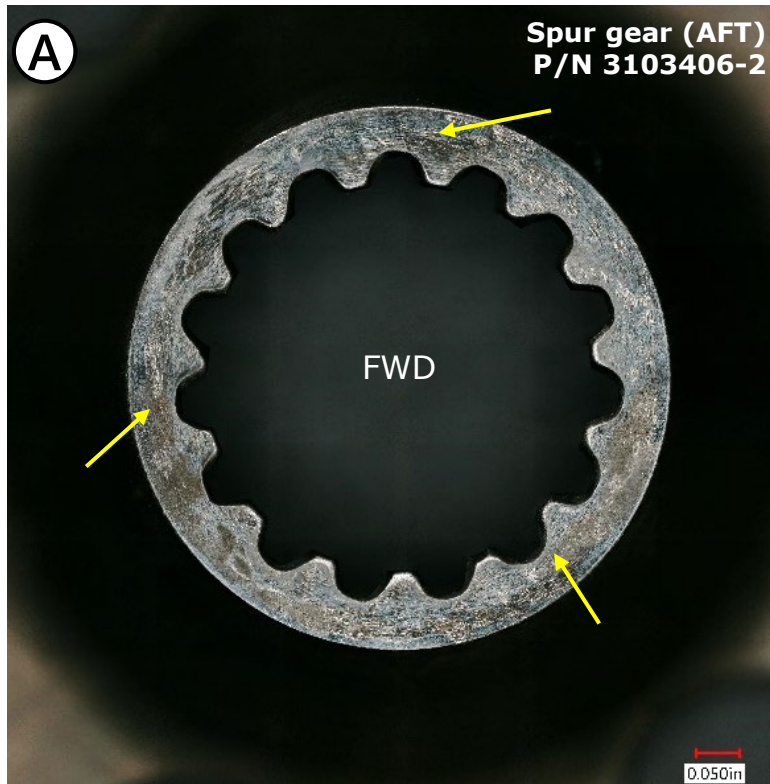


Figure 8.

(A-D) Images showing the as-received condition of the 2nd idler aft spur gear (P/N 3103406-2) from TPE331 engine S/N P92122C. Wear (yellow arrows) was observed on the forward and aft sides of the spur gear from contact with the duplex ball bearing and shouldered splined shaft head, respectively.

**Figure 9.**

(A-B) Digital microscope images showing the forward and aft ID surfaces of the 2nd idler aft spur gear. Fret wear (yellow arrows) was observed on the forward and aft sides of the spur gear from contact with the duplex ball bearing and shouldered splined shaft head, respectively. (C-D) Digital microscope images showing the internal spline of the 2nd idler aft spur gear. Wear (red arrows) was observed on the loaded side of the spline teeth from contact with the mating splines from the shouldered splined shaft.

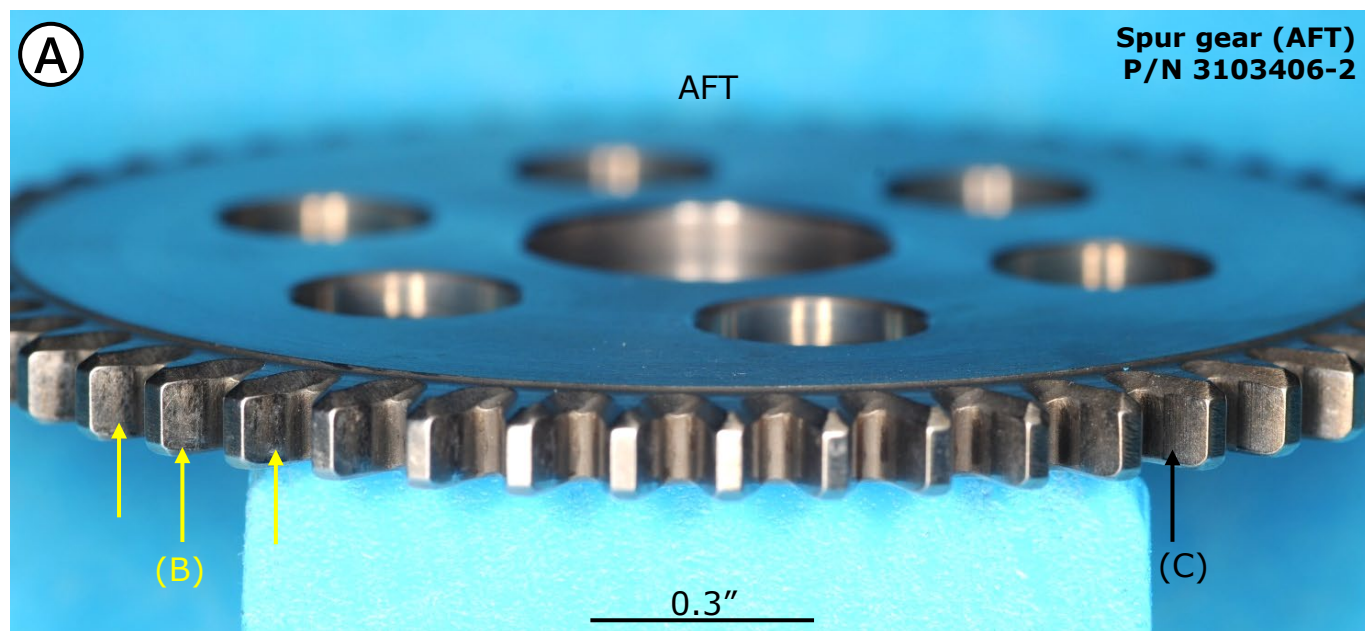
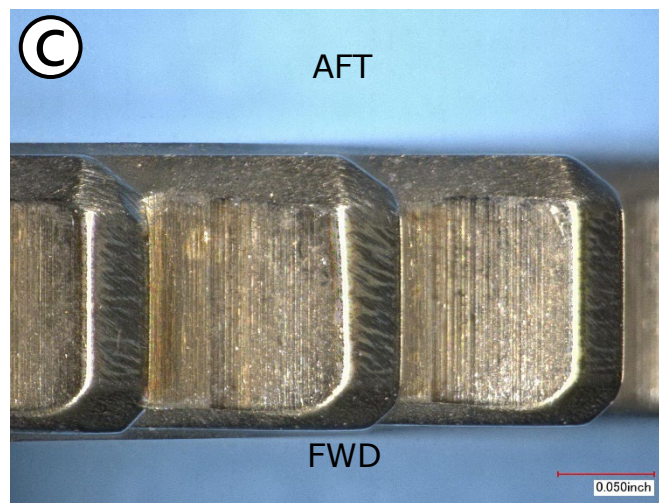
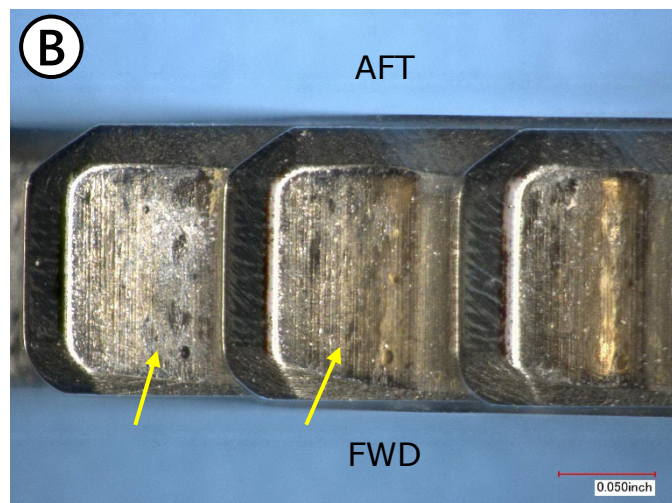


Figure 10. (A-C) Digital microscope images showing the gear teeth of the 2nd idler aft spur gear. Contact marks (yellow arrows in (A-B)) were observed on the loaded side of the gear teeth; however, no notable wear depth was observed.



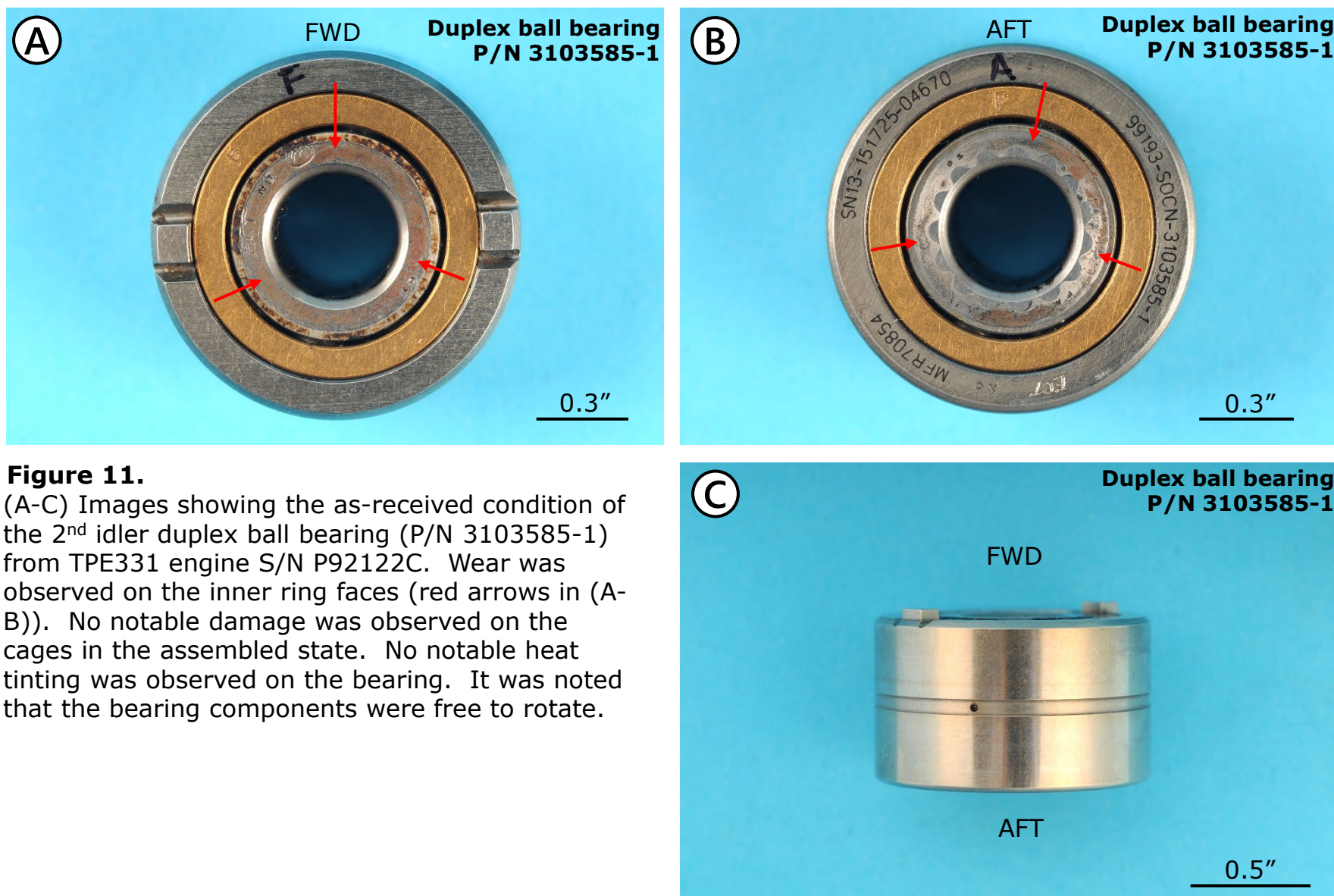


Figure 11.

(A-C) Images showing the as-received condition of the 2nd idler duplex ball bearing (P/N 3103585-1) from TPE331 engine S/N P92122C. Wear was observed on the inner ring faces (red arrows in (A-B)). No notable damage was observed on the cages in the assembled state. No notable heat tinting was observed on the bearing. It was noted that the bearing components were free to rotate.

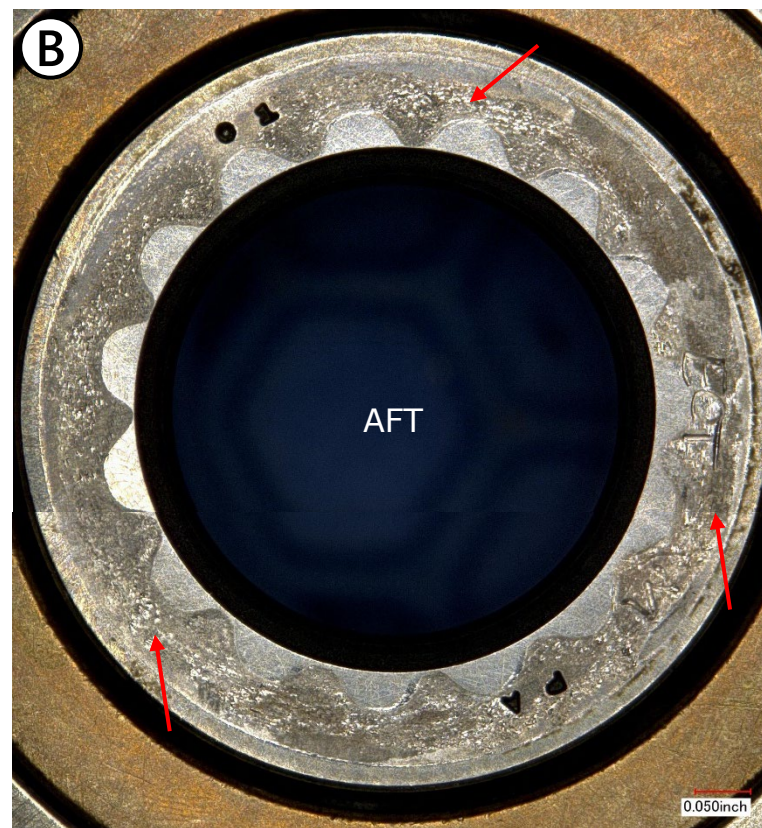
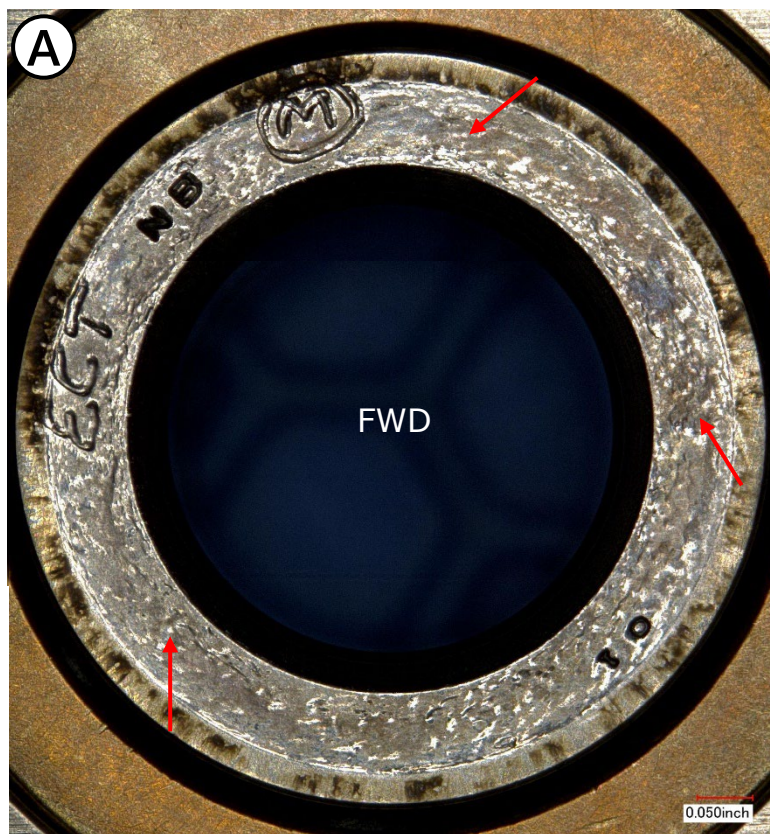


Figure 12.

(A-B) Digital microscope images showing the forward and aft sides, respectively, of the duplex ball bearing inner ring faces. Fret wear (red arrows) was observed on the forward and aft faces from contact with the mating 2nd idler forward and aft spur gears, respectively.

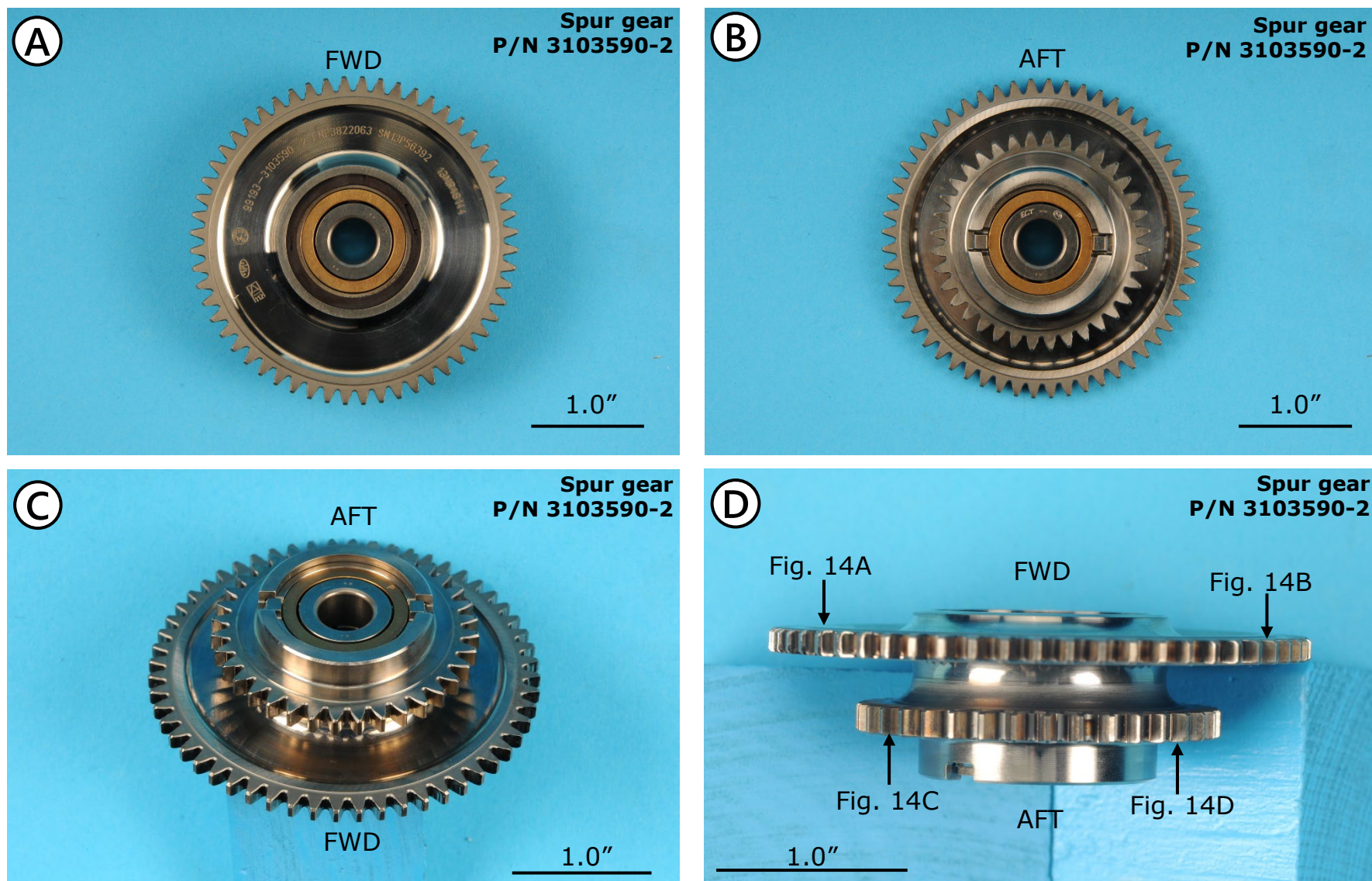


Figure 13.

(A-D) Images showing the as-received condition of the 3rd idler spur gear (P/N 3103590-2) from TPE331 engine S/N P92122C in the assembled state. Close-up images of the gear teeth in the areas of identified in (D) are shown in Figure 14.

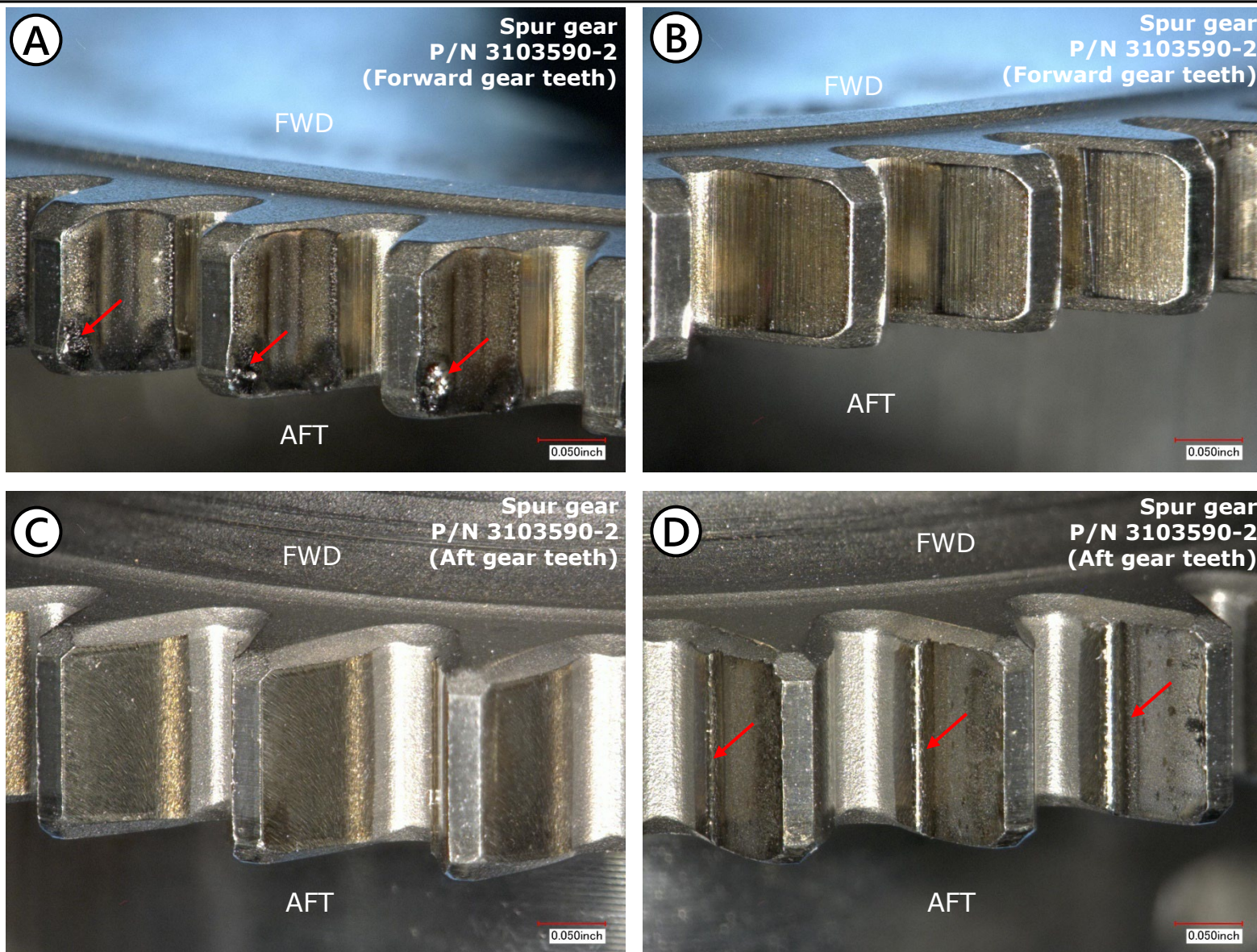


Figure 14.

(A-D) Digital microscope images showing the condition of the gear teeth of the 3rd idler spur gear (reference Figure 13D). Wear (red arrows) were observed predominantly on the loaded side of the gear teeth.

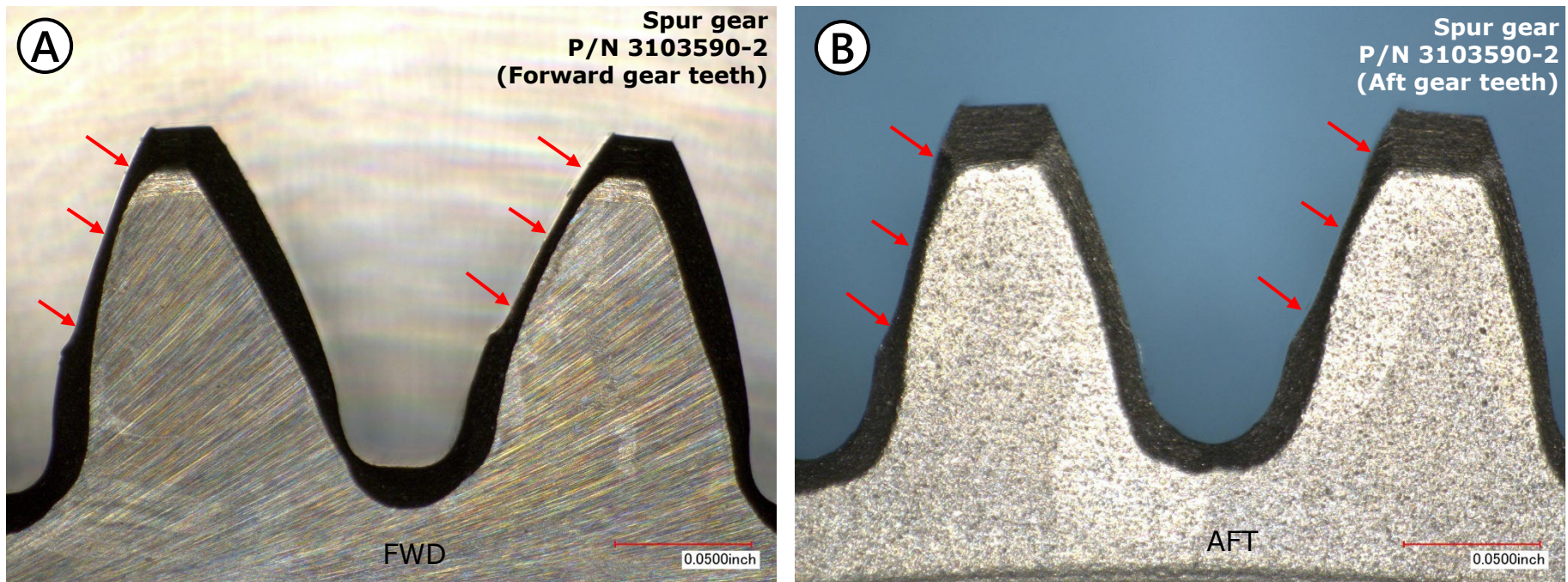


Figure 15.

Digital microscope images showing the condition of the (A) forward and (B) aft gear teeth of the 3rd idler spur gear (reference Figures 14-15). Wear (red arrows) was observed predominantly on one side of the gear teeth. The wear depths on the forward and aft gear teeth were measured to be approximately 0.003" and 0.004", respectively.

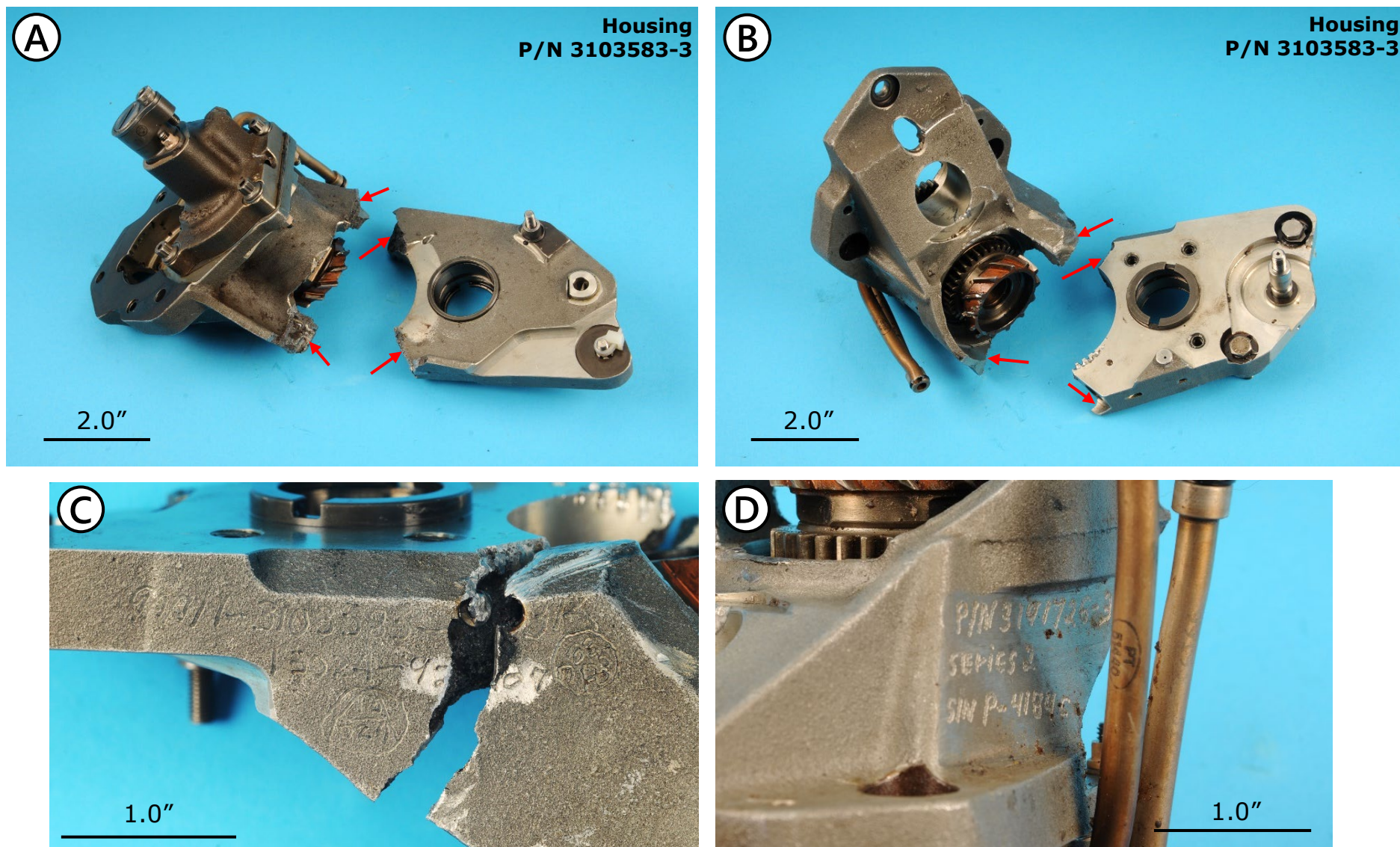


Figure 16.

(A-B) Overall images showing the as-received condition of the torque sensor housing assembly (P/N 3103583-3) from TPE331 engine S/N P92122C. The housing had separated (red arrows). (C-D) Close-up images showing the markings on the housing. Some of the markings observed on the housing were "P/N 3101726-3 Series 2 S/N P-4184C" and "9AA11-3103583-3."

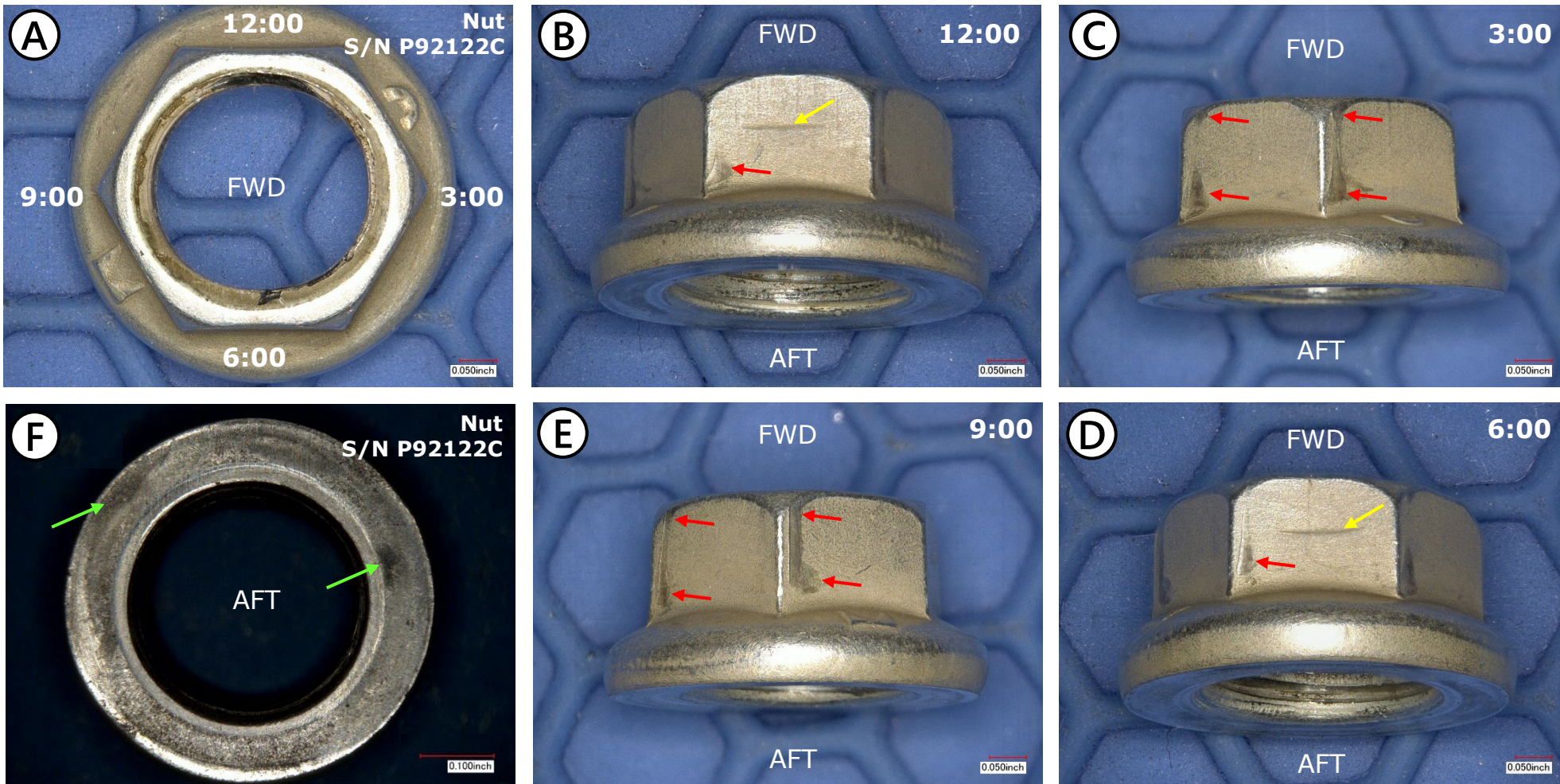


Figure 17.

(A-F) Digital microscope images showing the condition of the nut (P/N MS21043-5) from TPE331 engine S/N P92122C. The yellow arrows in (B) and (D) identify the locking tool marks. Wear marks were observed on one side of each of the nut faces (red arrows in (B-E)). Wear was observed on the aft side of the nut aft face (green arrows in (F)).

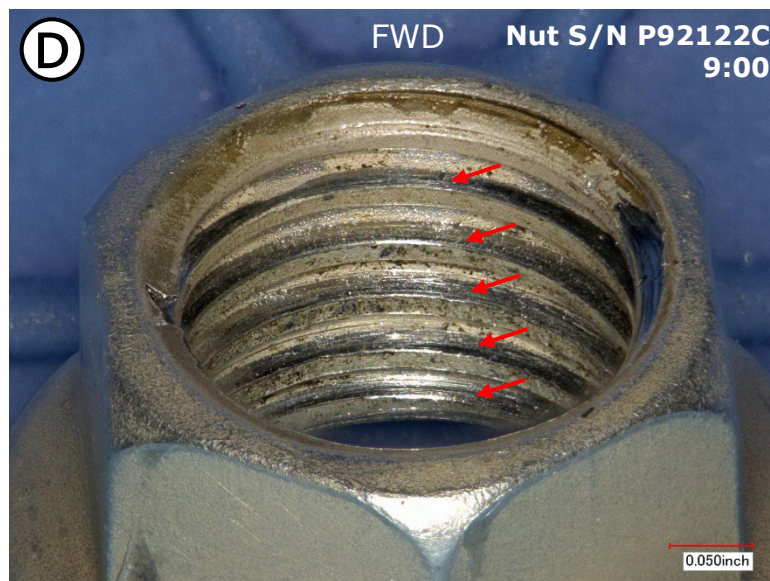
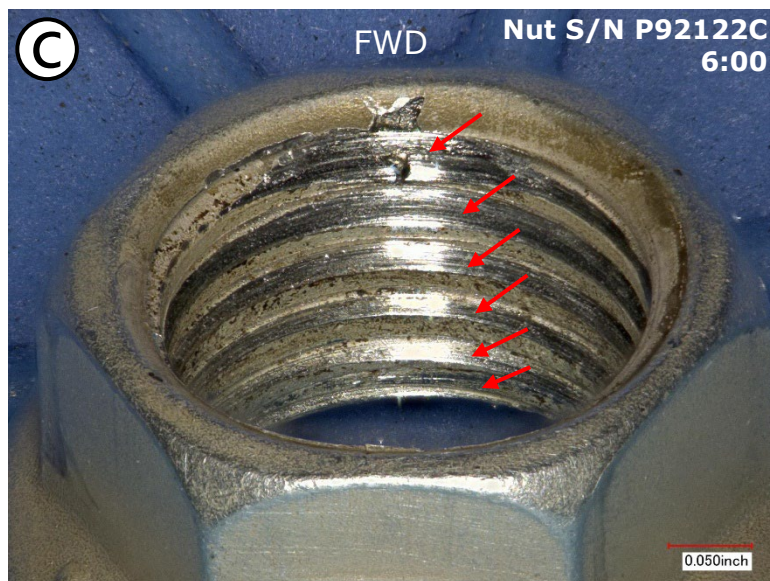
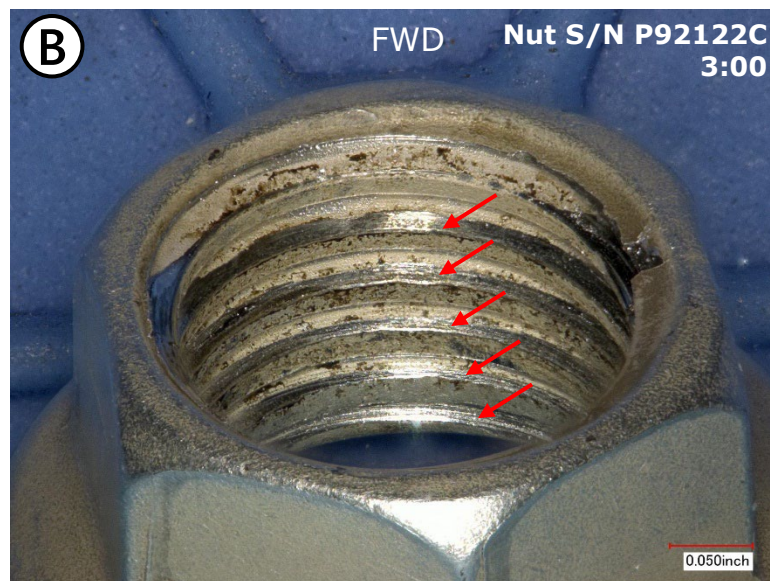
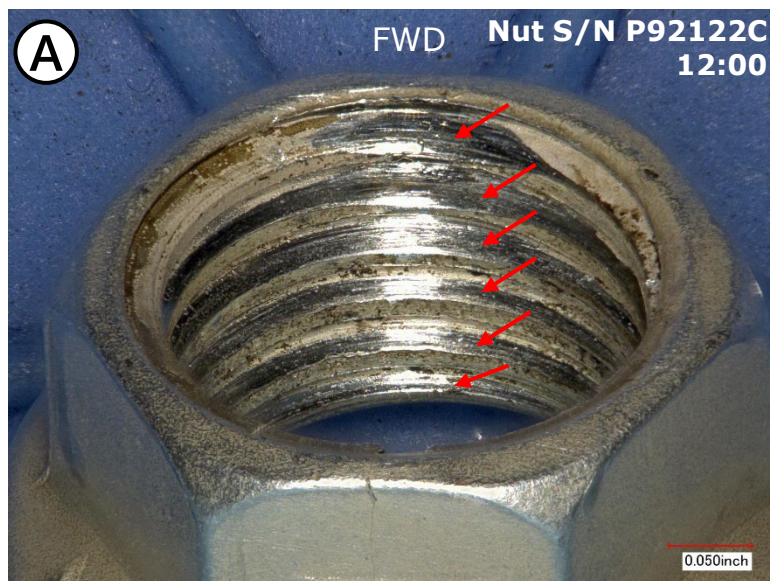


Figure 18. (A-D) Digital microscope images showing the condition of the threads as viewed from the forward side of the nut from TPE331 engine S/N P92122C. The red arrows identify wear on the threads that had penetrated through the silver plating.

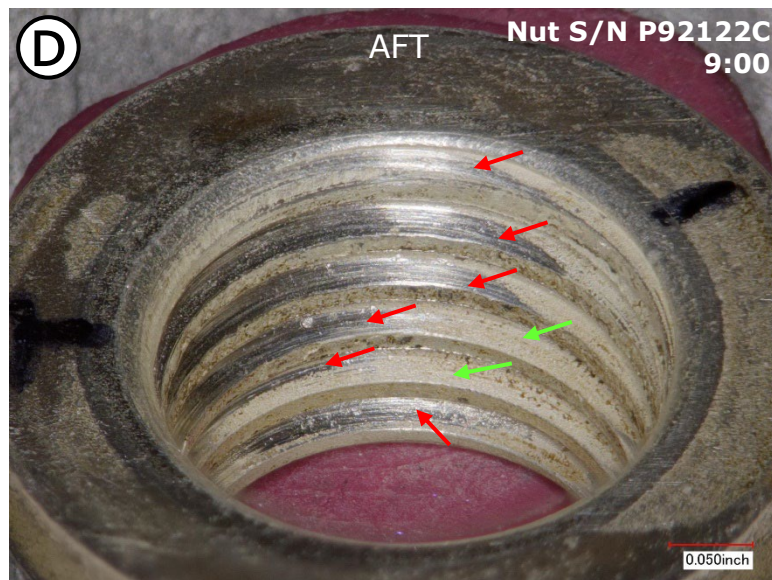
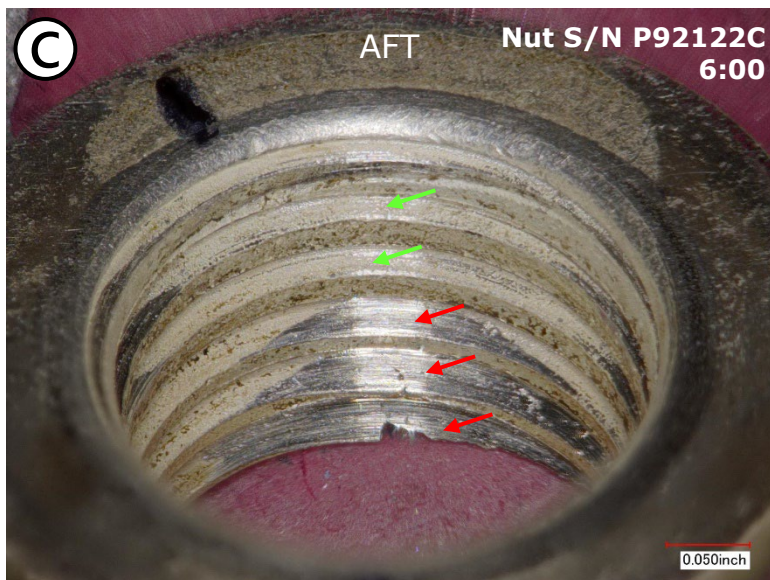
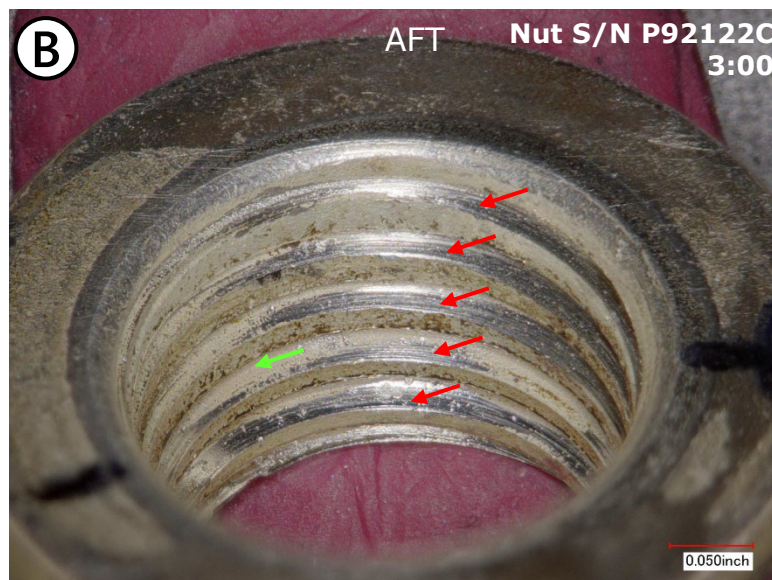
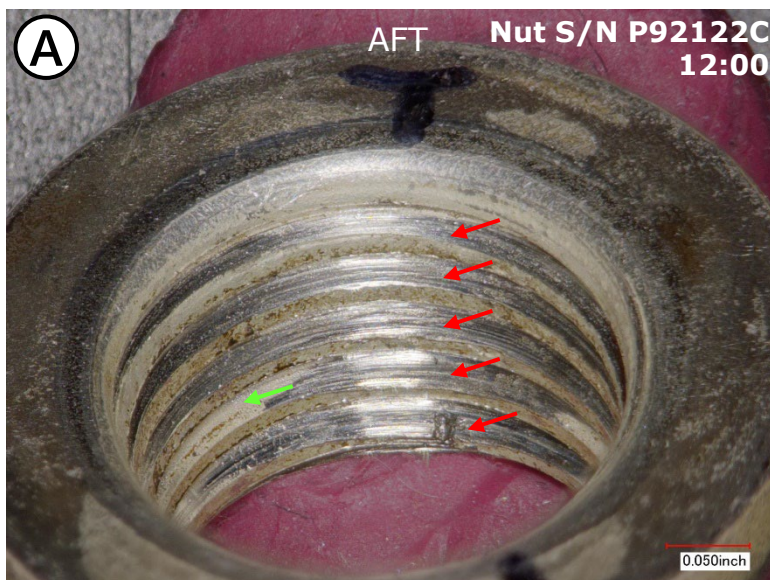


Figure 19. (A-D) Digital microscope images showing the condition of the threads as viewed from the aft side of the nut from TPE331 engine S/N P92122C. The red arrows identify wear on the threads that had penetrated through the silver plating. Note that the contact on the aft side of the thread was not uniform around the circumference (green arrows).

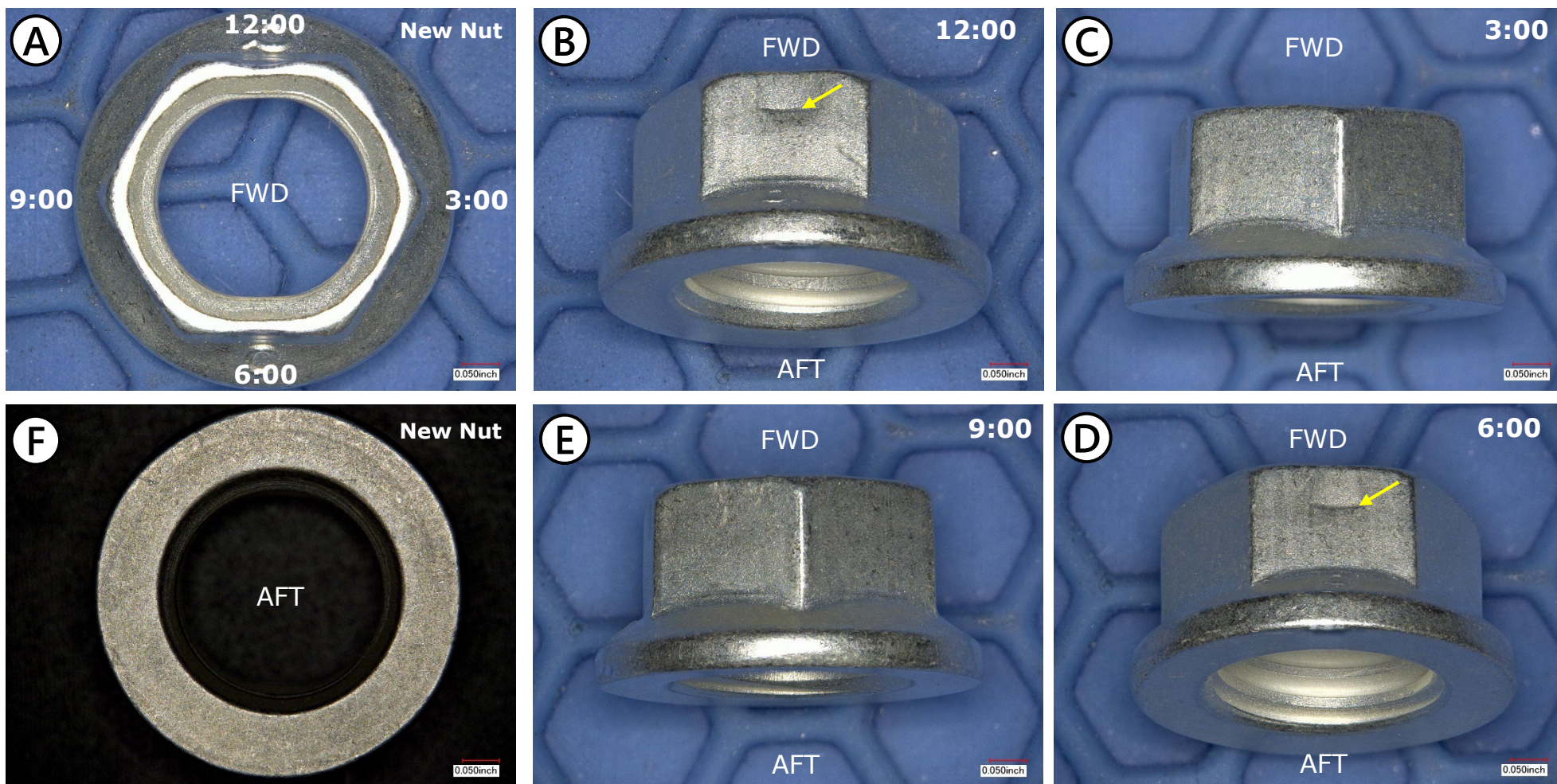


Figure 20.

(A-F) Digital microscope images showing the condition of a new nut (P/N MS21043-5). The yellow arrows in (B) and (D) identify the locking tool marks.

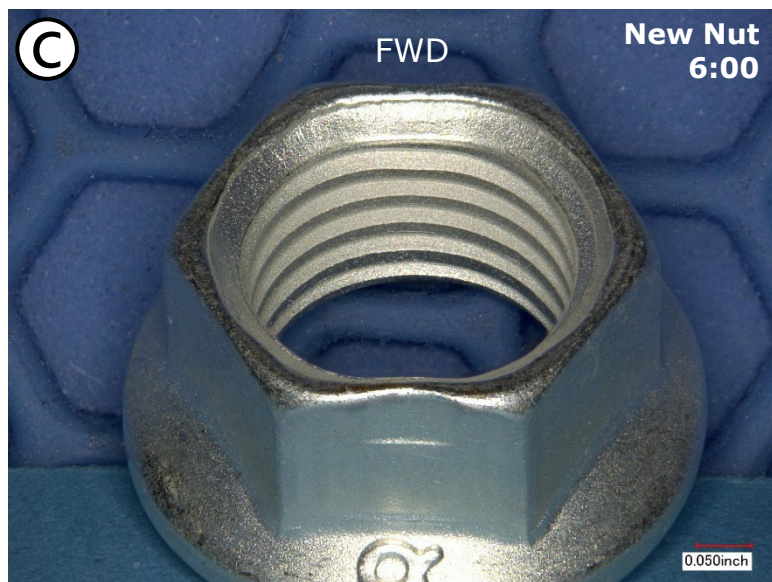
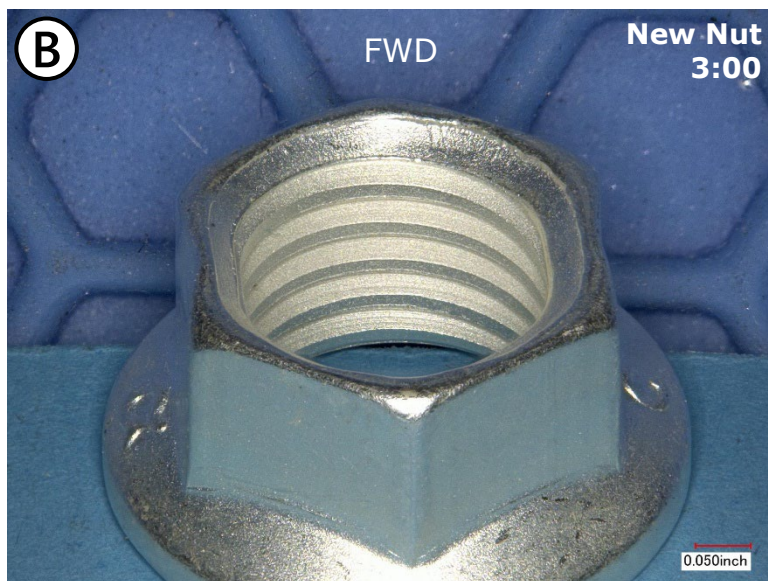
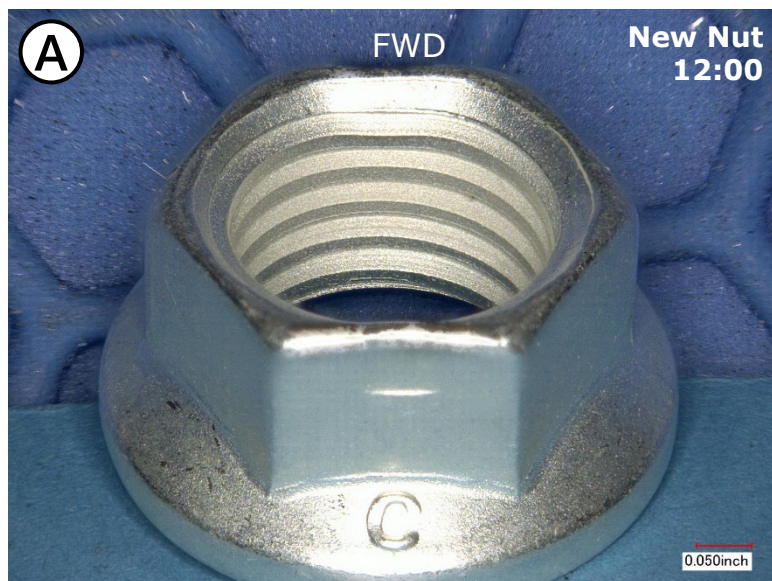


Figure 21.
(A-D) Digital microscope images showing the condition of the threads as viewed from the aft side of a new nut (P/N MS21043-5).

Table 2. New Nuts

Nut ID	Torqued?	MoS2 Lubricant Used?	Point Socket Used
1	Yes	No	6 (assembled) 12 (disassembled)
2	No	Yes	12 (assembled and disassembled)
3	Yes	No	12 (assembled and disassembled)
4	Yes	Yes	12 (assembled and disassembled)
5	No	No	6 (assembled and disassembled)

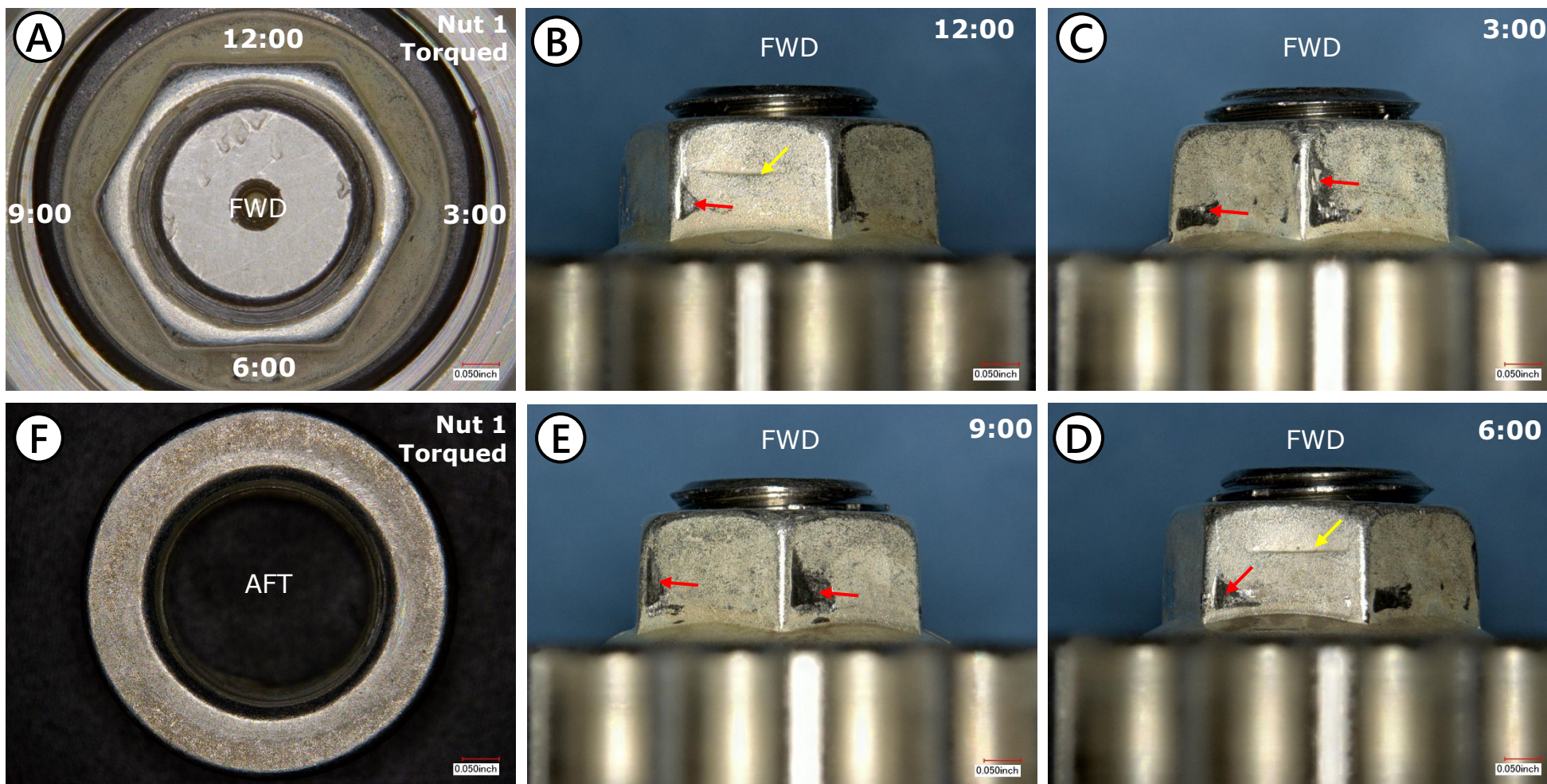


Figure 22.

(A-F) Digital microscope images showing the condition of Nut 1 (P/N MS21043-5), which was a new nut torqued with no lubricant. The yellow arrows in (B) and (D) identify the locking tool marks. Wear marks were observed on one side of each of the nut faces (red arrows in (B-E)).

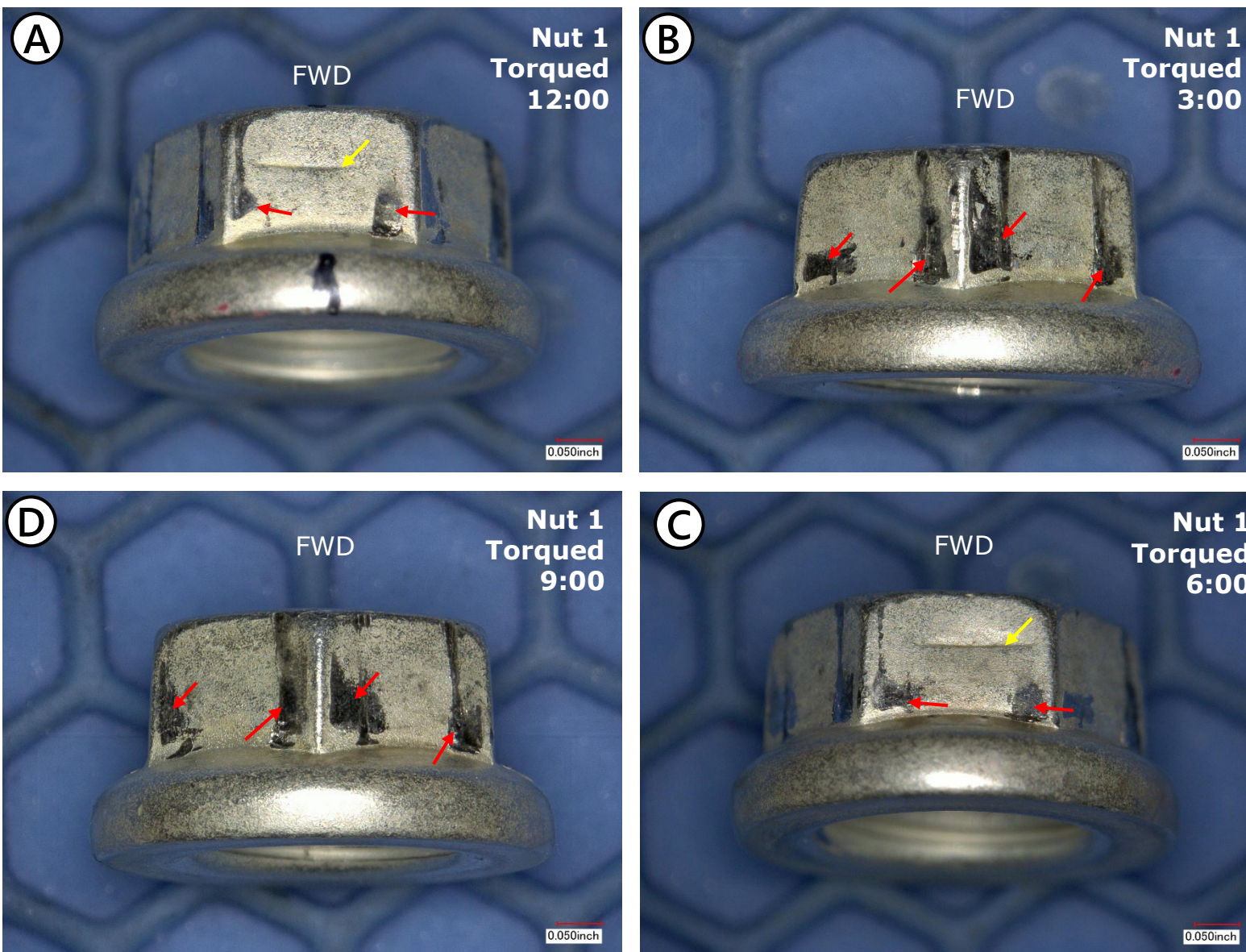


Figure 23.

(A-D) Digital microscope images showing the condition of Nut 1 (P/N MS21043-5) after removal from the assembly. The yellow arrows in (B) and (C) identify the locking tool marks. Wear marks were observed on both sides of each of the nut faces (red arrows).

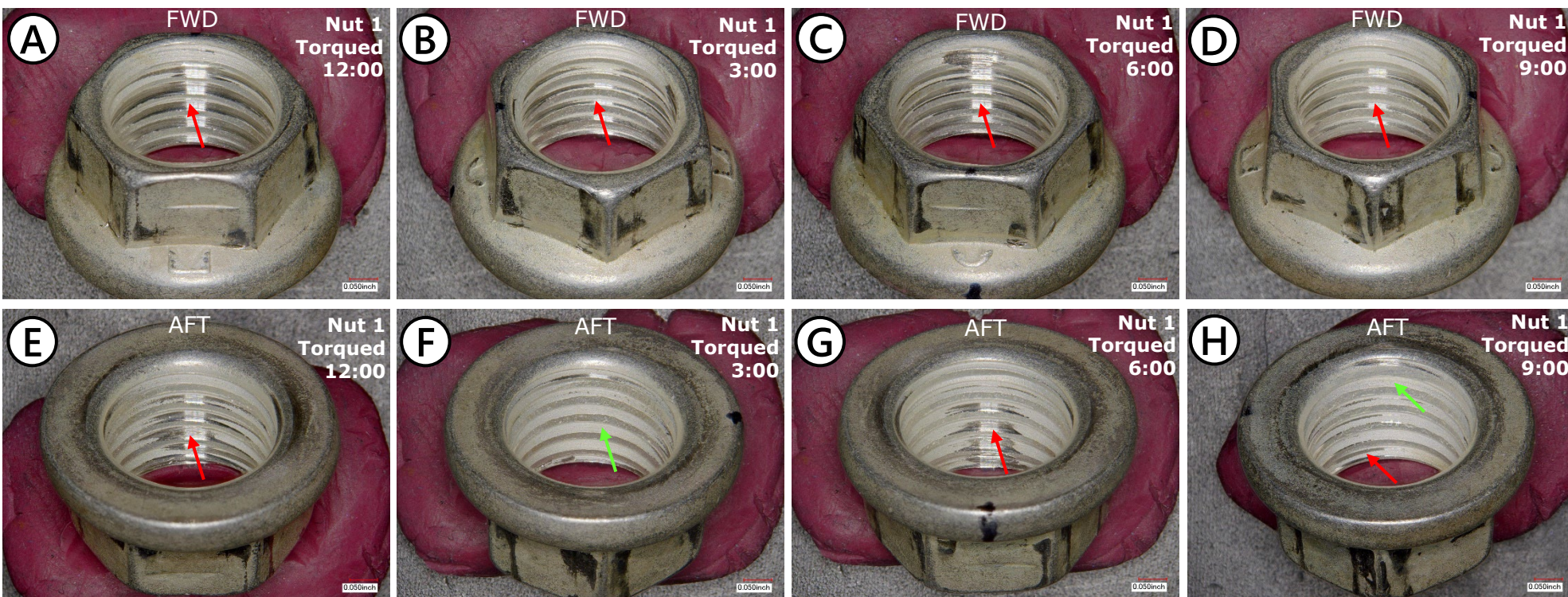


Figure 24.

Digital microscope images showing the condition of the threads as viewed from the (A-D) forward and (E-H) aft sides of Nut 1. The red arrows identify wear on the threads that had penetrated through the silver plating. Note that the contact on the aft side of the threads was not uniform around the circumference (green arrows).

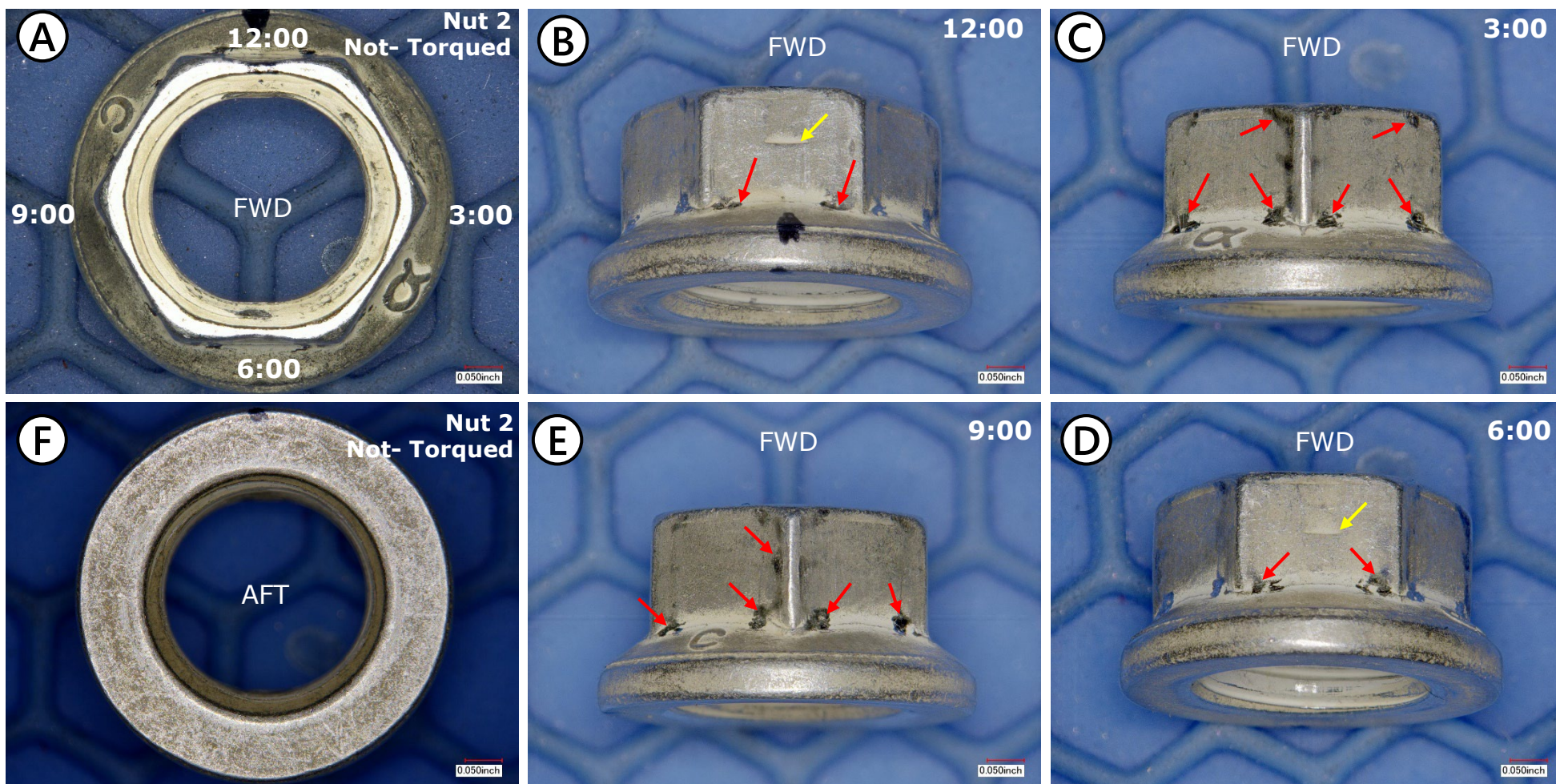


Figure 25.

(A-F) Digital microscope images showing the condition of Nut 2 (P/N MS21043-5) after removal from the assembly, which was a new nut screwed with no torque using lubricant. The yellow arrows in (B) and (D) identify the locking tool marks. Wear marks were observed on one side of each of the nut faces (red arrows in (B-E)).

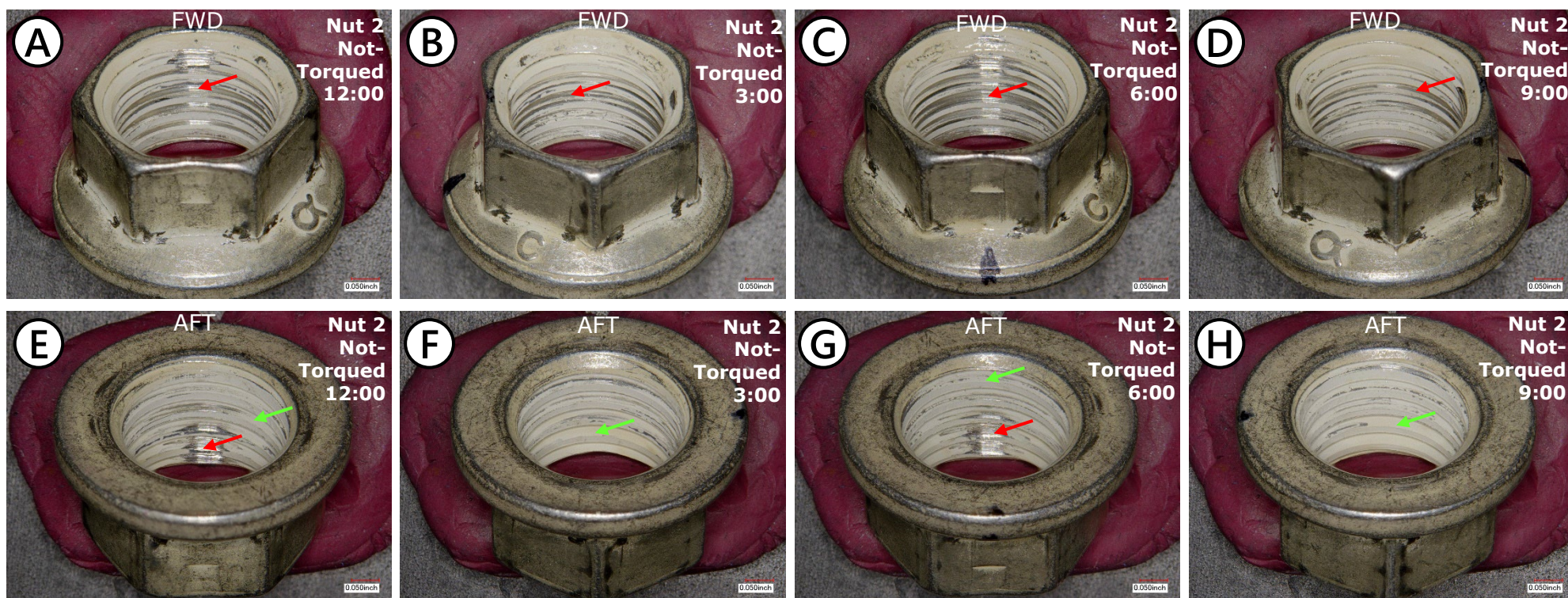


Figure 26. Digital microscope images showing the condition of the threads as viewed from the (A-D) forward and (E-H) aft sides of Nut 2. The red arrows identify wear on the threads that had penetrated through the silver plating. Note that the contact on the aft side of the threads was not uniform around the circumference (green arrows).

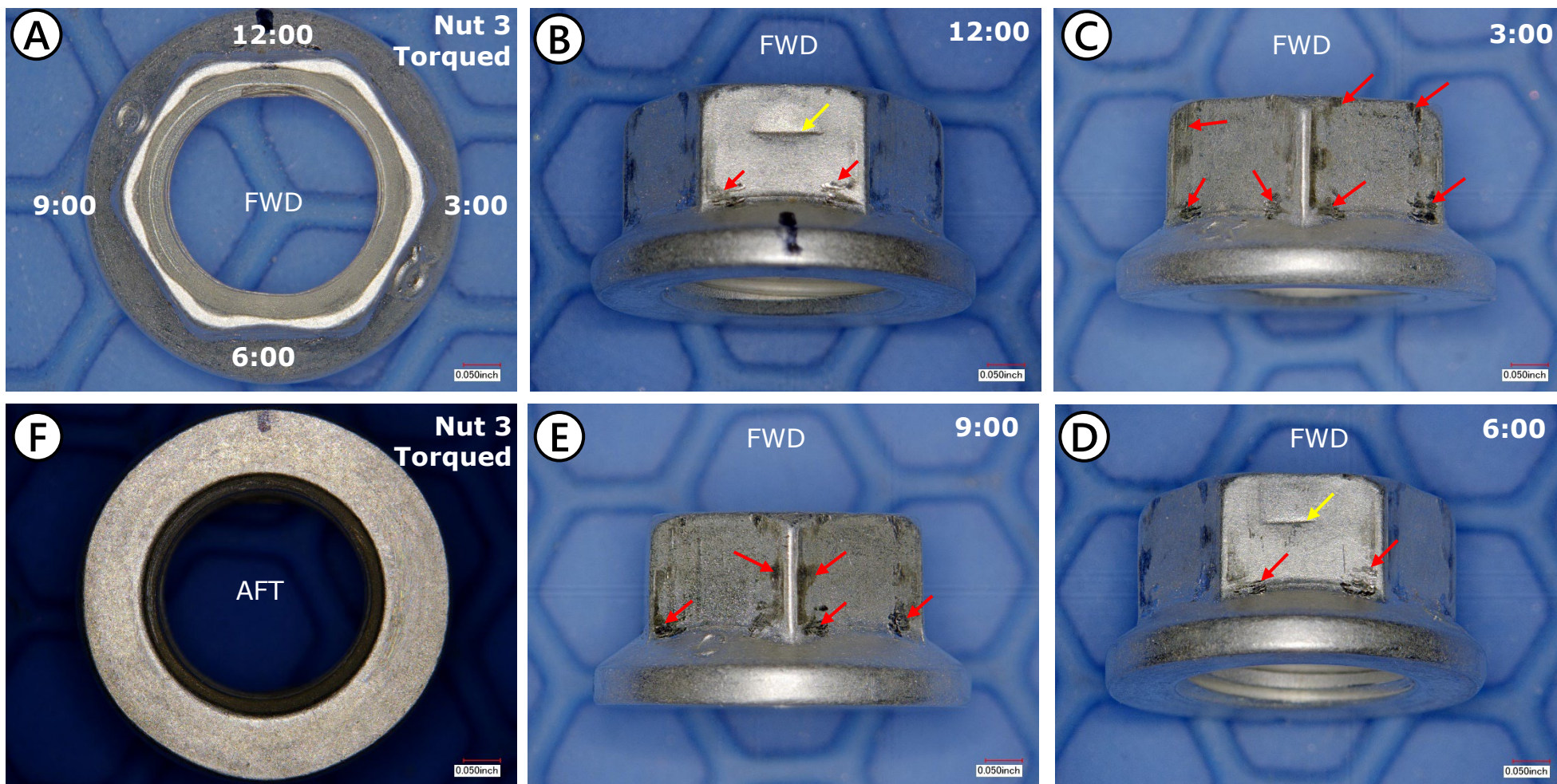


Figure 27.

(A-F) Digital microscope images showing the condition of Nut 3 (P/N MS21043-5) after removal from the assembly, which was a new nut torqued without using lubricant. The yellow arrows in (B) and (D) identify the locking tool marks. Wear marks were observed both sides of each of the nut faces (red arrows in (B-E)).

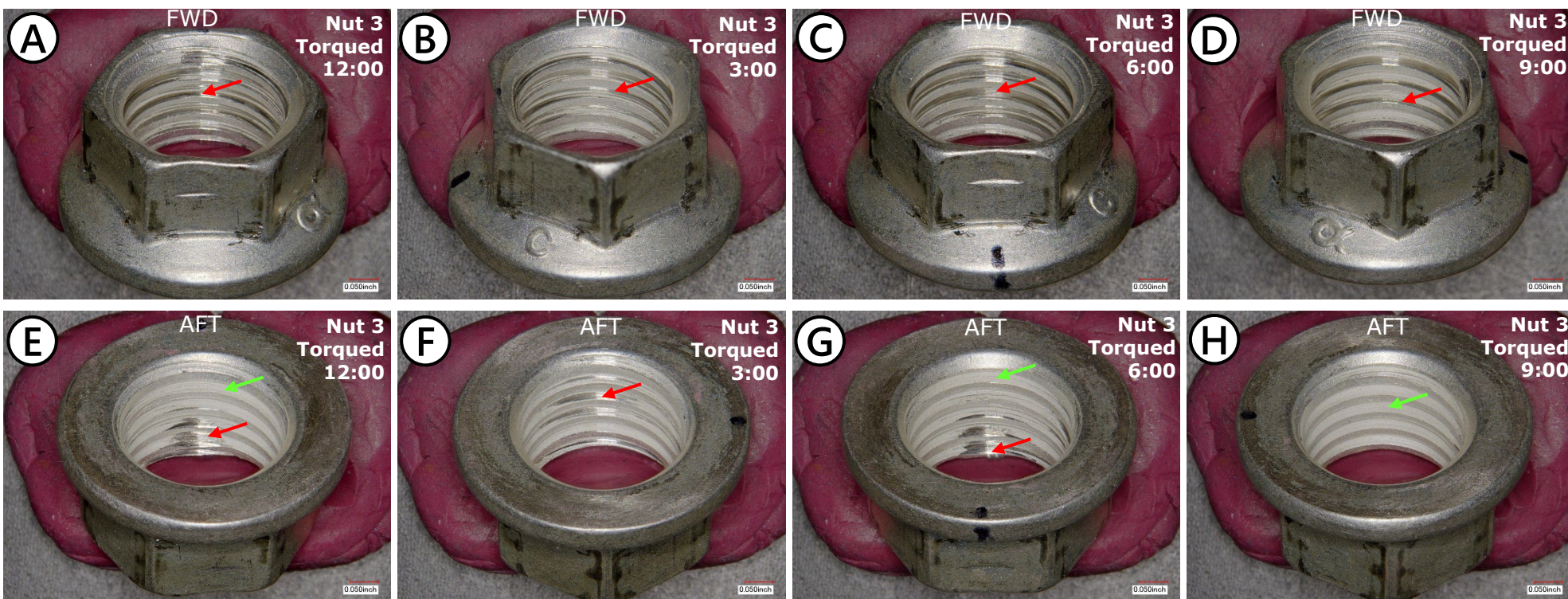


Figure 28.

Digital microscope images showing the condition of the threads as viewed from the (A-D) forward and (E-H) aft sides of Nut 3. The red arrows identify wear on the threads that had penetrated through the silver plating. Note that the contact on the aft side of the thread was not uniform around the circumference (green arrows).

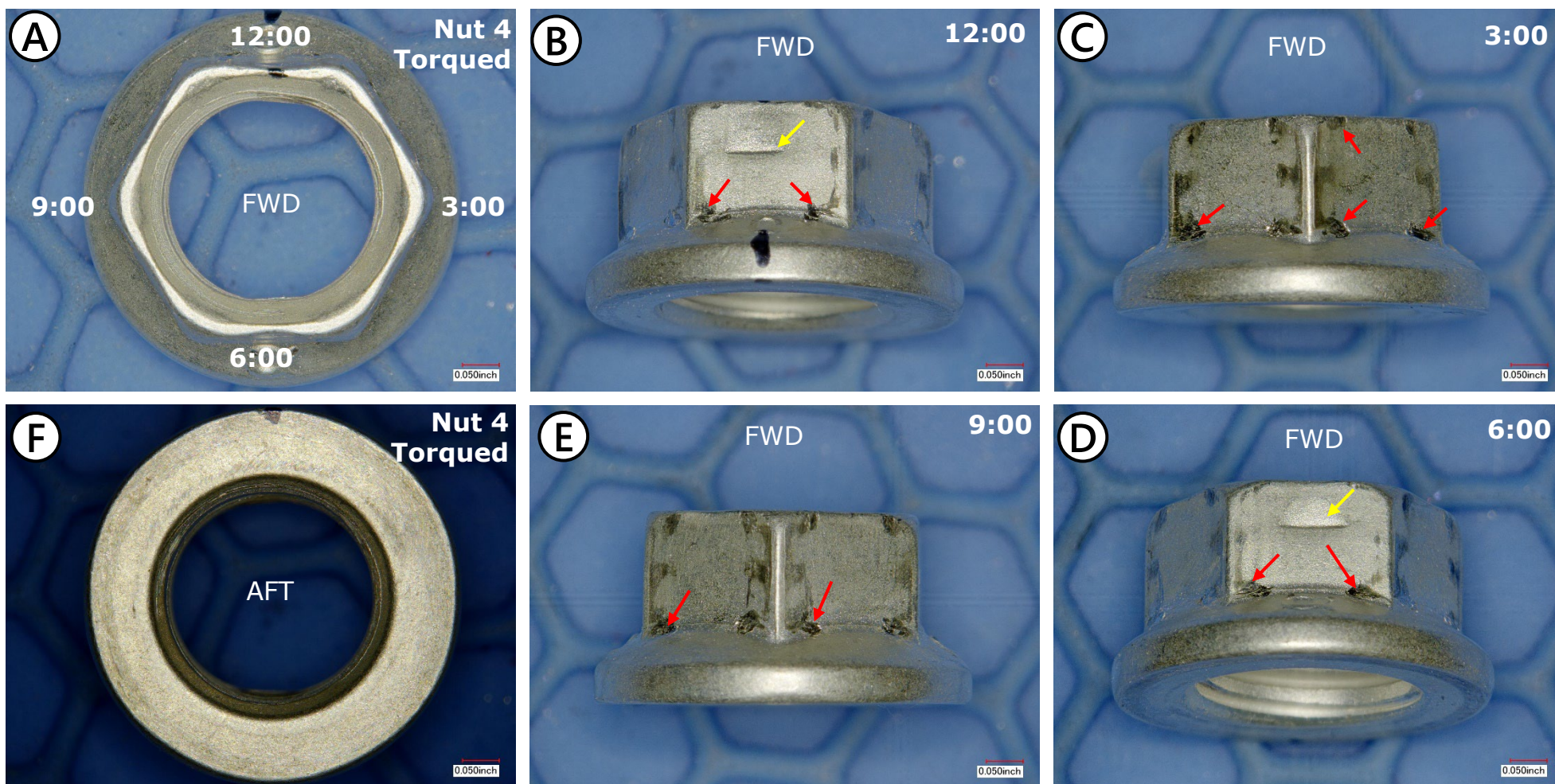


Figure 29.

(A-F) Digital microscope images showing the condition of Nut 4 (P/N MS21043-5) after removal from the assembly, which was a new nut torqued using lubricant. The yellow arrows in (B) and (D) identify the locking tool marks. Wear marks were observed both sides of each of the nut faces (red arrows in (B-E)).

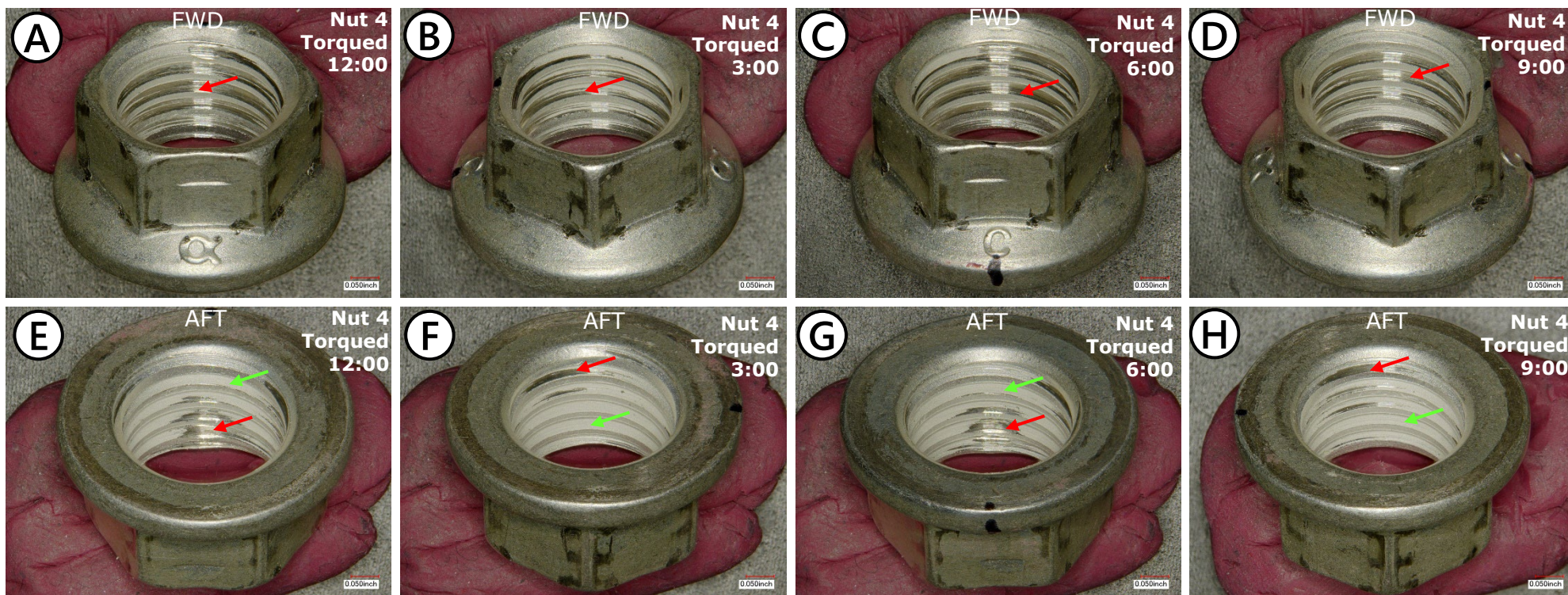


Figure 30. Digital microscope images showing the condition of the threads as viewed from the (A-D) forward and (E-H) aft sides of Nut 4. The red arrows identify wear on the threads that had penetrated through the silver plating. Note that the contact on the aft side of the thread was not uniform around the circumference (green arrows).

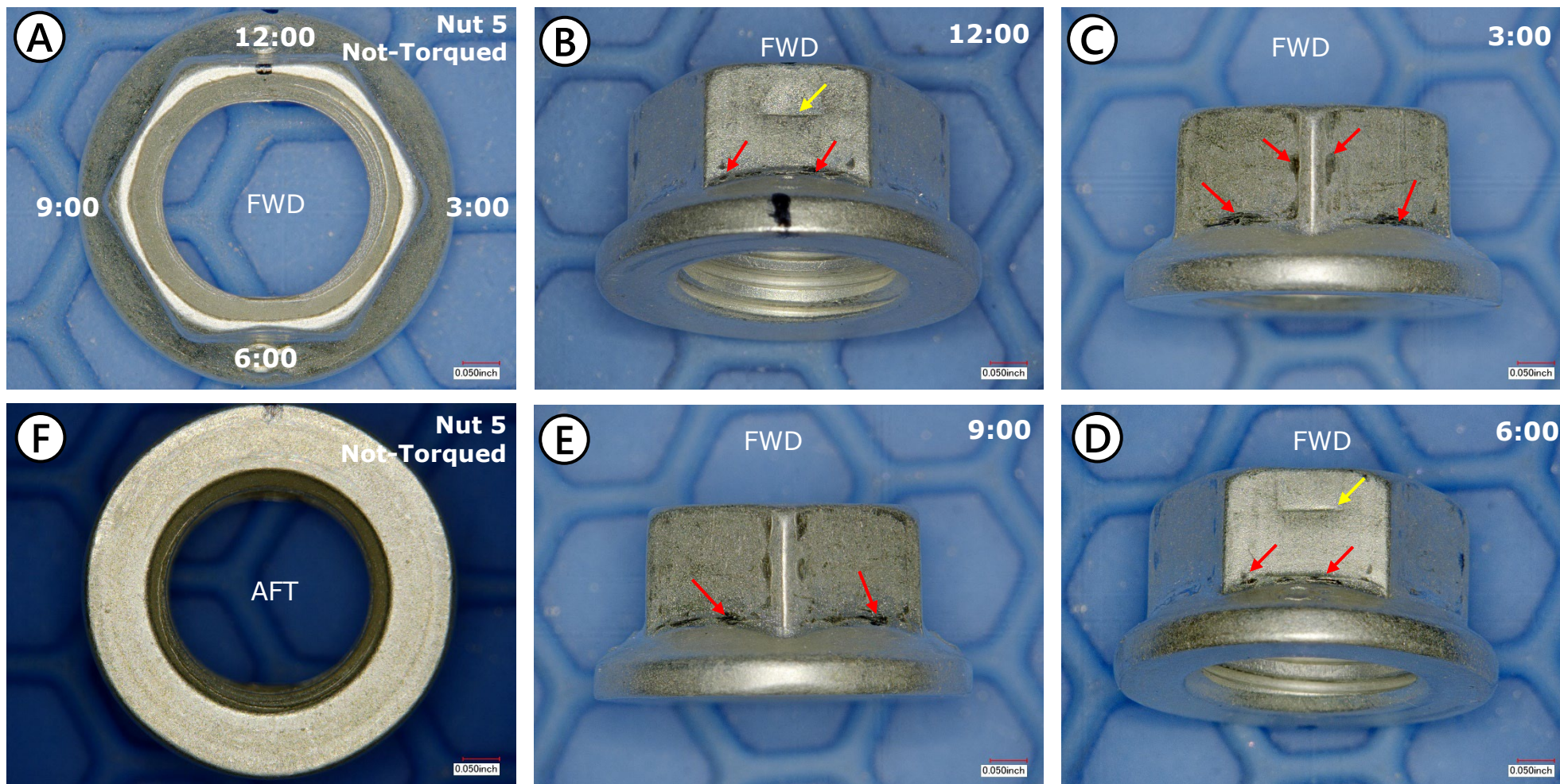


Figure 31.

(A-F) Digital microscope images showing the condition of Nut 5 (P/N MS21043-5) after removal from the assembly, which was a new nut screwed with no torque without lubricant. The yellow arrows in (B) and (D) identify the locking tool marks. Wear marks were observed both sides of each of the nut faces (red arrows in (B-E)).

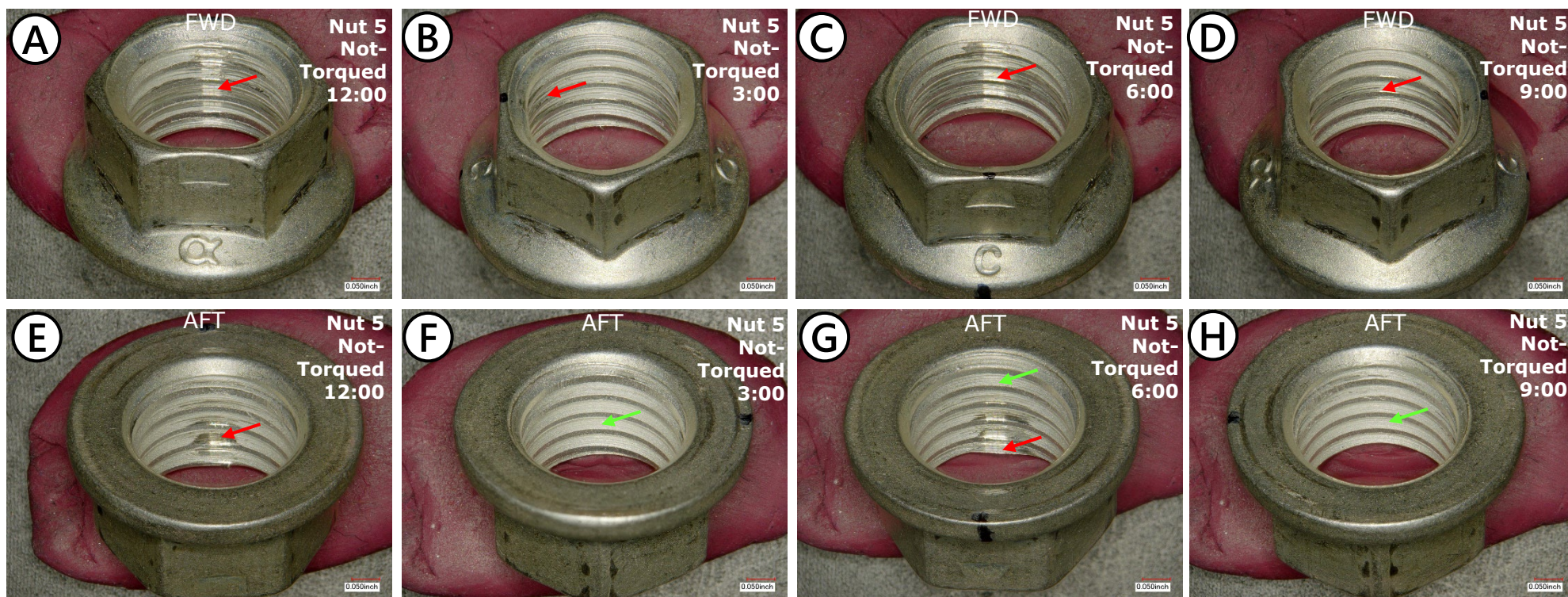


Figure 32.

Digital microscope images showing the condition of the threads as viewed from the (A-D) forward and (E-H) aft sides of Nut 5. The red arrows identify wear on the threads that had penetrated through the silver plating. Note that the contact on the aft side of the thread was not uniform around the circumference (green arrows).

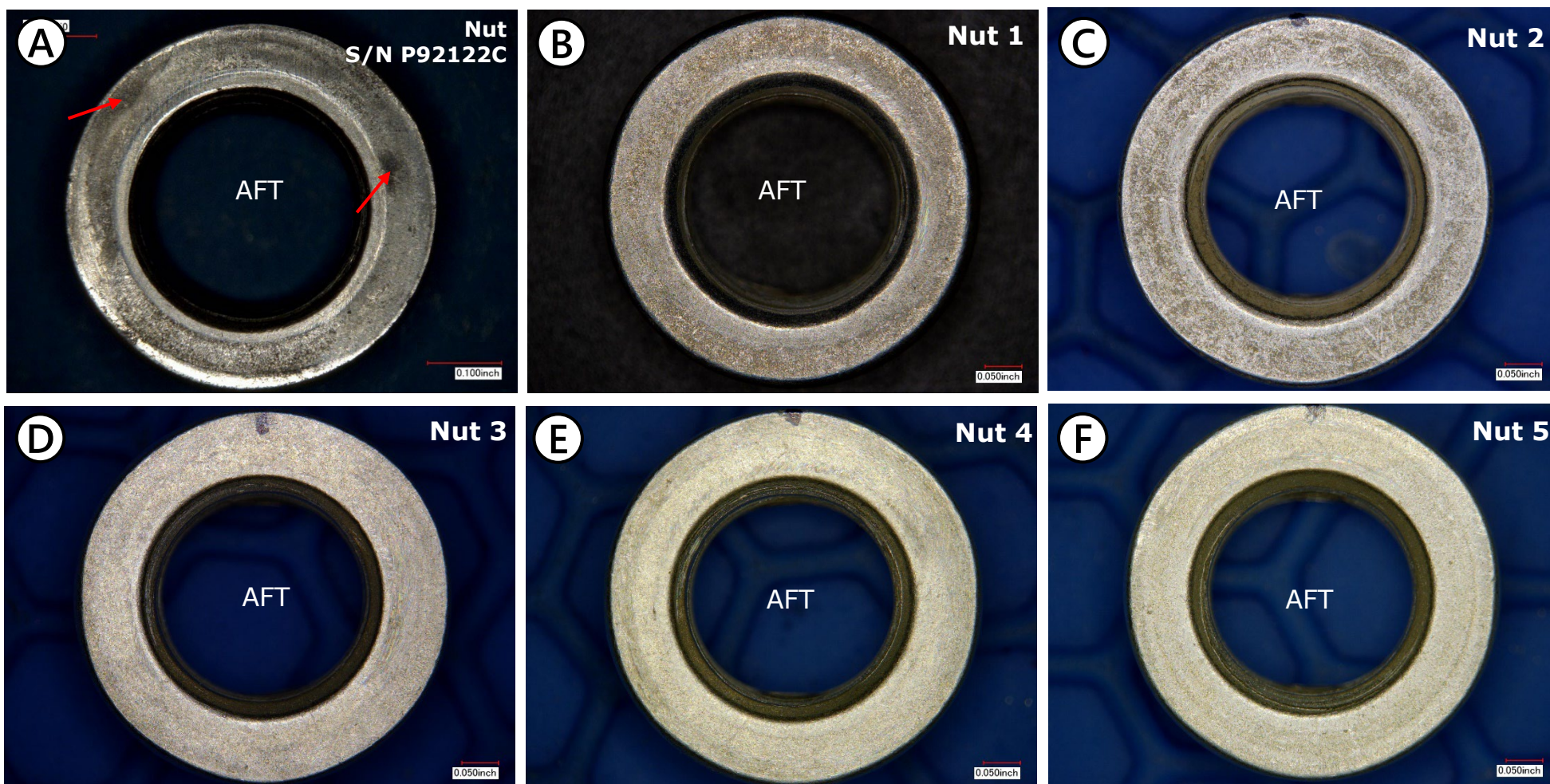


Figure 33.

(A-F) Digital microscope images showing the aft sides of the submitted nuts. Wear was observed on the surface of nut S/N P92122C (red arrows in (A)). Elemental dot map images of the aft sides of the nuts are shown in Figure 34.

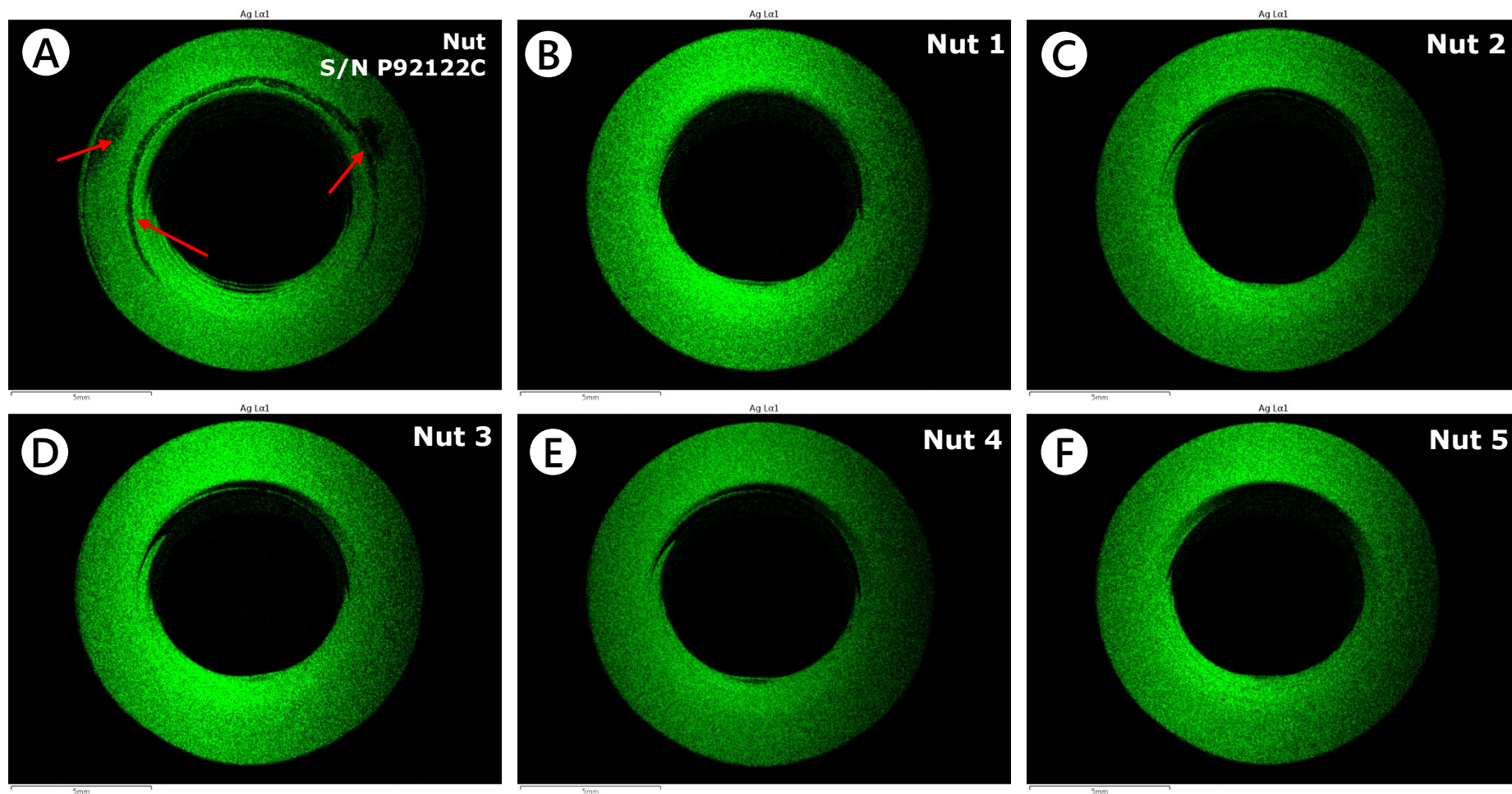


Figure 34.

(A-F) Elemental dot maps showing the silver concentration on the aft sides of the submitted nuts (reference Figure 33). The green colored regions in each photo indicate the presence of the silver plating. The red arrows in (A) identify areas where the silver plating had worn away.

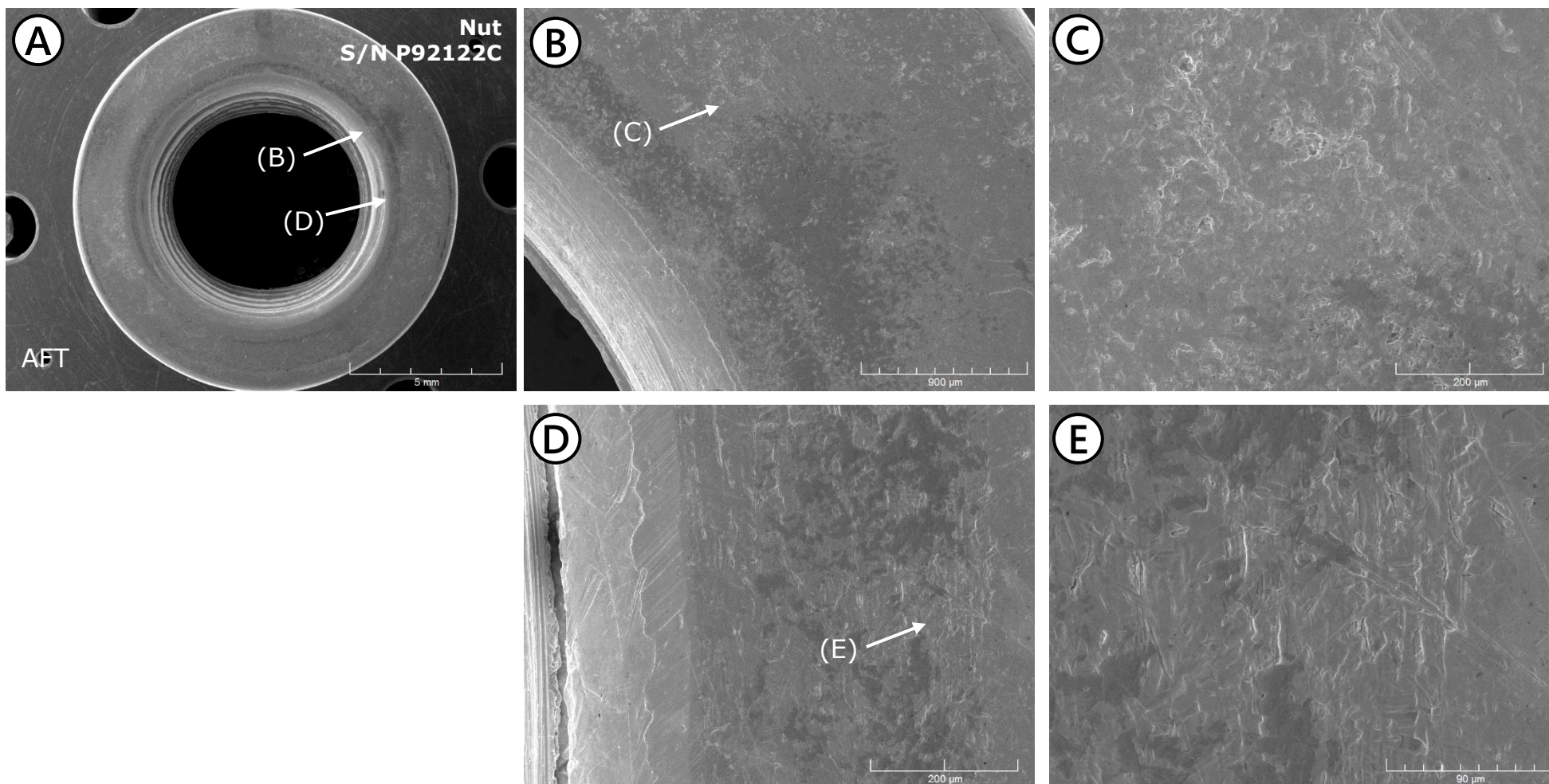


Figure 35.

(A-E) Secondary electron (SE) scanning electron microscope (SEM) images showing the condition of the aft surface of the nut from TPE331 engine S/N P92122C. The surface condition appeared matted and no clear wear directionality was observed.

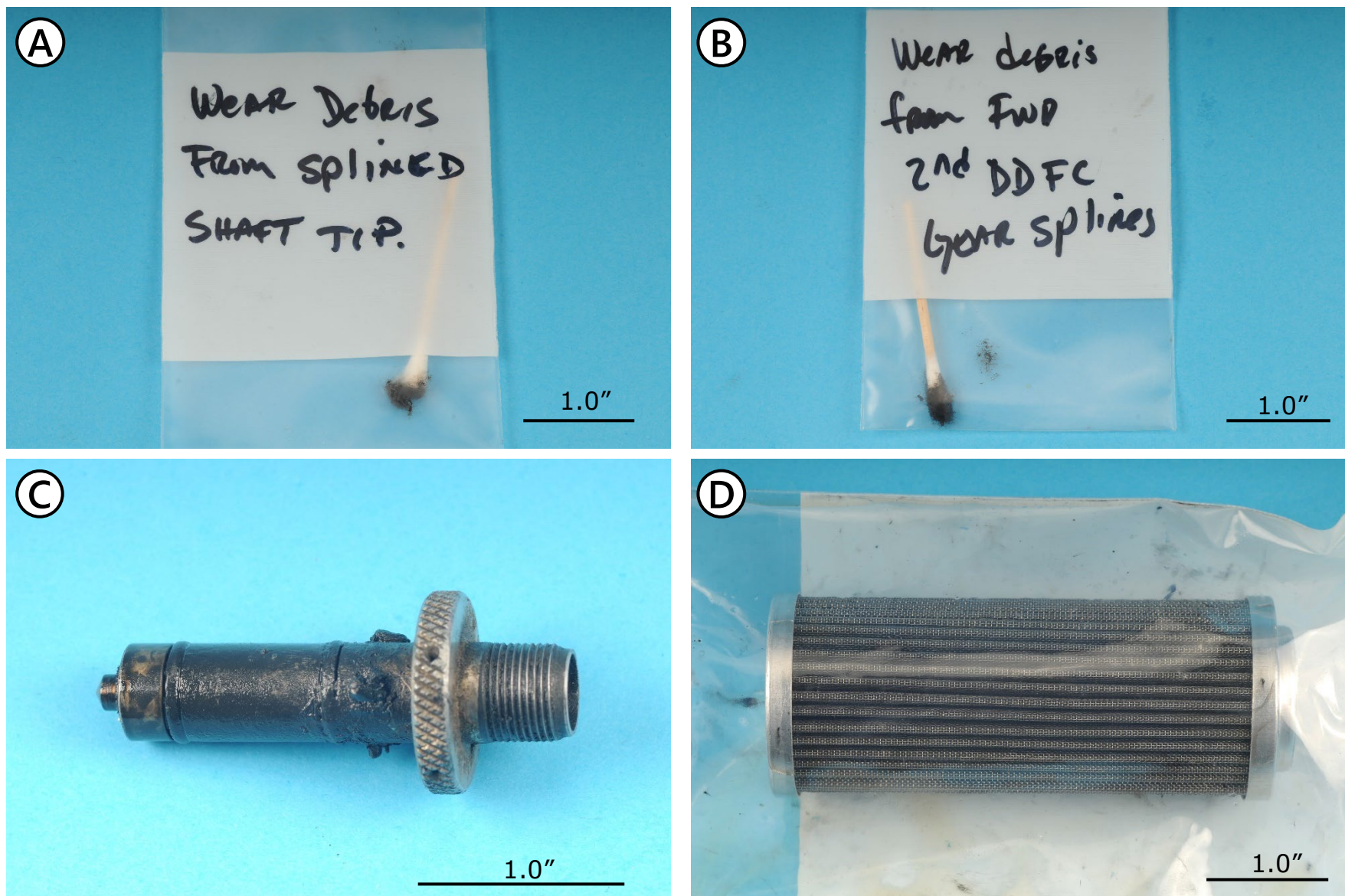


Figure 36.

Overall images showing the submitted debris captured from the (A) splined shaft tip and (B) forward 2nd direct drive fuel control (DDFC) gear splines from TPE331 engine S/N P92122C. Overall images showing the submitted (C) magnetic chip detector and (D) oil filter from TPE331 engine S/N P92122C. SEM images of representative debris removed from each sample/component are shown in Figures 37-41.

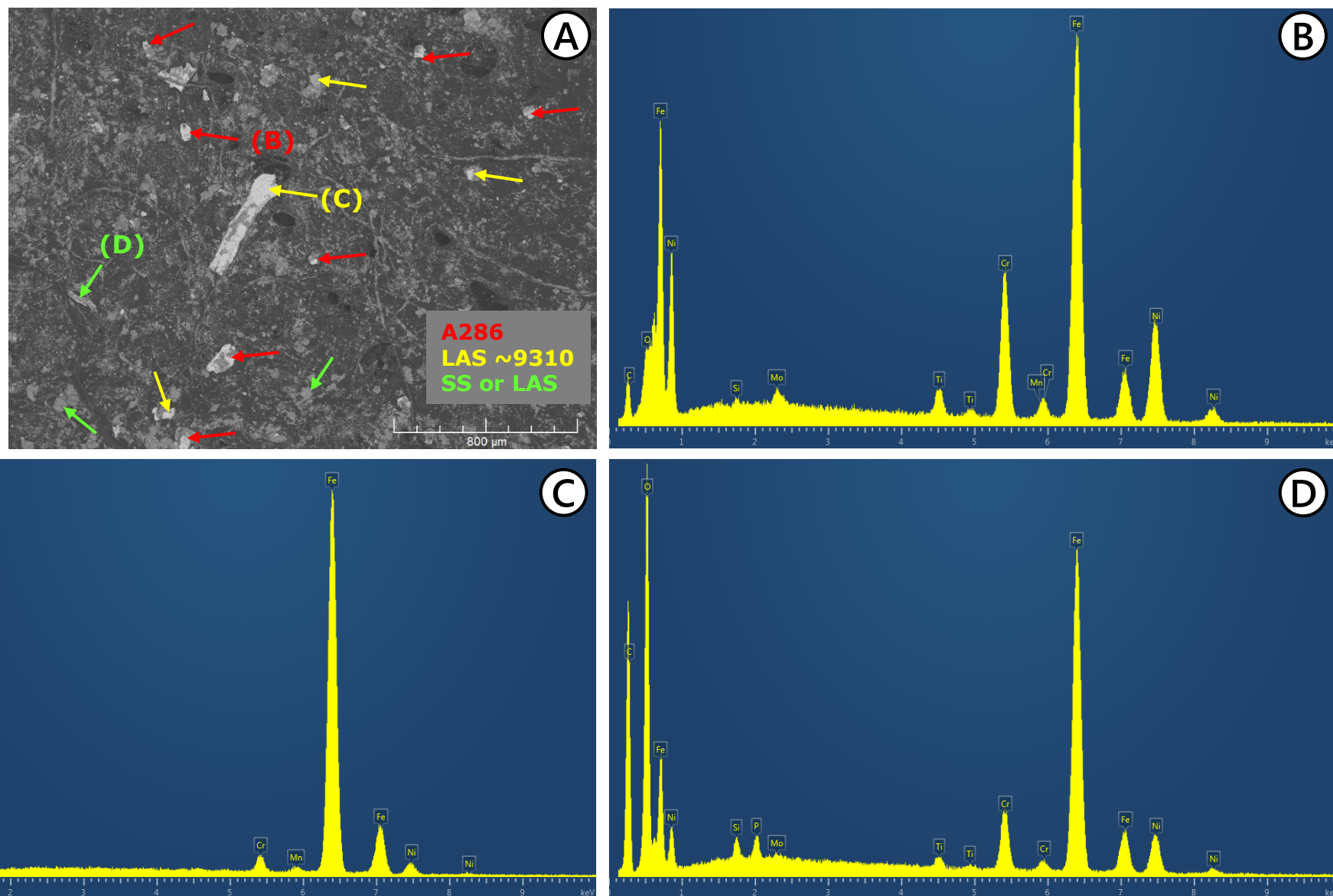


Figure 37.

(A) Backscattered electron (BSE) SEM image showing representative debris collected from the splined shaft tip (reference Figure 36A). (B-D) Energy dispersive X-ray (EDX) spectra produced from the areas identified by the red, yellow and green arrows in (A). The spectrum in (B) was indicative of a stainless steel similar to A286. The spectrum in (C) was indicative of a low alloy steel (LAS) similar to 9310. The spectrum in (D) was suggestive of an oxidized stainless steel or low alloy steel.

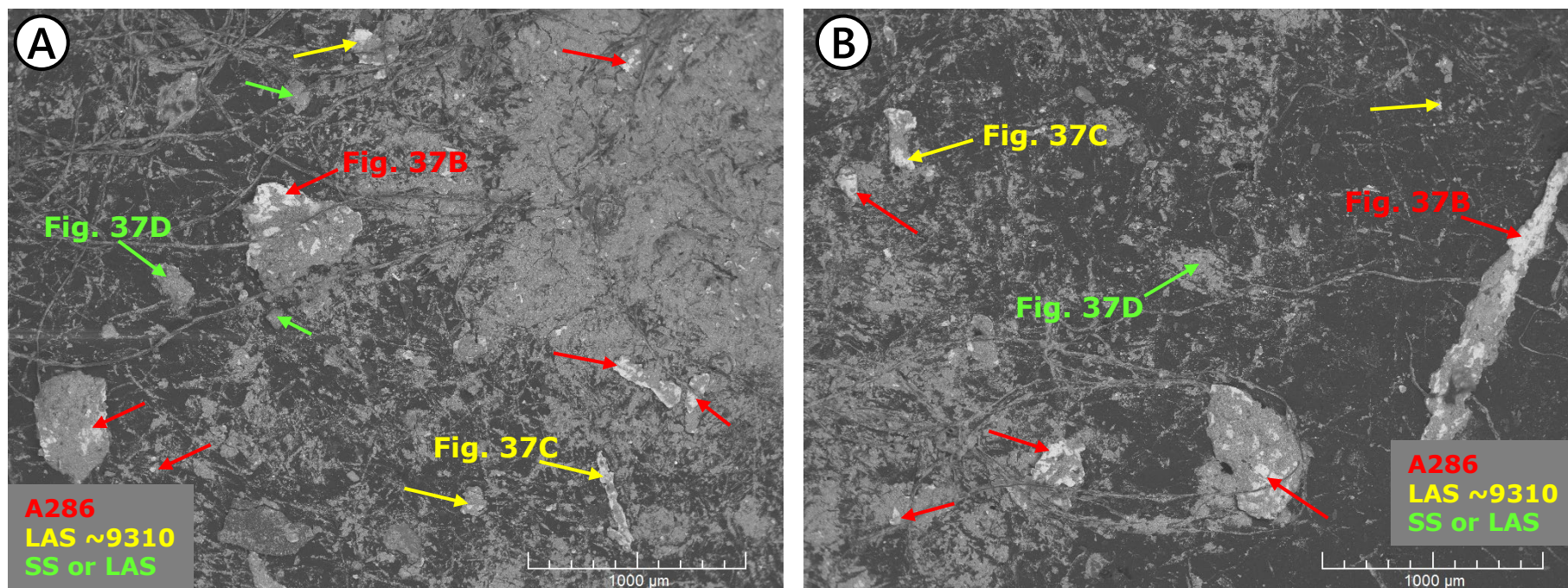


Figure 38.

(A-B) BSE SEM image showing representative debris collected from the forward 2nd DDFC gear splines (reference Figure 36B). The red arrows identify debris indicative of a stainless steel similar to A286. The yellow arrows identify particles indicative of a low alloy steel (LAS) similar to 9310. The green arrows identify particles suggestive of an oxidized stainless steel or low alloy steel. Reference Figure 37 for EDX spectra.

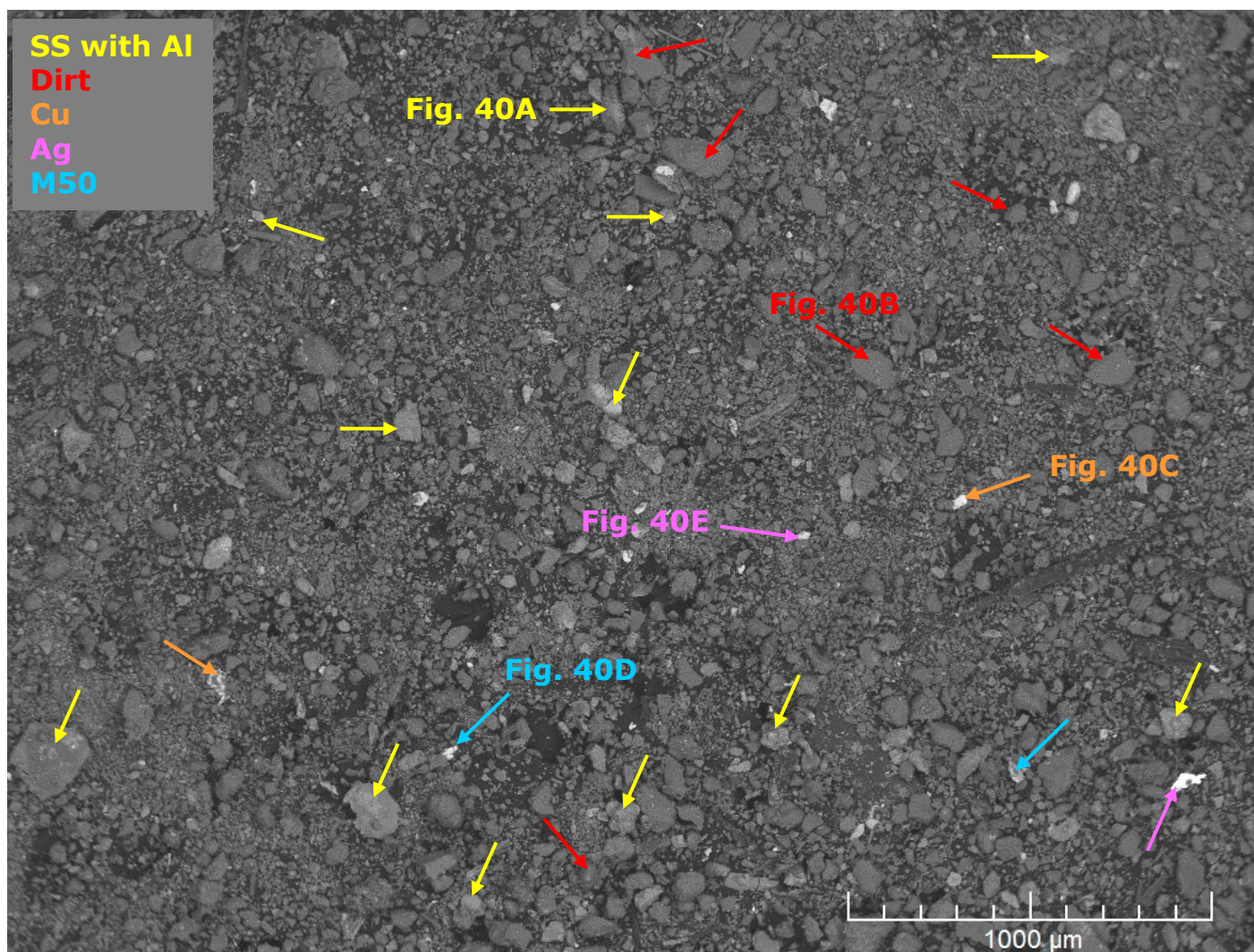


Figure 39.

BSE SEM image showing representative debris collected from the submitted magnetic chip detector (reference Figure 36C). The yellow arrows indicate particles suggestive of a stainless steel (SS) with aluminum oxide. The red and orange arrows indicate particles suggestive of dirt and copper, respectively. The pink and blue arrows indicate particles suggestive of silver and M50 materials, respectively. Reference Figure 40 for representative EDX spectra.

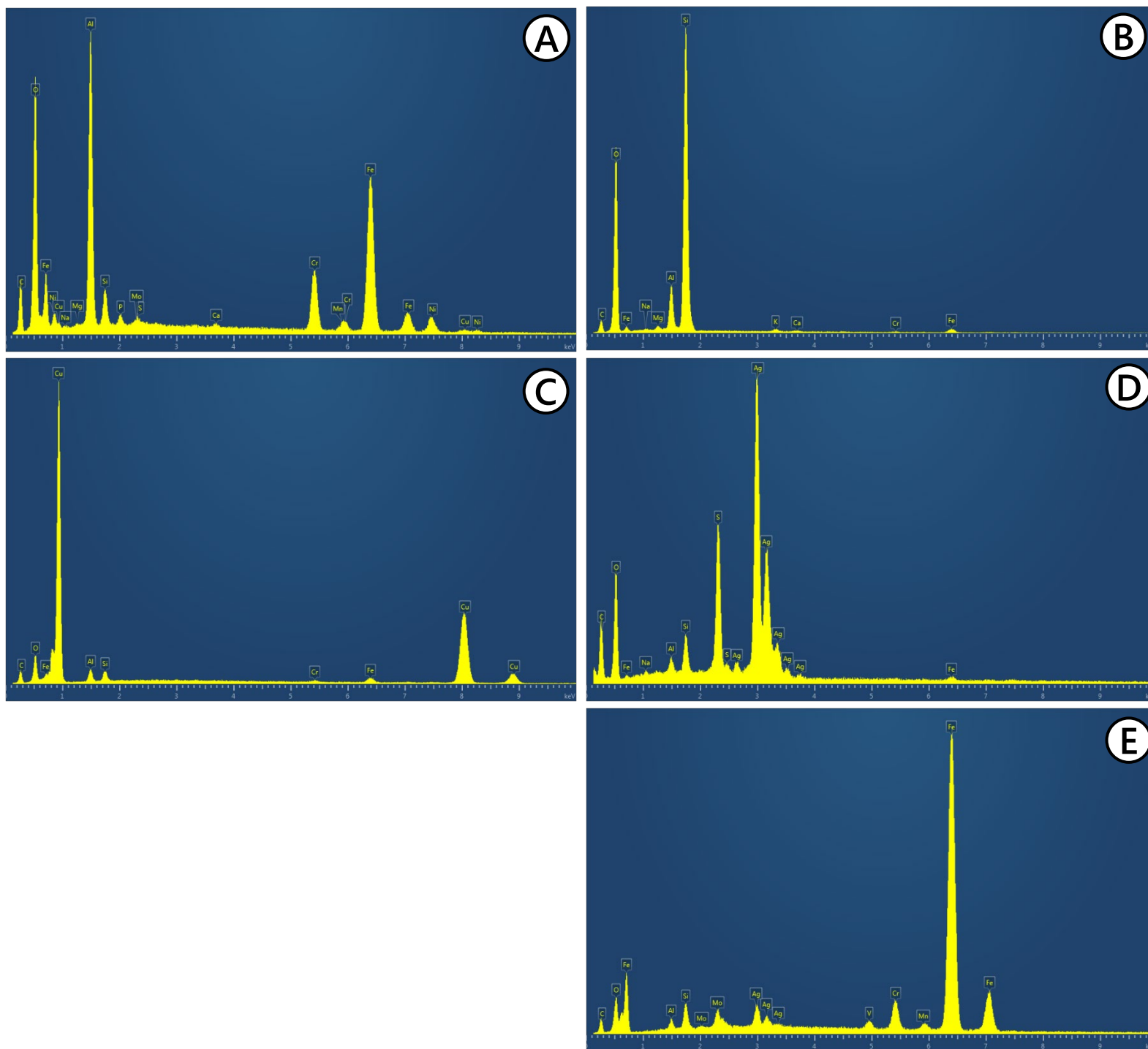


Figure 40. (A-E) Representative EDX spectra produced from analysis of the areas identified in Figure 39. The spectrum in (A) was indicative of aluminum oxide and a stainless steel. The spectrum in (B) was suggestive of dirt. The spectrum in (C) consisted primarily of copper. The spectrum in (D) consisted primarily of silver with sulfur. The spectrum in (E) was indicative of low alloy steel similar to M50 with silver.

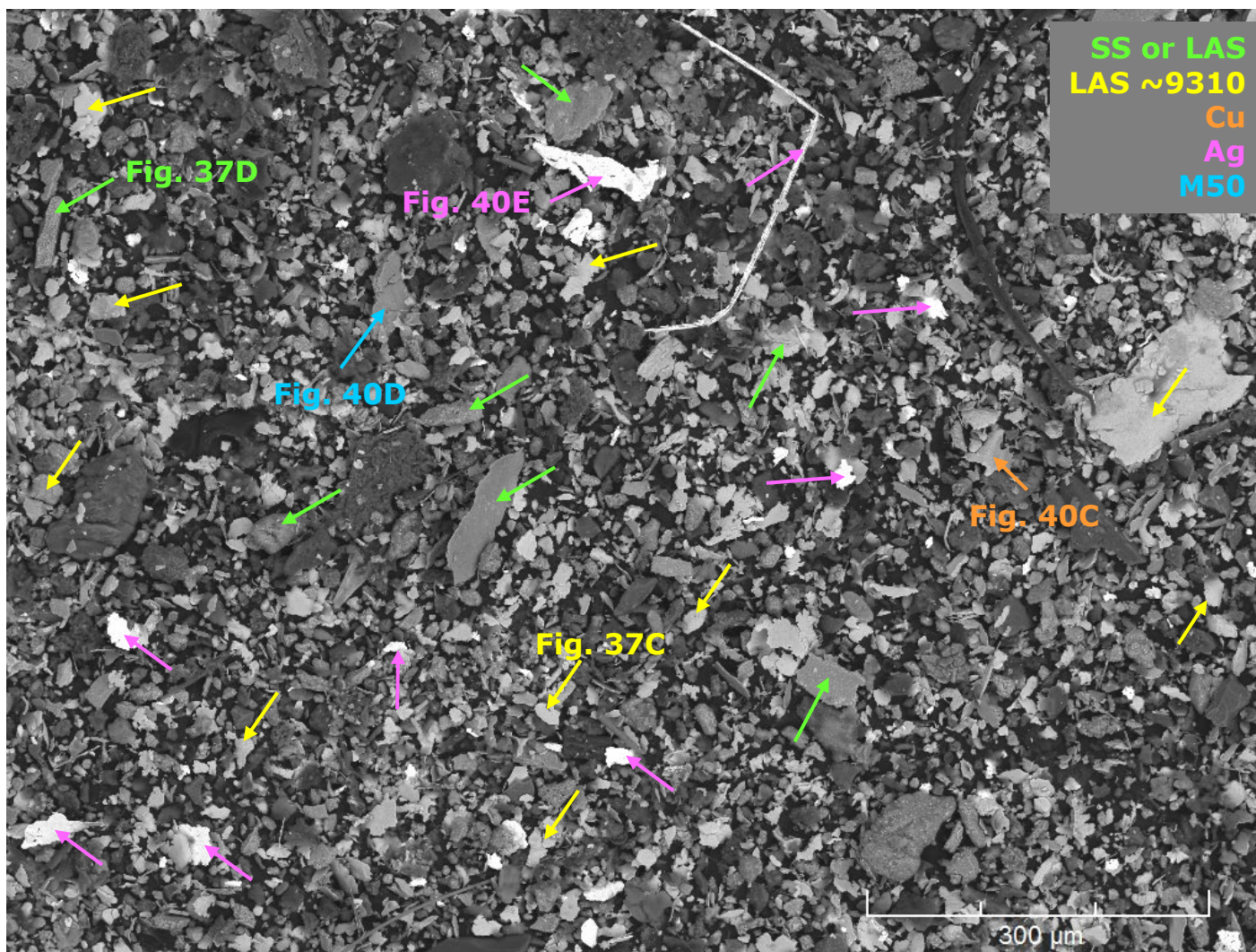


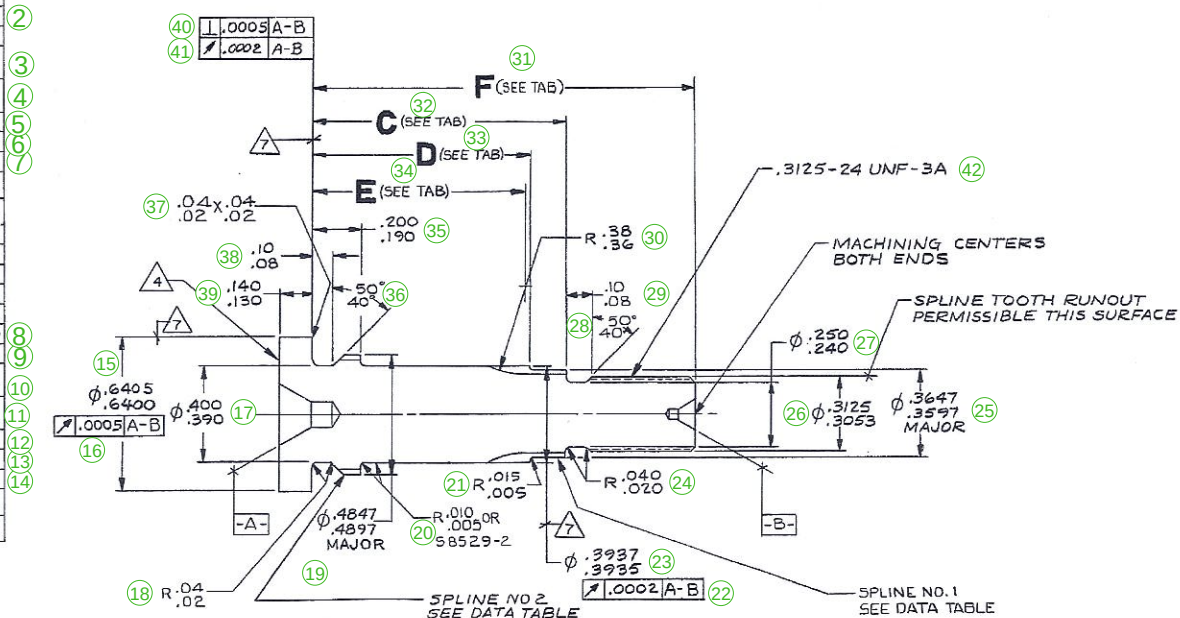
Figure 41.

BSE SEM image showing representative debris collected from the oil filter (reference Figure 36D). The green arrows indicate particles suggestive of a stainless steel (SS) or a low alloy steel (LAS). The yellow and orange arrows identify particles suggestive of low alloy steel similar to 9310 and copper, respectively. The pink and blue arrows indicate particles suggestive of silver and M50 materials, respectively. Reference Figures 37 and 40 for representative EDX spectra.

Appendix A: Shouldered Splined Shaft Dimensional Analysis

EXTERNAL SPLINE DATA NO. 1		
ASA B15 1960	STANDARD INVOLUTE	17 TEETH
DIAMETRAL PITCH	32/64	
PRESSURE ANGLE	30°	
TYPE - FLAT ROOT SIDE FIT	SPECIAL	
MINOR DIAMETER	.2908-.2988	
INVOLUTE FORM DIAMETER	.3096	
MEASUREMENT OVER .060 DIA PINS	.4245 MAX REF .4228 MIN	
CIRCULAR TOOTH THICKNESS WITH GAGE	.0456 MAX EFFECTIVE	
TOOTH PARALLELISM	.0003 A-B	
PITCH DIAMETER	.0015 A-B	
ACTIVE TOOTH PROFILE SURFACE FINISH	AA G3	
MATES WITH	3103406	

EXTERNAL SPLINE DATA NO. 2		
ASA B15 1960	STANDARD INVOLUTE	15 TEETH
DIAMETRAL PITCH	32/64	
PRESSURE ANGLE	30°	
TYPE - FLAT ROOT SIDE FIT	SPECIAL	
MINOR DIAMETER	.4158-.4238	
INVOLUTE FORM DIAMETER	.4314 MAX	
MEASUREMENT OVER .060 DIA PINS	.5509 MAX REF .5491 MIN	
CIRCULAR TOOTH THICKNESS WITH GAGE	.0456 MAX EFFECTIVE	
TOOTH PARALLELISM	.0003 A-B	
PITCH DIAMETER	.0015 A-B	
ACTIVE TOOTH PROFILE SURFACE FINISH	AA G3	
MATES WITH	3103406	



3103405-2 INACTIVE FOR NEW DESIGN AND PROCUREMENT AFTER 990528, USE 3103405-3.

8. INTERPRET MARKING REQUIREMENTS PER MC9014. APPLY INSPECTION AND TEST MARKING PER MC9014.

7. SURFACE MAY BE CHROME PLATED PER EMS 52443 .0001 TO .0005 THICK OR QQ-C-320, CLASS 2, .002 TO .005 THICK, WITHIN 4 HOURS AFTER PLATING, BAKE IN AIR AT 275°-300° F FOR 6 HOURS MINIMUM.

6. NO MATERIAL SUBSTITUTIONS AUTHORIZED WITHOUT PRIOR ENGINEERING APPROVAL.

5. MAGNETIC PARTICLE INSPECT PER EMS 52308, CLASS I.

4. MARK WITH INFORMATION SHOWN WITHIN THE QUOTES PER AS478-7A1 OR -7A2, EXCEPT DEPTH .001 MAX: ZONE CG "99193-3103405-X" WHERE X IS THE APPLICABLE DASH NUMBER.

3. SURFACE ROUGHNESS 125 MICROINCHES ALL OVER.

2. SIMILAR TO 3103163.

1. DRAWING INTERPRETATION PER SC6500.

11	X	-	-	TAB	C=1.135-1.155 D=.985-.995 E=.955-.995 F=1.534-1.540																																								
-	X	-	-	TAB	C=1.135-1.155 D=.985-.995 E=.955-.995 F=1.61-1.63																																								
-	-	X	-	TAB	C=1.06-1.08 D=.910-.920 E=.88-.92 F=1.61-1.63																																								
<table border="1"> <tr> <td>QUANTITY REQD</td><td>1</td><td>3103405-TAB</td><td>SHAFT</td><td>CRES, A286, AMS 5737</td></tr> <tr> <td>FINO NO</td><td></td><td>PART NO OR IDENTIFYING NO</td><td>SYM</td><td>NOMENCLATURE OR DESCRIPTION</td></tr> <tr> <td>DASH NUMBER</td><td>1-3-2-1</td><td></td><td></td><td></td></tr> </table>						QUANTITY REQD	1	3103405-TAB	SHAFT	CRES, A286, AMS 5737	FINO NO		PART NO OR IDENTIFYING NO	SYM	NOMENCLATURE OR DESCRIPTION	DASH NUMBER	1-3-2-1																												
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0	99193	3103405	SHAFT, SHOULDERED, SPLINED																																										
SCALE 4/1			SHEET 1 OF 1																																										

BUBBLE NUMBER	DIMENSIONAL REQUIREMENT	DIMENSIONAL RESULTS	METHOD
1	3103405	- 3 REQUIREMENTS	
1.1	TABS	C / D / E / F	
2	MINOR DIAMETER .2908 - .2988	0.2977	GEAR CHART
3	MEASUREMENT OVER .060 DIA PINS .4228 MIN	0.4241	GEAR CHART
4	CIRCULAR TOOTH THICKNESS WITH GAGE .0456 MAX	UNABLE TO VERIFY DUE TO DAMAGE	
5	TOOTH PARALLELISM // .0003 A-B	LEFT .00007 / RIGHT -.00144	GEAR CHART
6	PITCH DIAMETER  .0015 A-B	0.0006	GEAR CHART
7	ACTIVE TOOTH PROFILE SURFACE FINISH AA63	63 AA (VISUALLY COMPARISON)	VISUALLY
8	MINOR DIAMETER .4158 - .4238	0.4220	GEAR CHART
9	INVOLUTE FORM DIAMETER .4314 MAX	UNABLE TO VERIFY DUE TO DAMAGE	
10	MEASUREMENT OVER .060 DIA PINS .5491 MIN	0.5470	GEAR CHART
11	CIRCULAR TOOTH THICKNESS WITH GAGE .0456 MAX EFF	UNABLE TO VERIFY DUE TO DAMAGE	
12	TOOTH PARALLELISM // .0003 A-B	LEFT -.00009 / RIGHT .00023	GEAR CHART
13	PITCH DIAMETER  .0015 A-B	0.0012	GEAR CHART
14	ACTIVE TOOTH PROFILE SURFACE FINISH AA63	32AA (VISUALLY COMPARISON)	VISUALLY
15	DIAMETER .6400 - .6405	0.6401	0-1 MICROMETER
16	RUNOUT  .0005 A-B	<.0001	CENTERS AND DIAL INDICATOR
17	DIAMETER .390 - .400	0.4952	0-1 BLADE MICROMETER
18	RADIUS .02 - .04	0.0300	OPTICAL COMPARATOR
19	MAJOR DIAMETER .4847 - 4897	0.4853	CMM
20	RADIUS .005 - .010	0.0088	TRACER
21	RADIUS .005 - .015	0.0093	TRACER
22	RUNOUT  .0002 A-B	0.0002	CENTERS AND DIAL INDICATOR
23	DIAMETER .3935 - .3937	0.3933	0-1 MICROMETER
24	RADIUS .020 - .040	.0298 / .0337	TRACER
25	DIAMETER MAJOR .3597 - .3647	UNABLE TO VERIFY DUE TO DAMAGE	
26	DIAMETER .3053 - .3125	OUT OF ROUND 0.3017 - .3055 (LEADING THREAD .3065)*	0-1 MICROMETER
27	DIAMETER .240 - .250	0.2445	0-1 BLADE MICROMETER
28	ANGLE 40 - 50°	UNABLE TO VERIFY DUE TO DAMAGE	
29	LINEAR DIMENSION .08 - .10	UNABLE TO VERIFY DUE TO DAMAGE	
30	RADIUS .36 - .38	0.3777	TRACER
31	(TAB) -3 F = 1.534 -1.540	1.5402	OPTICAL COMPARATOR
32	(TAB) -3 C = 1.135 - 1.155	UNABLE TO VERIFY DUE TO DAMAGE	
33	(TAB) -3 D = .985 - .995	0.9916	OPTICAL COMPARATOR
34	(TAB) -3 E = .955 - .995	0.9501*	OPTICAL COMPARATOR
35	LINEAR DIMENSION .190 - .200	0.1983	OPTICAL COMPARATOR
36	ANGLE 40 - 50°	46°30'	OPTICAL COMPARATOR
37	CHAMFER .04/.02 X .040/.02	.0296 X .0253	TRACER
38	LINEAR DIMENSION .08 - .10	0.0814	TRACER
39	LINEAR DIMENSION .130 - .140	0.1365	OPTICAL COMPARATOR
40	PERPENDICULARITY  .0005 A-B	0.0001	CENTERS AND DIAL INDICATOR
41	RUNOUT  .0002 A-B	0.0006	CENTERS AND DIAL INDICATOR
42	THREADS .3125 - 24 UNF -3A	WILL NOT ACCEPT THREADS*	THREAD RING GAGE SN G250313E

*FEATURE DAMAGED