

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594



July 21, 2020

MATERIALS LABORATORY FACTUAL REPORT

Report No. 19-009

A. ACCIDENT INFORMATION

Place : Roll, Arizona
Date : January 19, 2019
Vehicle : Hill Group LLC CCX-2000, N57FX
NTSB No. : WPR19LA070
Investigator : Joshua Cawthra, ASI-WPR

B. COMPONENTS EXAMINED

Components from an Aero Sport Power CC363i 4-cylinder engine, ESN: CC363i-1002, Total Engine Time Since New: 77.3 hours;

1. Superior Air Parts Crankshaft fractured in 2 pieces, P/N: SL36650C, S/N: TA06B-000322, manufactured in 2006;
2. Superior Air Parts Crankcase Assembly (2 halves), P/N: SX36850-R3, S/N: 2334D02;
3. Superior Air Parts bearing shells:
 - a. MID and AFT main bearings, P/N: SL16711A F, Lot: 06-16;
 - b. FWD main bearing, P/N: SL13B84A D, Lot: 06-16.
4. Connecting rod assemblies from numbers 3 and 4 cylinders.

C. DETAILS OF THE EXAMINATION

A crankshaft fractured in two pieces was submitted to the NTSB Materials Laboratory for examination along with the two crankcase halves, the bearing shells, and the connecting rod assemblies for the numbers 3 and 4 cylinders (still attached to the crankshaft), as shown in figures 1 – 3. The cylinder positions and connecting rod journals were numbered starting at the front end and increased in number toward the aft end. Using this numbering system, the crankshaft was fractured at the aft end of the number 3 connecting rod bearing journal at the transition radius to the counterweight assembly as seen in figures 1 and 4. The fracture surface was examined using a stereo binocular microscope and the fracture was observed to be comparatively flat with radial lines and curved crack progression marks that were consistent with fatigue crack progression. Examination of the origin area indicated that the crack originated at the surface at the location indicated in figure 4b. As seen in the images, with the crankshaft clocked with the number 3 connecting rod journal at the 12 o'clock position, the origin was approximately at the 6 o'clock position on the journal itself. The journal surface at the fracture origin was examined for any notable features but none were found. Other areas around the origin exhibited rubbing and deformation consistent with damage after

separation of the crankshaft into two pieces. The main bearing and connecting rod bearing journal diameters were measured using a micrometer at 45° intervals as shown in table 1. All journal diameters were within the required limits on the engineering drawing.

The numbers 3 and 4 connecting rods were disassembled and the bearing shells were examined visually. The number 3 connecting rod and endcap are shown in figure 5 and the yoke and endcap bearing surfaces are shown in figures 6a and 6b, respectively. The aft face of the yoke and endcap exhibited mechanical and thermal damage. Similarly, the aft ends of the bearing shells were mechanically damaged and discolored and the shells had been displaced forward from the installed position. The features were consistent with damage after the separation of the crankshaft.

The main bearing shells were also examined visually. For convenience, the main bearings were also numbered starting at the front of the engine and increasing toward the aft end. The end faces of the number 3 main bearing shells (aft end of engine) are shown in figures 7a – d. For comparison, images of one of the number 2 main bearing shells (mid-engine) are shown in figures 8a and b. The number 3 main bearing shell end faces exhibited a comparatively shiny appearance with spots of disturbed material, consistent with polishing and galling. The end face of the right side insert tang in figure 7a also exhibited a polished appearance. By comparison, the end faces of the number 2 main bearing shells exhibited a machined surface finish with spots of polishing. The backsides of the number 3 shells, shown in figure 3b, exhibited a black appearance where in contact with the saddle whereas the other shells exhibited a silver metallic appearance in similar areas.

The crankcase main bearing saddle boss landings similarly exhibited differences in their surface condition. The number 3 boss landings, shown for the left crankcase half in figures 9a and 9b, exhibited polishing of the landings and galling of the forward regions. By contrast the remaining landings exhibited a matte appearance consistent with the machined finish on the as-manufactured case, as shown for one of the number 2 landings in figure 10.

The crankcase halves were sent to a Superior Air Parts facility to measure the following attributes: flatness of the parting line, diameter and roundness of the main bearing saddle bores in the bolted and torqued condition, and concentricity of the saddle bores. These attributes were not measured at the time the crankcase was machined, therefore there were no records to which the results could be compared. The measurements were made on a three-axis coordinate measurement machine (CMM) with an NTSB representative in attendance. The flatness of the right and left halves was 0.00018 inch and 0.00169 inch, respectively. The left half exceeded the requirement of 0.0010 inch on the manufacturer's drawing. The bore diameters measured 2.5664 inch, 2.5666 inch, and 2.5664 inch for bores 1 through 3, respectively and were within the limits on the manufacturer's drawing. The roundness for bores 1 through 3 were 0.00019 inch, 0.00036 inch, and 0.00153 inch, with the number 3 bore exceeding the limit of 0.0010 inch. Finally, the concentricity of the numbers 1 and 2 bores (relative to a

reference datum at the number 3 bore) were 0.0021 inch and 0.0020 inch, respectively, compared to the limit of 0.0010 inch on the engineering drawing.

The bearing shells were also sent to Superior Air Parts for examination. The shells were inspected visually and dimensionally by CMM. The bearing examination report is included in Appendix A of this report.

Finally, the material microstructure of the crankshaft at the journal surface near the fatigue origin was examined by cutting a section of the number 3 connecting rod journal and preparing a metallographic cross section. The forward fracture face is shown in figure 11a with a red dashed line indicating the plane of the cut (in and out of the page). The journal was cut and sectioned using a water-cooled abrasive cutting saw and mounted in resin. The cross sectioned face was ground using silicon carbide papers and polished with a series of diamond and aluminum oxide suspensions in accordance with standard laboratory procedures. The polished face was etched with a 5% solution of nitric acid in methanol (5% Nital) to reveal the material microstructure as shown in figure 11b. The location of the journal bearing surface and the direction toward the fracture face are indicated in the figure. A higher magnification view of the surface is shown in figure 11c. The material at the surface was examined for indications of a white layer but none were found.

Donald Kramer, Ph.D.
Sr. Materials Engineer

Table 1: Main bearing and connecting rod bearing journal diameters as measured by a micrometer in 45° increment. The forward main bearing journal was measured near its forward end (FWD main/fwd) and its aft end (FWD main/aft). The connecting rod journals were numbered starting at the forward end of the crankcase and increasing toward the aft end.

Journal	Diameter 1, inch	Diameter 2, inch	Diameter 3, inch	Diameter 4, inch
AFT main	2.3752	2.3753	2.3753	2.3752
MID main	2.3750	2.3750	2.3750	2.3750
FWD main/aft	2.3750	2.3752	2.3750	2.3751
FWD main/fwd	2.3753	2.3752	2.3752	2.3752
CR 1	2.1243	2.1243	2.1243	2.1244
CR 2	2.1242	2.1243	2.1243	2.1242
CR 3	2.1243	2.1244	2.1243	2.1243
CR 4	2.1244	2.1244	2.1244	2.1243

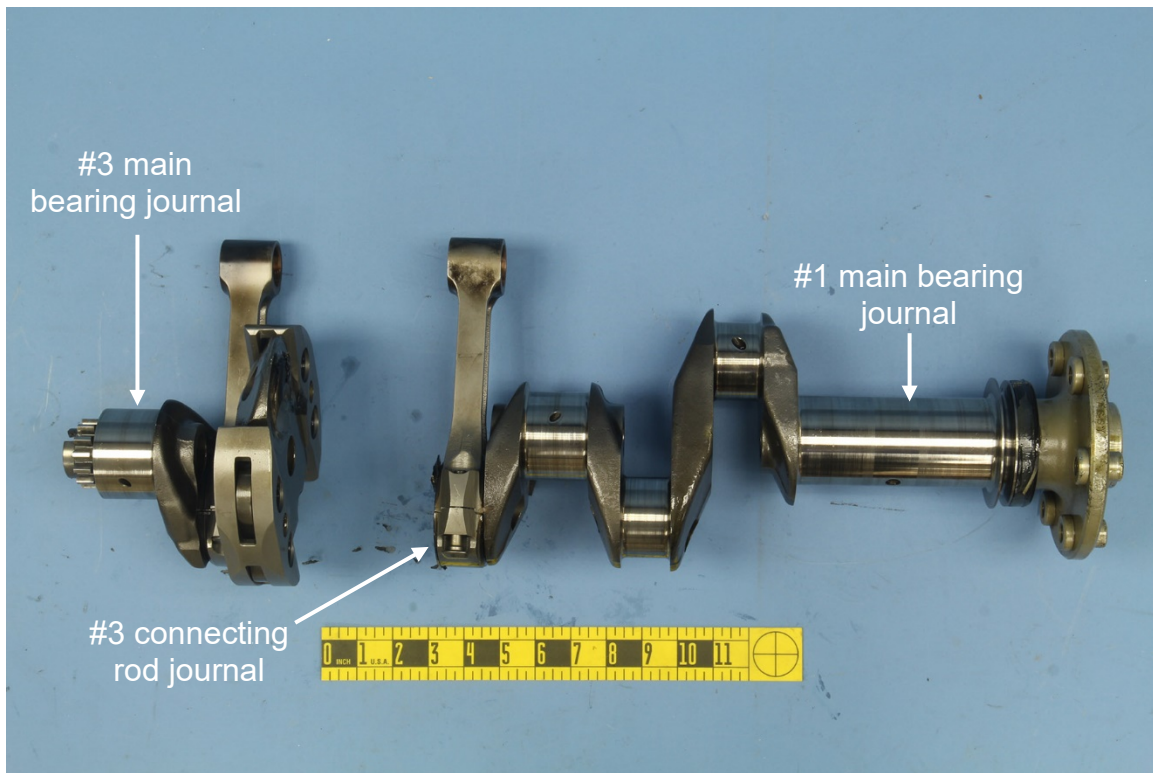
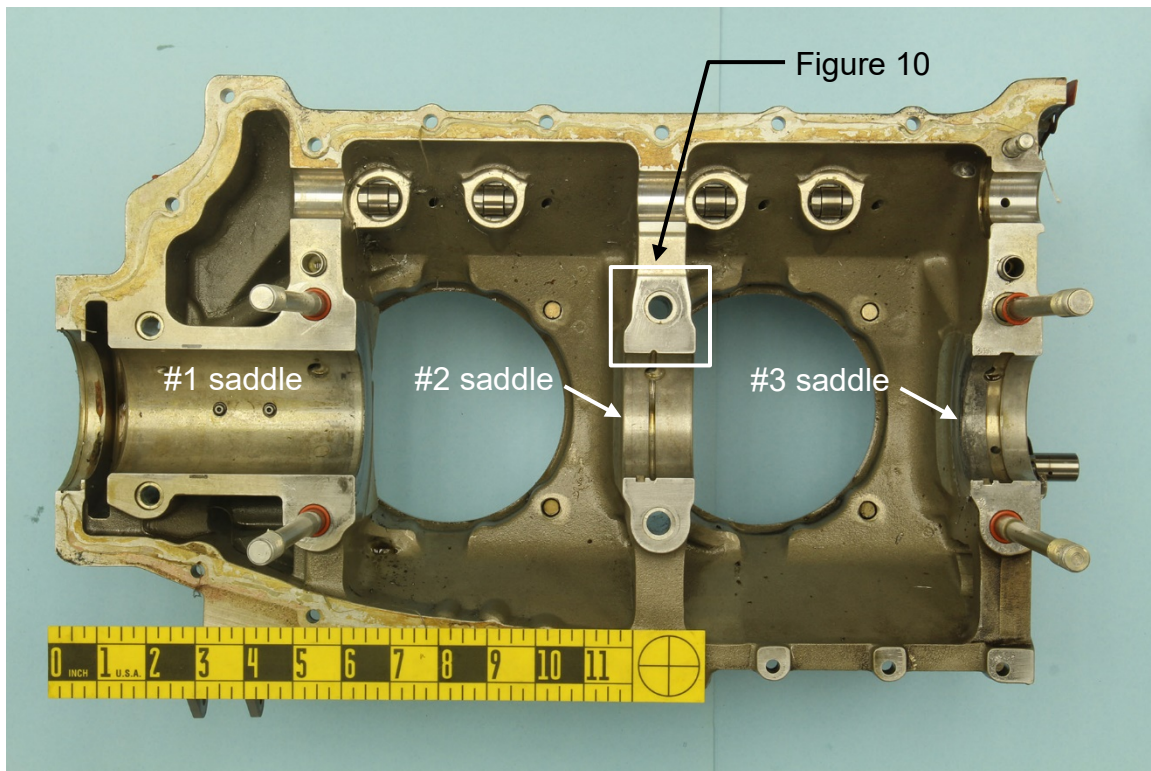
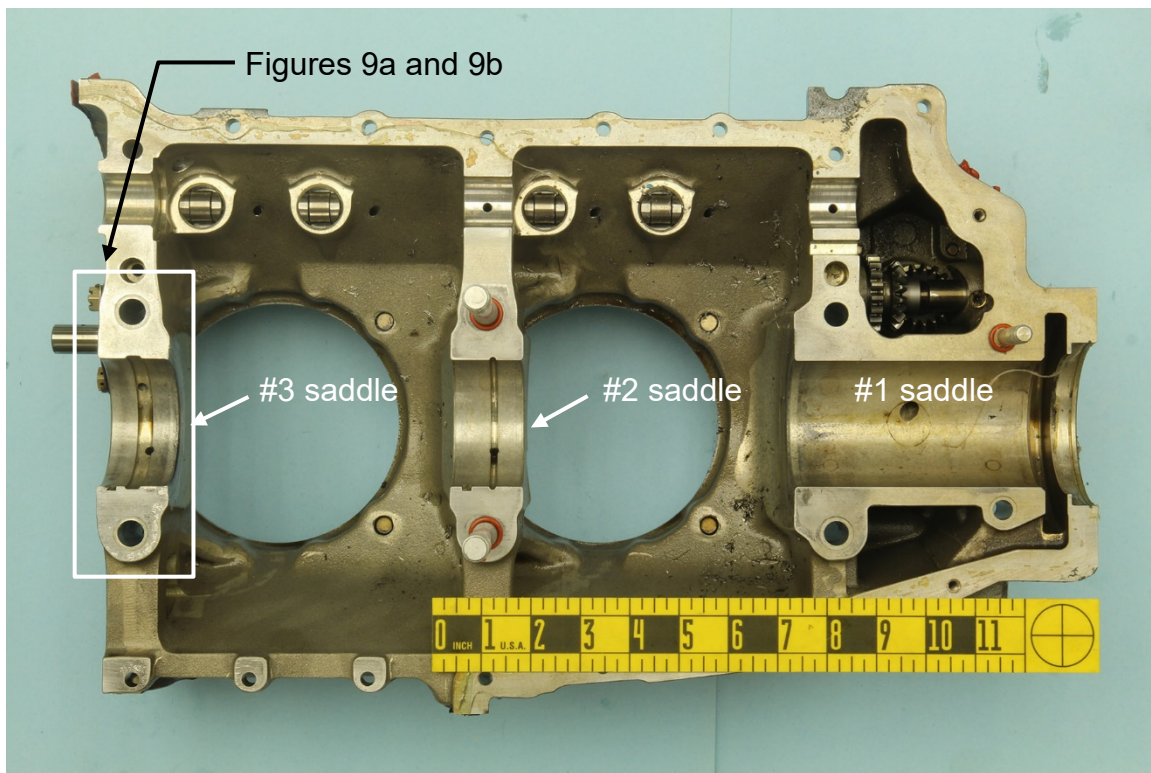


Figure 1: Image of the fractured crankshaft with the numbers 3 and 4 connecting rod assemblies still attached. The crankshaft fractured at the aft end of the number 3 connecting rod bearing.

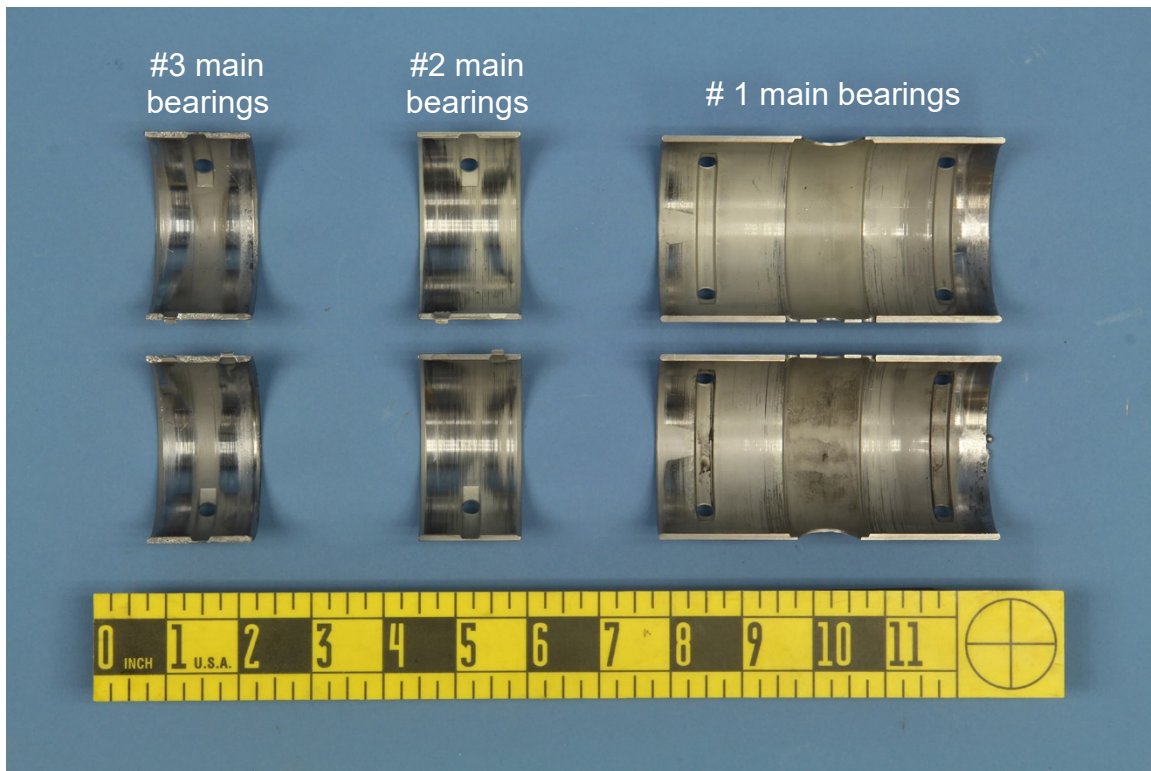


a)



b)

Figure 2: Images of the two crankcase halves: a) right side and b) left side.

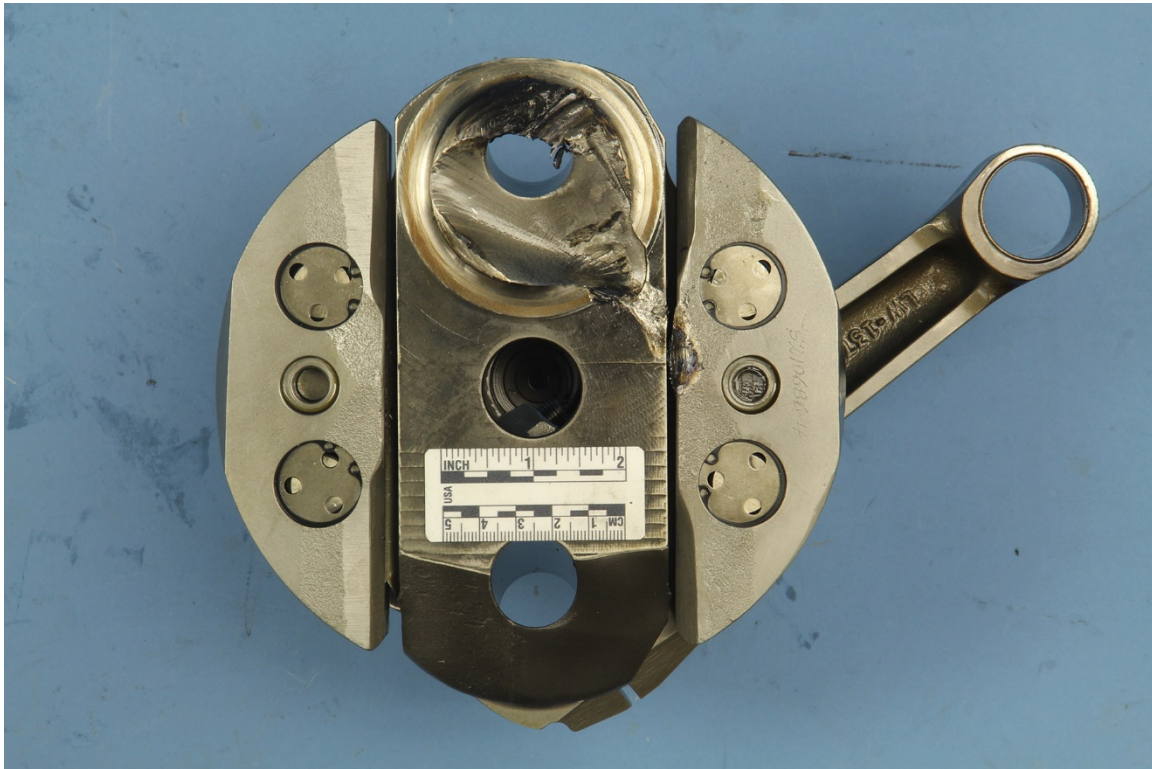


a)

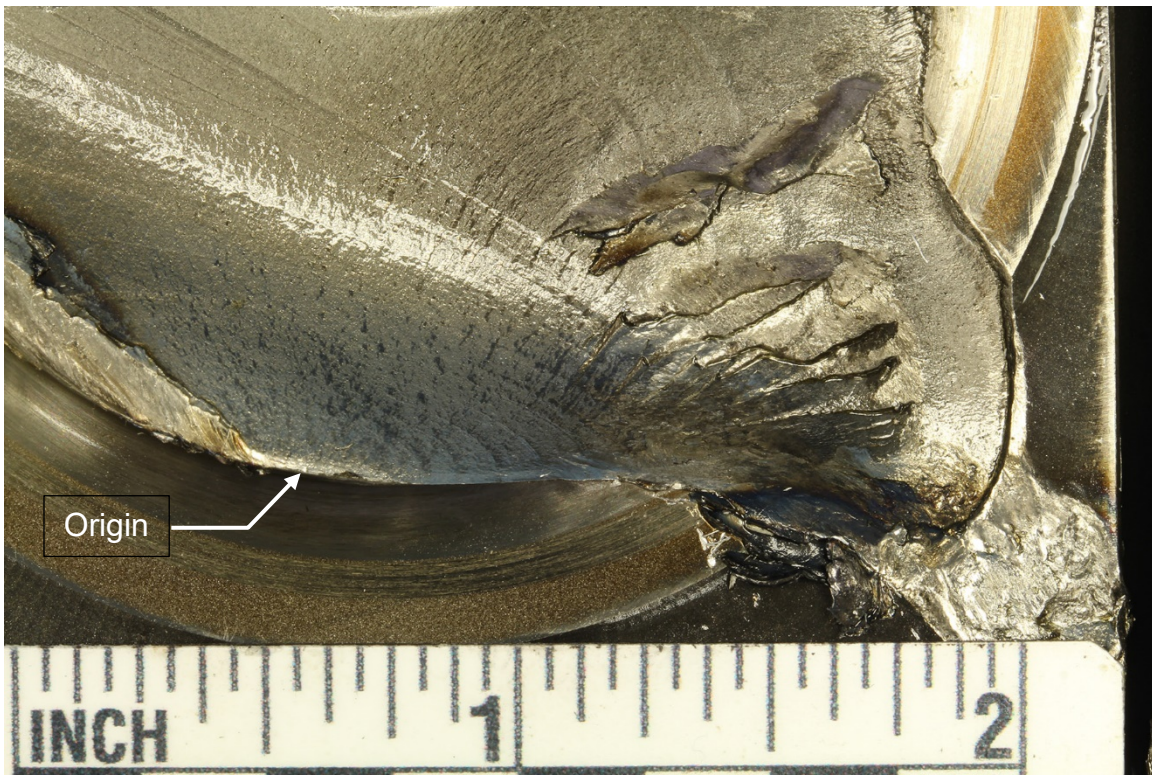


b)

Figure 3: Images of the bearing shells: a) bearing surfaces and b) backsides in contact with the crankcase saddles.



a)



b)

Figure 4: Images of the crankshaft aft fracture face at the aft end of the number 3 connecting rod journal: a) Image showing the counterweight assembly and the fracture surface and b) higher magnification image of the fracture origin area.



Figure 5: Image of the number 3 connecting rod and endcap after removal from the crankshaft.

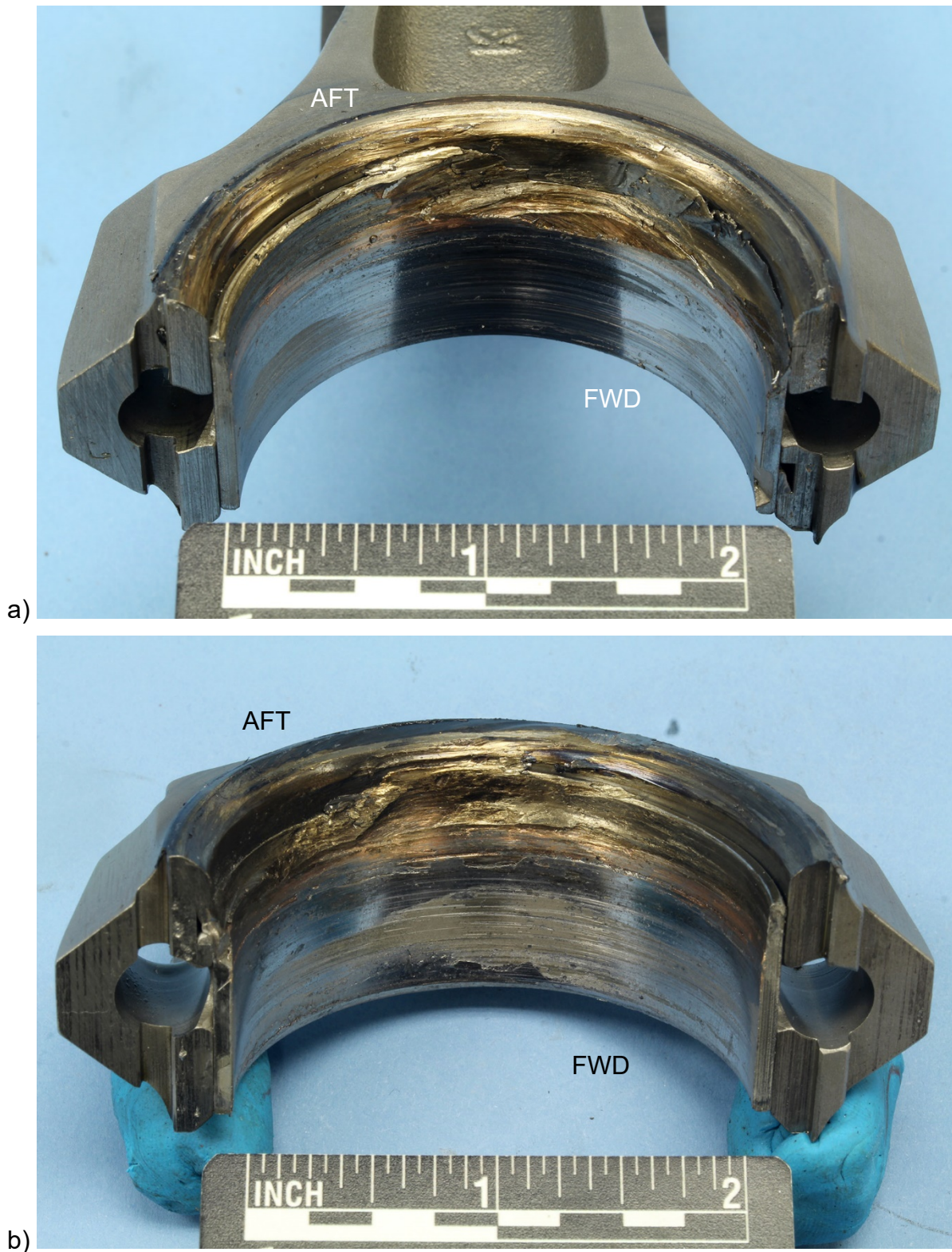


Figure 6: Images of the number 3 connecting rod bearing inserts: a) yoke side and b) endcap side.

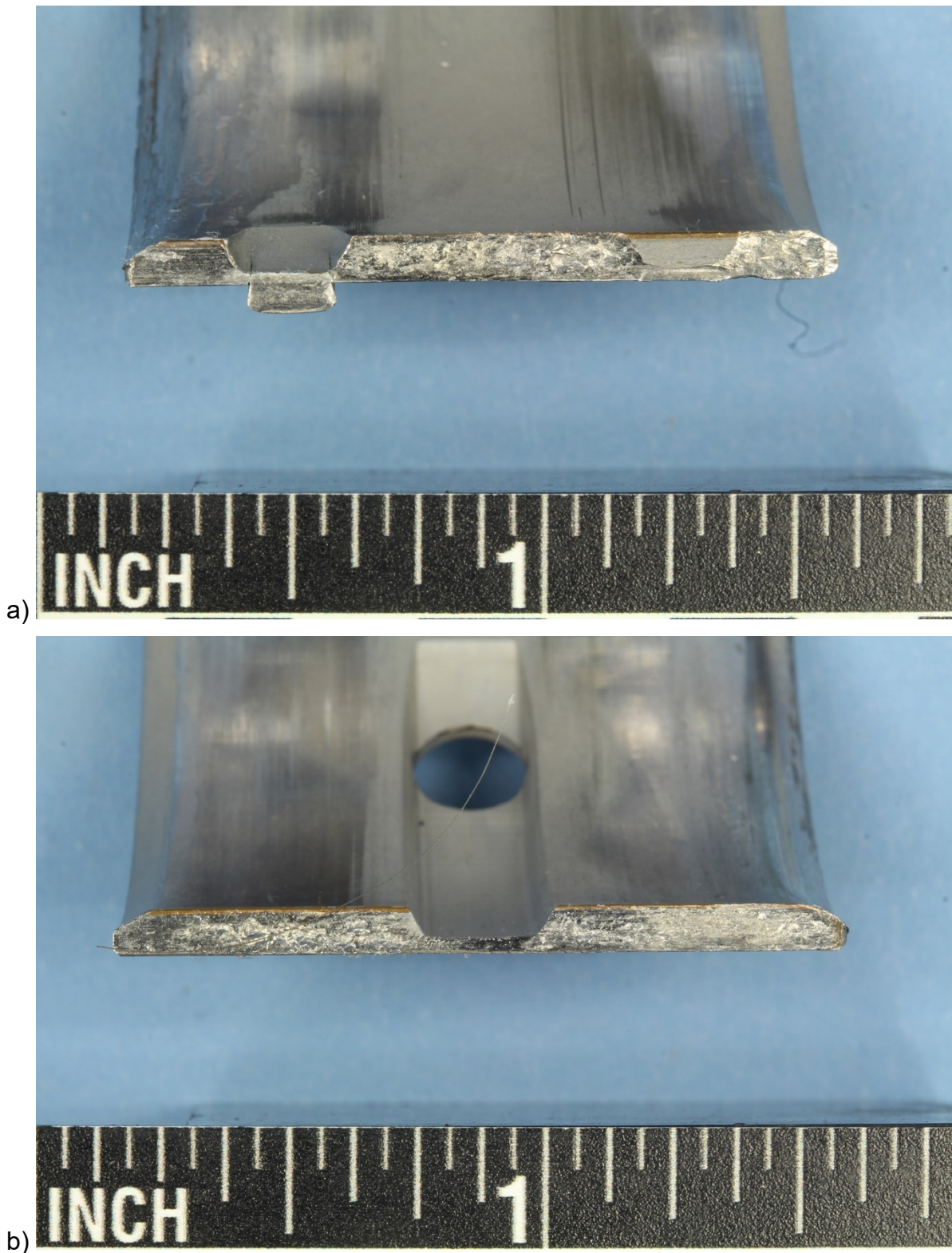


Figure 7: Images of the number 3 (aft) main bearing shell end faces showing galling and rubbing damage: a) right-side insert – tang end; b) right-side insert – flat end;

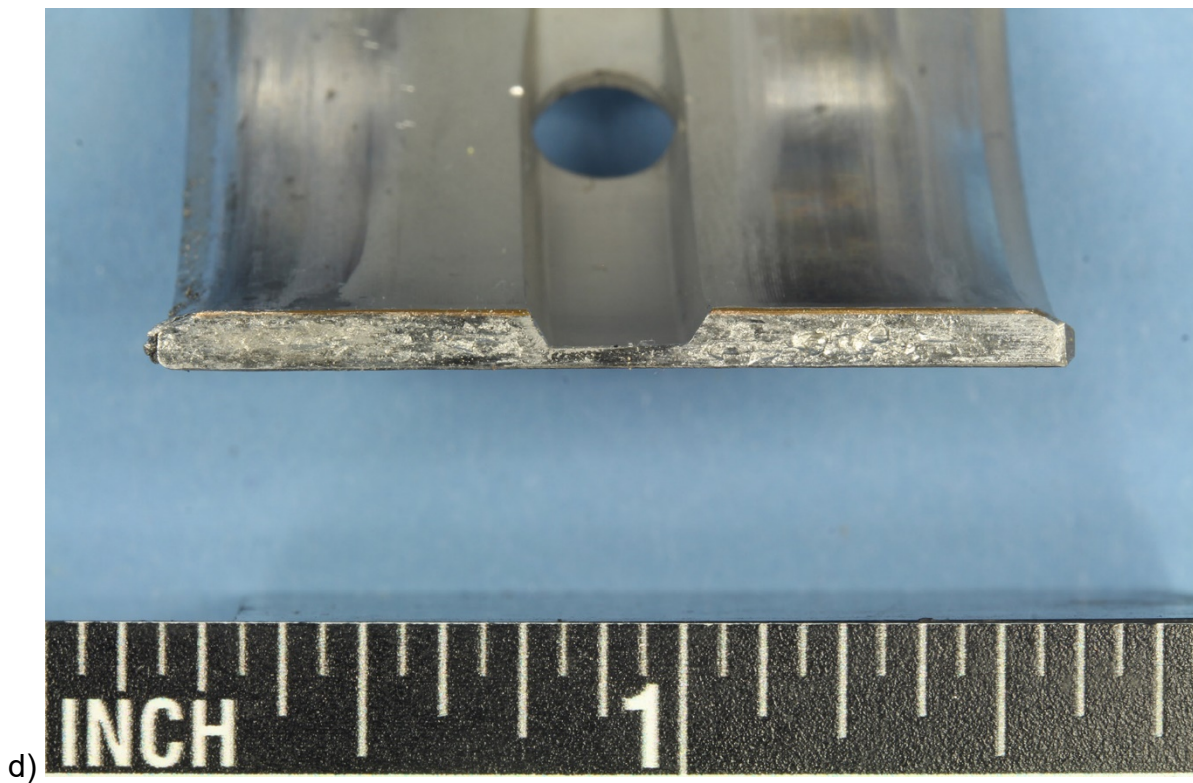
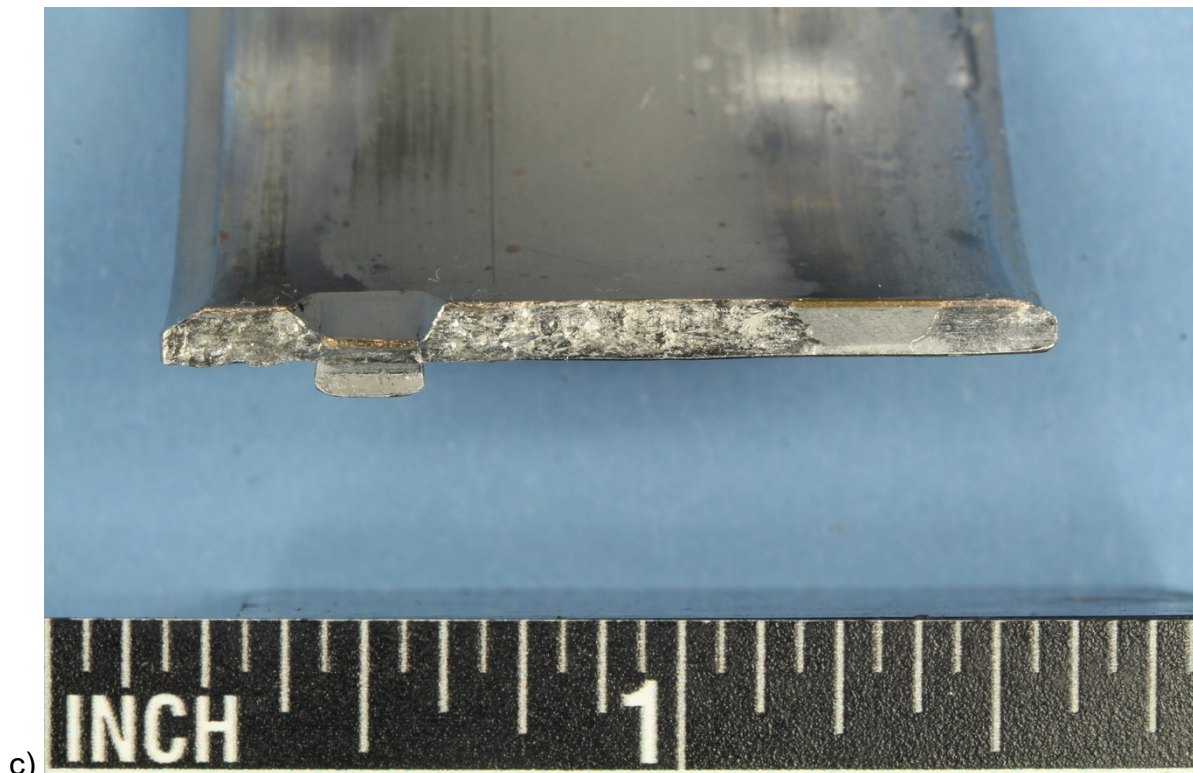


Figure 7 (cont.): c) left-side insert – tang end; and d) left-side insert – flat end.

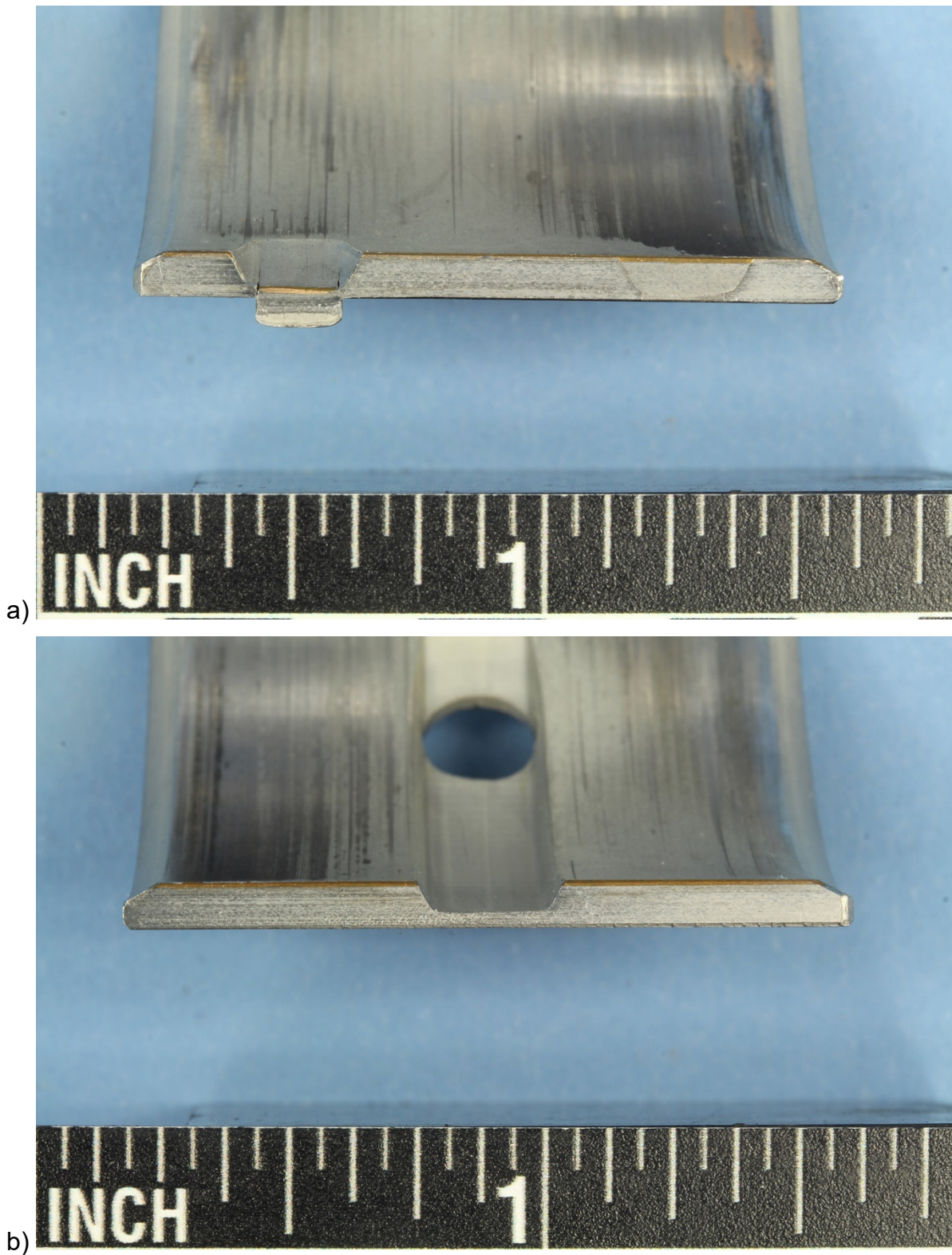


Figure 8: Images of the number 2 (mid) main bearing right-side shell end faces: a) tang end and b) flat end.

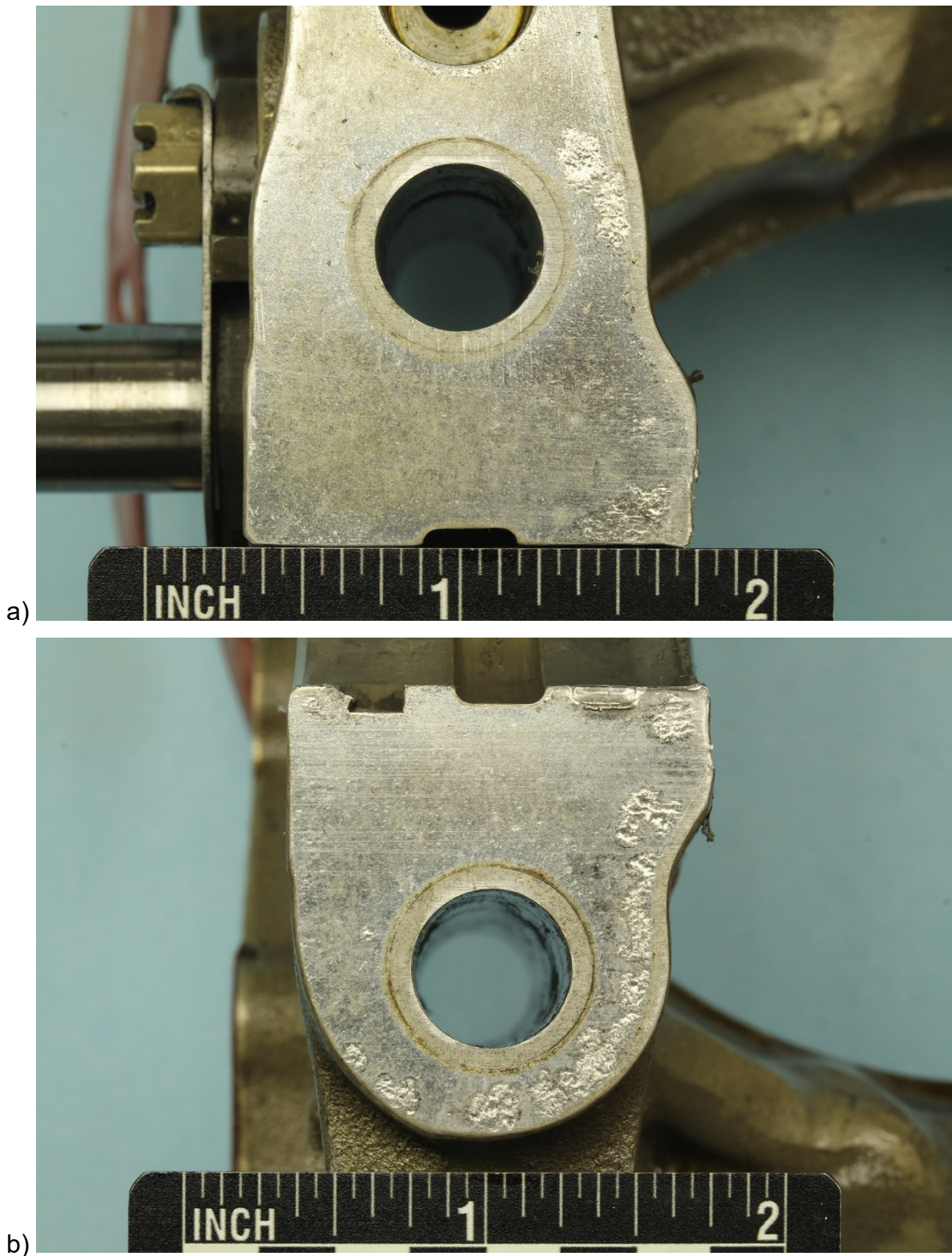


Figure 9: Images of the crankcase left-side aft saddle boss landings (see figure 2b). The landings exhibited features consistent with polishing and galling: a) upper landing and b) lower landing.

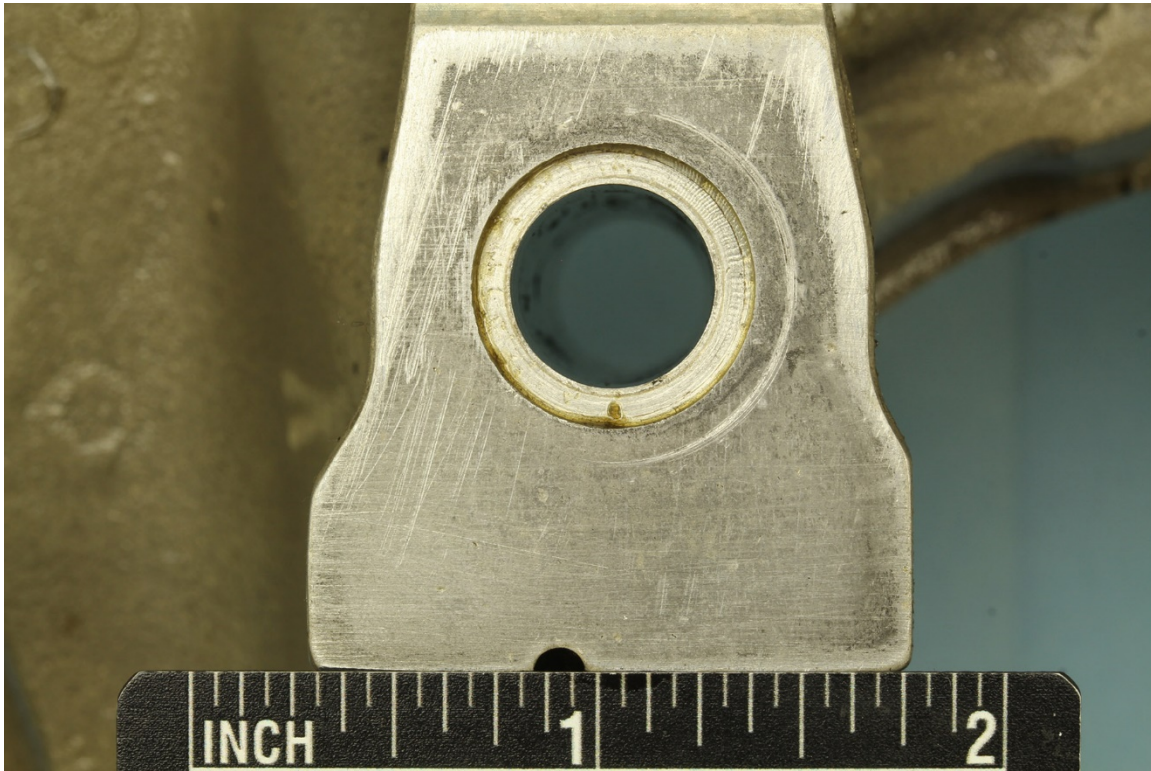


Figure 10: Image of the crankcase right-side number 2 (mid) upper landing. The landing had a matte appearance, consistent with a machined surface finish.

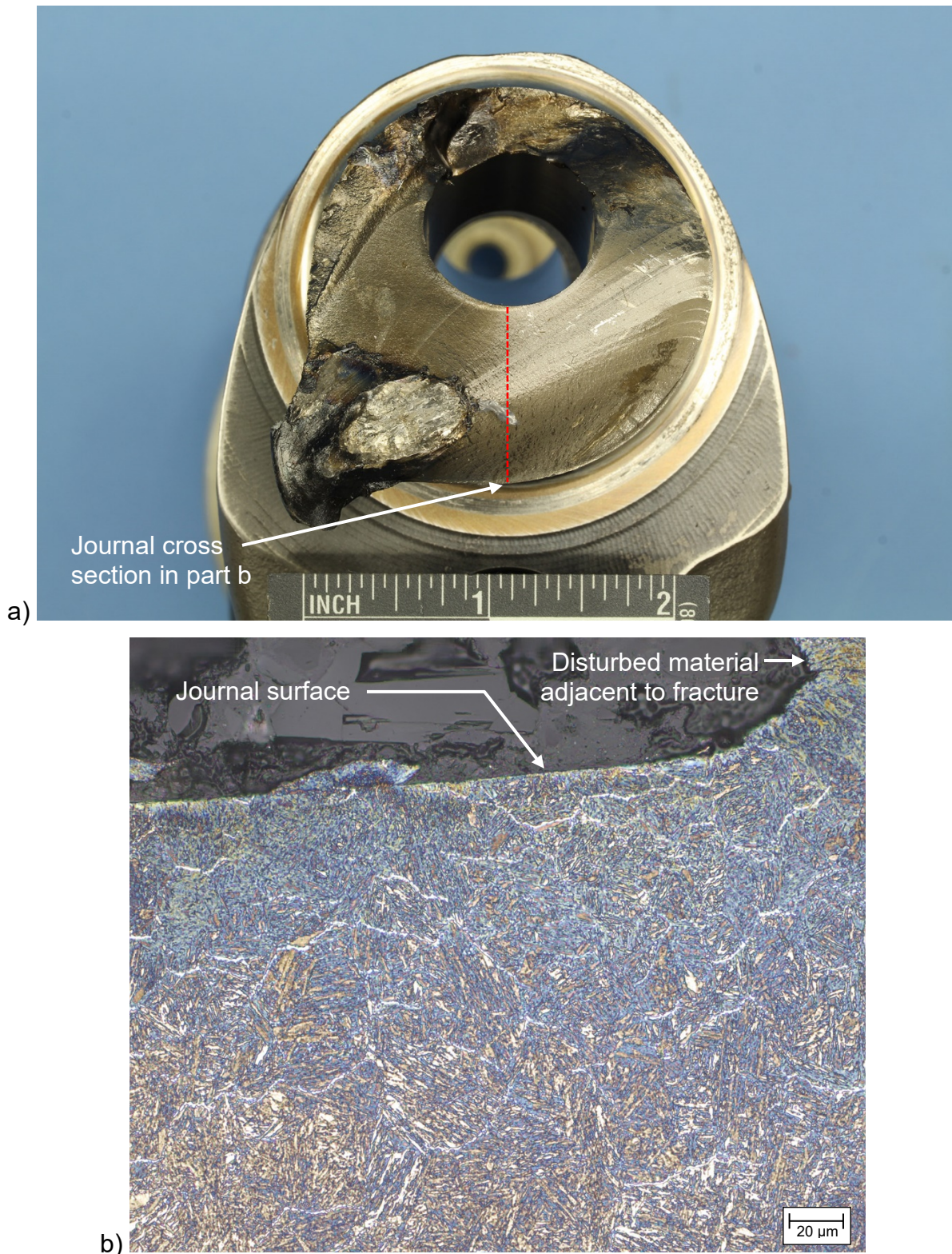


Figure 11: a) Axial view of the forward piece of the fractured crankshaft viewing the forward fracture face. A red dashed line indicated the location of the cut for the metallographic cross section; b) etched and polished metallographic cross section at the journal surface adjacent to the fracture (5% Nital, bright field);

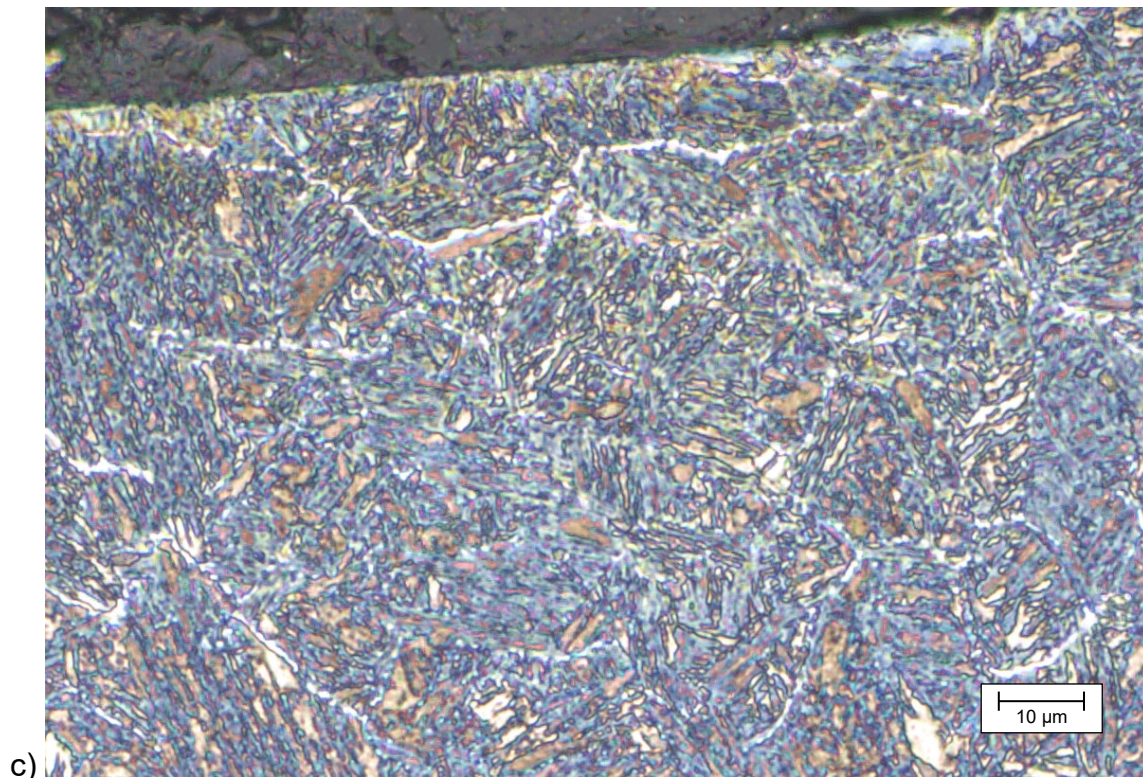


Figure 11 (cont.): and c) Higher magnification image of the microstructure showing the absence of a white layer at the journal bearing surface.

APPENDIX A: Superior Air Parts Bearing Failure Analysis Report – PDR 141

Bearing Failure Analysis
Product Development Report

Revision Information

Date	Rev	Affected Pages	Description
6/4/14	A	All	CR0004026; Initial Release

List of Referenced Documents

VIC 008	Visual Inspection for Bearing Shells
---------	--------------------------------------

Scope

This document outlines the inspection process performed on Superior Air Parts, Inc. SL16711A bearing as dictated by the National Transportation Safety Board. This process involved visual and dimensional inspections performed by Superior Air Parts quality assurance and engineering personnel. Visual inspection was used to identify the part information such as part number, revision, lot number, and material. The visual inspection was also used to identify any unusual wear marking that occurred during operation. The dimensional inspection was used to confirm the proper bearing sized and geometry. A Coordinate-Measuring Machine (CMM) is the main tool used to measure the critical dimensions that define the proper fit and function for each bearing.

Bearing Failure Analysis
Product Development Report

Visual Identification

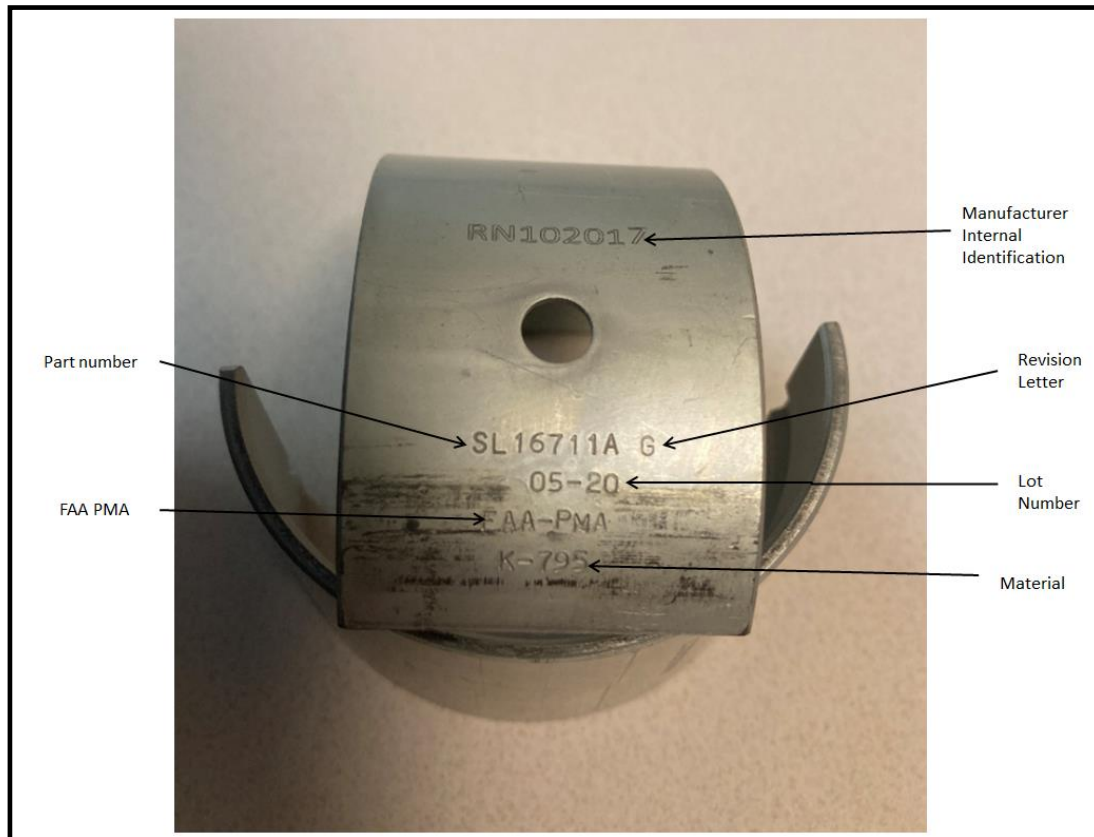


Figure-1: Part marking example for Superior Air Parts bearing.

Use Table-1 below to record all specified part marking shown in Figure-1.

*Part Marking Identification	
Part Number	SL16711A
Revision Letter	F
Lot Number	06-16
FAA PMA	Present
Material	K-795

***Table-1: Inter all specified markings**

Bearing Failure Analysis
Product Development Report

Visual Inspection

If a bearing failure occurs, the majority of the time a visual inspection is more valid than a dimensional. Once a bearing is installed and subjective to any load, bearings will plastically deform by design. This plastic deformation will cause the bearing to no longer meet its free state dimensional requirement, which can make any bearing failure hard to diagnose with dimensional measurement alone.

Visual Inspection Results (Left Rear Main Bearing)	
Inspection Area	Recorded Findings
Bearing Face	Bearing face wear has a polish finish with light scoring. The wear is mostly located on the side of the bearing, and very light wear in the middle.
Tang	Tang has light polishing on the tip.
Parting Surface	Bearings show fretting and displaced material on the parting surface.
Side Edges	Bearings show significant wear on the front side chamber.
Back Surface	Fretting signatures are present. Fretting appear to be worse on front side of the bearing.
Oil Grooves/Holes	No visual indication.

Table-2: Observed wear patterns and failure characteristics for the left rear main bearing shown in Figure-2.



Figure-2: This figure shows the left side rear main bearing

Bearing Failure Analysis
Product Development Report

Visual Inspection Results (Right Rear Main Bearing)	
Inspection Area	Recorded Findings
Bearing Face	Bearing face wear has a polish finish with light scoring. The wear is mostly located on the side of the bearing, and very light wear in the middle.
Tang	Tang has light polishing on the tip.
Parting Surface	Bearing show fretting and displaced material on the parting surface.
Side Edges	Bearings show significant wear on the front side chamber. Chamfer is completely rounded through the side edge.
Back Surface	Fretting signatures are present. Fretting appears to be worse on front side of the bearing.
Oil Grooves/Holes	No visual indication.

Table-3: Observed wear patterns and failure characteristics for the right rear main bearing shown in Figure-3.



Figure-3: This figure shows the right side rear main bearing

Bearing Failure Analysis
Product Development Report

Visual Inspection Results (Left Middle Main Bearing)	
Inspection Area	Recorded Findings
Bearing Face	Bearing face shows mostly normal wear. There is some scoring and most of the wear is on the aft side of the bearing with some discoloration.
Tang	No visual indications.
Parting Surface	No visual indications.
Side Edges	No visual indications.
Back Surface	No visual indications.
Oil Grooves/Holes	No visual indications.

Table-4: Observed wear patterns and failure characteristics for the left middle main bearing shown in Figure-4.

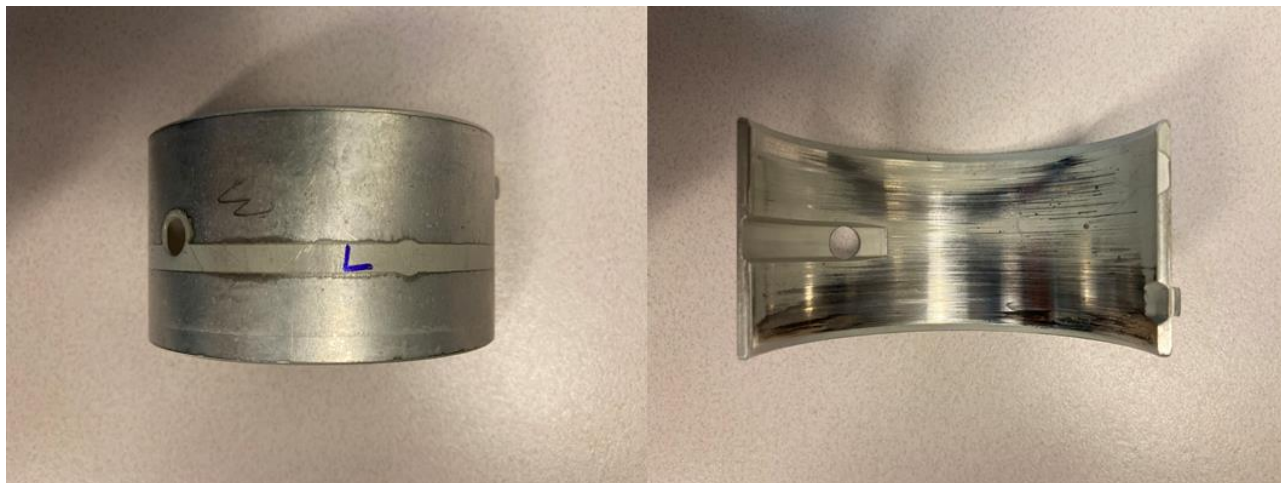


Figure-4: This figure shows the left side middle main bearing

Bearing Failure Analysis
Product Development Report

Visual Inspection Results (Right Middle Main Bearing)	
Inspection Area	Recorded Findings
Bearing Face	Bearing face shows mostly normal wear. There is some scoring and most of the wear is on the aft side of the bearing with some discoloration.
Tang	No visual indications.
Parting Surface	No visual indications.
Side Edges	No visual indications.
Back Surface	No visual indications.
Oil Grooves/Holes	No visual indications.

Table-5: Observed wear patterns and failure characteristics for the right middle main bearing shown in Figure-5.



Figure-5: This figure shows the right side middle main bearing

Bearing Failure Analysis
Product Development Report

The following are examples of different type of failures.

Normal Wear

Signs of normal wear will show uniform and symmetric wear to 1/2 - 2/3 of the bearing half surface. Bearings with long service life will normally show significant wear with few signs of foreign particles that are introduced over time.

Oil Starvation

This type of wear is caused by improper oil supply or a lack of lubrication which causes the journal surface to make direct contact with the bearing surface. Signs of oil starvation with show smearing and displaced material throughout the bearing surface.

Surface Fatigue

With any bearings that are used with cyclical loading, fatigue failure will eventually occur. Signs of fatigue failure will show cracks at the surface of the inner lining and will eventual break away into small flakes.

Dirt Embedment/Foreign Particles

Dirt and/or foreign particles are very common in bearing failures. Dirt can cause scoring on both the bearing and the journal, and embed its self in the bearing lining.

Dirt on Bearing Back

If the bearing saddle is not properly cleaned before installation, dirt can get behind the bearing. This can warp the bearing in the local area were the dirt is local. There will be signs of excess wear on both the inner and outer shell of the bearing at the location of the dirt particle.

Incorrect Crush Height

Excessive crush and insufficient crush can cause extreme wear and as well as failure. Excessive crush can warp the ends of the bearing causing contact with journal. The parting lines will show extreme wear under this issue. Insufficient crush will allow the bear to shift in the bearing saddle which will cause wear on the back side of the bearing.

Fretting

Fretting is caused by the bearing movement in the housing bore. Signs of fretting will show micro-welds or material transfer to the back of the bearing and parting lines. Fretting can be cause by improper crush height and fit or excessive vibrations.

Wiping

Excessive loads with an insufficient supply of oil can cause excessive heating of the bearing which can displace material toward the side of the bearing as well as delamination.

Corrosion

Corrosion occurs when a corrosive material is introduce to the bearing surface and is a rare type failure. Corrosion will cause significant pitting on the bearing surface which will lead to inadequate surface finish.

Bearing Failure Analysis
Product Development Report

Improper installation

Improper installation can lead to excessive wear in localized areas of the bearing. Improper torque on connecting rod and thru bolt can lead to misalignment, distorted crankcase, and out of round bearing. Misaligned bearing will show wear at the bearing sides, and out of round bearings will show excessive wear on both bearing shells 180 degrees apart. Distorted crankcase will show wear on all main journal bearings.

Out of Spec Dimensions

Concentricity, Straightness, roundness, cylindricity, and surface finish all affect the life span and performance of the bearing. Issues with Crankshaft/Crankcase concentricity and straightness will cause noticeable wear across all main bearings. Out of round bearings/journals will show excessive wear on both bearing shells 180 degrees apart. Cylindricity issues will cause concentrated wear at both side edges or concentrated load in the center. Too high of surface finish will cause accelerated wear evenly on the loaded side of the bearing.

Noted Findings:

From these examples, the wear characteristics record in Table-2 and -3 showed the rear two bearings have signs of fretting, wiping, and misalignment. The back of the bearing and parting lines show displaced material and material transfer on the surfaces which would fall under fretting. The front edges of the bearings showed significant wear on the chamfer. Each chamfer had displaced material from what looks to be metal to metal contact similar to the conditions under wiping. Since the center of the bearing face shows almost no wear and the edges showing excess wear, this is likely due to misalignment or out of spec journal geometry.

The wear characteristics record in Table-4 and -5 showed the middle two bearings have signs of light wiping. Slight excessive wear on the aft side of the bearing face showed sign that metal to metal contact had occurred.

Bearing Failure Analysis
Product Development Report

Dimensional Inspection

Dimensional inspection will be used to assure the proper fit and function of the bearing.

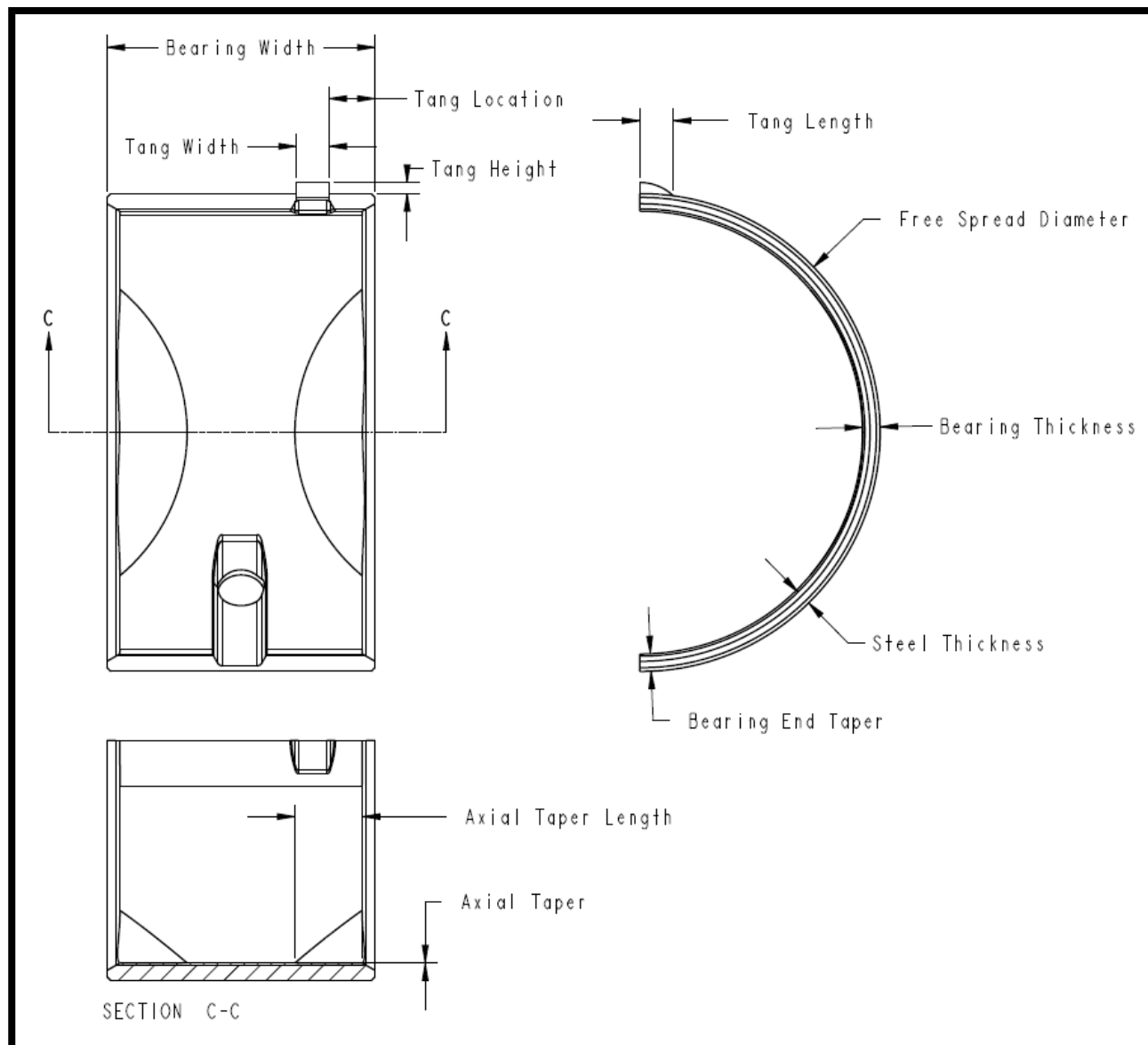


Figure-6: This figure show critical dimensions for proper fit and function

Bearing Failure Analysis
Product Development Report

Dimensional Inspection Results (Left Rear Main Bearing)		
Bearing Drawing Number: SL16711A		
	Drawing Requirement	Measurement Results
Bearing Width	1.435–1.445	1.446
Bearing Thickness	.0945–.0950	.09430
Steel Thickness	.077–.087	N/A
Axial Taper	.0015–.002	.00242-.00531
Axial Taper Length	.340–.380	.380
Bearing End Taper	MAX .0005	.00107
Free Spread Diameter	Ø 2.582–2.612	2.587
Tang Width	.170–.180	.174
Tang Height	.055–.065	.059
Tang Length	.140–.220	.211
Tang Location	.242–.252	.252

Table-6: Record Drawing #, Drawing Requirements, and Measured Values specified in Figure-6

Dimensional Inspection Results (Right Rear Main Bearing)		
Bearing Drawing Number: SL16711A		
	Drawing Requirement	Measurement Results
Bearing Width	1.435–1.445	1.4474
Bearing Thickness	.0945–.0950	.094
Steel Thickness	.077–.087	N/A
Axial Taper	.0015–.002	.001-.0038
Axial Taper Length	.340–.380	.380
Bearing End Taper	MAX .0005	.0004
Free Spread Diameter	Ø 2.582–2.612	2.5817
Tang Width	.170–.180	.175
Tang Height	.055–.065	.055
Tang Length	.140–.220	.206
Tang Location	.242–.252	.253

Table-7: Record Drawing #, Drawing Requirements, and Measured Values specified in Figure-6

Both rear bearings measured oversized on the bearing width and undersized on the bearing thickness and axial taper. This is a result of the wear and displaced material on the bearing edges.

Bearing Failure Analysis
Product Development Report

Dimensional Inspection Results (Left Middle Main Bearing)		
Bearing Drawing Number: SL16711A		
	Drawing Requirement	Measurement Results
Bearing Width	1.435 – 1.445	1.4381
Bearing Thickness	.0945 – .0950	.0944
Steel Thickness	.077 – .087	N/A
Axial Taper	.0015 – .002	.00198-.00251
Axial Taper Length	.340 – .380	.380
Bearing End Taper	MAX .0005	.0009
Free Spread Diameter	Ø 2.582 – 2.612	2.5968
Tang Width	.170 – .180	.180
Tang Height	.055 – .065	.059
Tang Length	.140 – .220	.205
Tang Location	.242 – .252	.250

Table-8: Record Drawing #, Drawing Requirements, and Measured Values specified in Figure-6

Dimensional Inspection Results (Left Middle Main Bearing)		
Bearing Drawing Number: SL16711A		
	Drawing Requirement	Measurement Results
Bearing Width	1.435 – 1.445	1.4390
Bearing Thickness	.0945 – .0950	.0945
Steel Thickness	.077 – .087	N/A
Axial Taper	.0015 – .002	.0023-.0024
Axial Taper Length	.340 – .380	.380
Bearing End Taper	MAX .0005	.0003
Free Spread Diameter	Ø 2.582 – 2.612	2.6031
Tang Width	.170 – .180	.175
Tang Height	.055 – .065	.054
Tang Length	.140 – .220	.198
Tang Location	.242 – .252	.251

Table-9: Record Drawing #, Drawing Requirements, and Measured Values specified in Figure-6

Both middle main bearings measured within acceptable values. The end taper and axial taper on the left middle main is a little high but normal after slight operational wear.

Summary

The middle bearings did show more wear than normal, but nothing was observed that would prevent the two bearing from operating normally. The bearing set that show significant wear and out of spec dimensional tolerances are the two rear bearings. The out of spec dimensions seems to be a result from the excess wear and displace material, possibly caused by metal to metal contact either by journal misalignment or improper oil supply. Although there are signs of metal to metal contact, the bearings showed no evidence that would prevent the engine from operating normally.