

NATIONAL TRANSPORTATION SAFETY BOARD

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



April 11, 2018

MATERIALS LABORATORY FACTUAL REPORT

Report No. 17-085

A. ACCIDENT INFORMATION

Place : Santa Barbara, California
Date : May 5, 2017
Vehicle : Robinson R44
NTSB No. : WPR17LA097
Investigator : Elliott Simpson, AS-WPR

B. COMPONENTS EXAMINED

Engine case halves, numbers 3 and 4 cylinder assemblies with piston assemblies, 6 connecting rods, 6 wrist pins, 12 wrist pin plugs, through bolts, and main bearings from a Lycoming O-540-F1B5 engine.

C. DETAILS OF THE EXAMINATION

An overall view of the components initially submitted for examination at the NTSB Materials Laboratory are shown in figure 1. After an initial examination of the components and a review of photographs of the engine, additional components were submitted for examination as shown in figures 2 through 4. The exterior surfaces of the submitted components were oxidized and sooted consistent with exposure to a fire. The number 3 cylinder had separated from the engine and had been found approximately $\frac{1}{4}$ mile from the main wreckage site. The number 4 connecting rod had been cut to facilitate disassembly of the engine. The lower side of the crankcase below the number 3 cylinder port was fractured, and pieces were missing. The number 3 connecting rod was fractured at the outboard (piston) end of the rod, and the bushing and outboard end of the connecting rod was missing. According to maintenance records at the time of the last entry on April 6, 2017, the engine had 1,473 hours time in service since overhaul in 2011 at Lycoming Engines.

The number 3 cylinder had been attached with 6 studs and 2 throughbolts. Fractured ends from the three upper studs remained in the case as shown in figure 5. The two throughbolts that had been installed at the forward side of the number 3 cylinder (based on a review of photographs taken during the engine teardown) were bent and fractured. At the lower side of the number 3 cylinder port, the portion of the case where the two middle lower studs were attached was fractured and missing, and the fracture in the case intersected the holes for the lower aft stud and the lower throughbolt. One of the lower middle studs was intact and remained trapped in its hole on the number 3

cylinder flange. Two studs from the lower middle forward and lower forward attachment positions for the number 3 cylinder were missing.

Close views of the fracture surfaces for the 3 upper studs for the number 3 cylinder are shown in figures 6 through 8. The studs showed relatively smooth fracture surfaces with smearing deformation consistent with ductile overstress fracture under shear loading. Deformation of the stud and adjacent surfaces of the crankcase were consistent with the mating sides of the studs moving downward and slightly aft as indicated with arrows in figure 5.

The inboard end of the number 3 cylinder assembly is shown in figure 9. The piston for the number 3 cylinder was mostly intact, and the wrist pin for attaching the connecting rod was in place. The piston had multiple impact marks on the interior surfaces and on the piston skirt. The barrel skirt was deformed inward at the forward and aft sides, trapping the piston within the barrel. A segment of the upper side of the piston skirt was fractured and missing, and the shape of the missing area was consistent with contact with the number 3 connecting rod. A segment of the skirt at the lower side of the barrel was fractured and flattened against the cylinder attachment flange, also consistent with contact with the number 3 connecting rod.

At the upper side of the number 3 cylinder flange, the holes corresponding to the 3 fractured studs were elongated with deformation at the upper side of the hole as indicated in figure 9 and as shown in a closer view in figure 10. The location of the hole elongation was consistent with the direction of shear deformation observed in the studs shown in figure 6. Contact marks were also observed at the upper side of the upper throughbolt hole as indicated in figure 9. At the lower side of the cylinder shown in figure 11, the flange was bent, and the flange was cracked through the middle two attachment holes. The cracks were associated with deformation, consistent with ductile overstress fracture.

Most of the number 3 cylinder attachment flange around the attachment holes appeared dark gray, but portions of the flange were oxidized with an orange oxide or appeared light gray and smeared. Machining marks were visible around most of the surfaces, including many of the oxidized areas. The oxidized and smeared areas were mostly present at the forward and aft sides of the cylinder flange.

Views of the fractured throughbolts for the number 3 cylinder are shown in figures 12 and 13. The upper throughbolt was fractured in the threaded section. Fracture features were rough and matte gray, consistent with ductile overstress fracture. The lower throughbolt was fractured in the smooth portion of the shank and showed necking deformation adjacent to the fracture, also consistent with ductile overstress fracture.

The crankcase was separated to reveal the mating sides of the crankcase halves. The mating surfaces for the crankcase had a smooth, polished appearance with scattered pits. Views of the saddle surfaces for the number 3 main journal bearing with typical surface features are shown. The dark specks on the surface are the pits. Similar pit

features were also observed on other machined surfaces including the saddle surfaces supporting the main journal bearings and the camshaft journal bore surfaces such as the camshaft journal bore surface shown in figure 14.

The pits on the machined surfaces of the crankcase were generally scattered as shown in figure 14. However, an area with a greater concentration of pits was observed at the number 2 main journal saddle boss as indicated in figure 15. The pits in this area appeared similar in depth and width as pits in other areas, but the pits in this area were elongated.

Views of the exterior of the left crankcase half at the number 2 main bearing throughbolt holes are shown in figure 15. The area around the holes had a raised deformation lip, and thread contact damage was present on the interior surfaces of the holes.

The numbers 3 and 4 piston assemblies were trapped or frozen in place within their respective cylinder assemblies. In order to separate the pistons from the cylinder assemblies, transverse cuts were made using a bandsaw through the barrel of the number 3 cylinder and the head of the number 4 cylinder. The pistons were then removed from the barrel by pushing them out the cut end.

An overall view of the number 3 piston is shown in figure 16 with a closer view of impact marks and a deformation lip at the edge of the piston crown. The shape and location of the impact marks and the deformation mark were consistent with the piston impacting the cylinder head dome.

The wrist pins were removed from the numbers 3 and 4 pistons using a hydraulic press, and a view of the wrist pins from all cylinders are shown in figure 17. The wrist pins from cylinders 1, 2, 4, 5, and 6 were mostly free of mechanical damage, but were tinted brown, bluish gray, and black consistent with heat exposure. By comparison, the number 3 wrist pin had mechanical damage in the area corresponding to the connecting rod attachment and was light gray in color across most of the surface.

Closer views of the inboard and outboard surfaces of the number 3 wrist pin are shown in figure 18. The wrist pin had a bluish gray circumferential tint band on one side where it intersected the boss on the piston, and a brown circumferential tint band adjacent to the other boss. Circumferential gouges and galling was present on the surface between the two tint bands. A longitudinal mark with galled material was present on the outboard side of the wrist pin (side not visible in figure 9) as indicated in the lower image in figure 18.

Bushings at the outboard ends of the numbers 1, 2, 4, 5, and 6 connecting rods were examined visually and using a stereo microscope. The bushing at the outboard end is manufactured from a flat sheet that is bent into a cylindrical shape and inserted into the

connecting rod. The split line for the bushing was located at the 1:30 clock position¹ in connecting rods 1, 2, and 4. In connecting rod 5, the split line was located at the 5:15 clock position, and in the number 6 connecting rod, the split line was located near the 12 o'clock position (see figure 19). In connecting rods 1, 5, and 6, the bushing was displaced laterally relative to the connecting rod. This displacement in the number 6 connecting rod is noted in the close views in figures 19 and 20 where the bushing extended beyond the side of the connecting rod as shown in figure 19 and was inset from the opposite side shown in figure 20.

The inside diameters of the bushings were measured on connecting rods 1, 2, 4, 5, and 6 at 4 locations approximately 45 degrees apart around the circumference. Measured diameters ranged from 1.124 inches to 1.127 inches. The results of each measurement are listed in table 1. The service limits for the bushing diameter as listed in Lycoming Special Service Publication SSP-1776-3² range from 1.1254 inches to 1.1262 inches.

Table 1. Connecting Rod Bushing Diameter Measurements

Connecting Rod Number	Diameter at 12 to 6 o'clock (inches)	Diameter at 3 to 9 o'clock (inches)	Diameter at the 4:30 to 10:30 clock position (inches)	Diameter at the 1:30 to 7:30 clock position (inches)
1	1.126	1.124	1.126	1.126
2	1.127	1.126	1.125	1.126
4	1.127	1.126	1.127	1.127
5	1.126	1.125	1.127	1.125
6	1.127	1.126	1.126	1.126

An overall view of the number 3 connecting rod is shown in figure 21. The web of the beam section of the rod had raised characters "11 LW-13305" on one side and "N" on the opposite side. At the crankshaft end of the connecting rod, "K100" and "011" were dot imprinted on one side of the saddle and strap. Characters "7247" and "04/08/08" were dot imprinted on the opposite side of the strap. A scribed digit "3" was also observed on the side of the saddle and the strap.

The connecting rod was fractured where the wrist pin bore intersected the beam section of the rod. The fracture surfaces of the rod were oxidized and had substantial impact damage. The outboard end of the connecting rod was cut from the rest of the rod to facilitate a detailed examination of the fracture surface. An end view of the cut piece is shown in the lower image in figure 21. A curved impact mark was observed on the outboard end of the connecting rod as indicated in the lower image in figure 21. The shape of the impact mark was consistent with the inboard end of the cylinder barrel skirt.

¹ Clock position as viewed looking at the side of the connecting rod with the forging part number LW13305 marked in the web and with the outboard end at the 12 o'clock position.

² SSP-1776-3, *Complete Service Table of Limits*, Lycoming Engines, Williamsport, Pennsylvania (2017).

The outboard end of the connecting rod was initially cleaned in an acetone bath using an ultrasonic cleaner. The fracture surfaces were then examined using a scanning electron microscope (SEM). Much of the surfaces were covered with oxides which obscured most of the underlying surface features. The fracture surface on one side of the wrist pin bore was completely obliterated by post-fracture impact damage. The fracture surface at the opposite side also appeared mostly damaged by post-fracture impact, but some areas with elongated dimples were observed.

Next, the outboard end of the connecting rod was soaked for approximately 16 hours in a bath of Evapo-Rust³ to remove oxidation, and the fracture surfaces were then reexamined. Most of the surfaces were obliterated by post-fracture contact damage, and fine features of the fractures were mostly obliterated by oxidation. Remaining fracture surfaces were visually smooth with sliding contact marks, consistent with ductile overstress fracture in compressive shear loading. Elongated dimple features were observed on remaining fracture surfaces in the SEM, also consistent with ductile overstress fracture.

Oily deposits were present on much of the surfaces of the remaining 5 connecting rods. Many of the deposits were removed using a soft bristle brush with a solution of Alconox detergent and warm water. After cleaning, the outboard ends of the number 2, 4, and 6 connecting rods had a bright blue color. The outboard end of the cleaned number 6 connecting rod noting the blue tint is shown in figure 20. A slight blue tint was also noted at the outboard ends of connecting rods 1 and 5.

Part number LW-11750-85 was marked in ink on the sides of connecting rods 1, 2, 5, and 6. No ink markings were detected on the oxidized surfaces of the number 3 connecting rod, and the number 4 connecting rod was torch cut in the area of the beam section expected to have the part number marking. According to a representative from Lycoming Engines, 6 part number LW-11750-85 connecting rods were installed during overhaul of the engine, but records did not include any lot numbers or serial numbers for the connecting rods. The heads of the connecting rod bolts on all 6 connecting rods were stamped with part number 14S23890, a part only available for factory installation.

According to Australian Airworthiness Bulletin AWB 85-020 Issue 3,⁴ all Lycoming reciprocating aircraft engines which were new, factory rebuilt (such as the accident engine), or factory overhauled during the 2011 calendar year are susceptible to premature wear of the connecting rod bushings. AWB 85-020 notes that in these engines, one or more bushings may shift axially during operation, leading to wear of the protruding edge of the bushing against the piston. AWB 85-020 further states that the development of this premature wear condition is relatively slow and predictable, and that regular oil and oil filter inspections have been shown to be effective in detecting this condition.

³ Evapo-Rust is manufactured by Harris International Laboratories, Springdale, Arkansas.

⁴ AWB 85-020 Issue 3, *Lycoming Engines – Connecting Rod Bushing Premature Wear*, Civil Aviation Safety Authority, Canberra, Australian Capital Territory, Australia (2017).

Maintenance records for the accident engine stated oil system servicing in accordance with Lycoming Engines Mandatory Service Bulletin 480E⁵ was completed at approximately 50-hour intervals prior to the accident. The entries specifically noted inspecting the oil screens at each oil change and noted inspecting the oil filter element at 2 of the last 4 oil changes including the last oil change on April 1, 2017 at 1,469.2 hours time in service since overhaul.

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Senior Materials Engineer

⁵ Mandatory Service Bulletin 480E, *Oil and Filter Change and Screen Cleaning and Oil Filter/Screen Content Inspection*, Lycoming Engines, Williamsport, Pennsylvania (April 13, 2005).

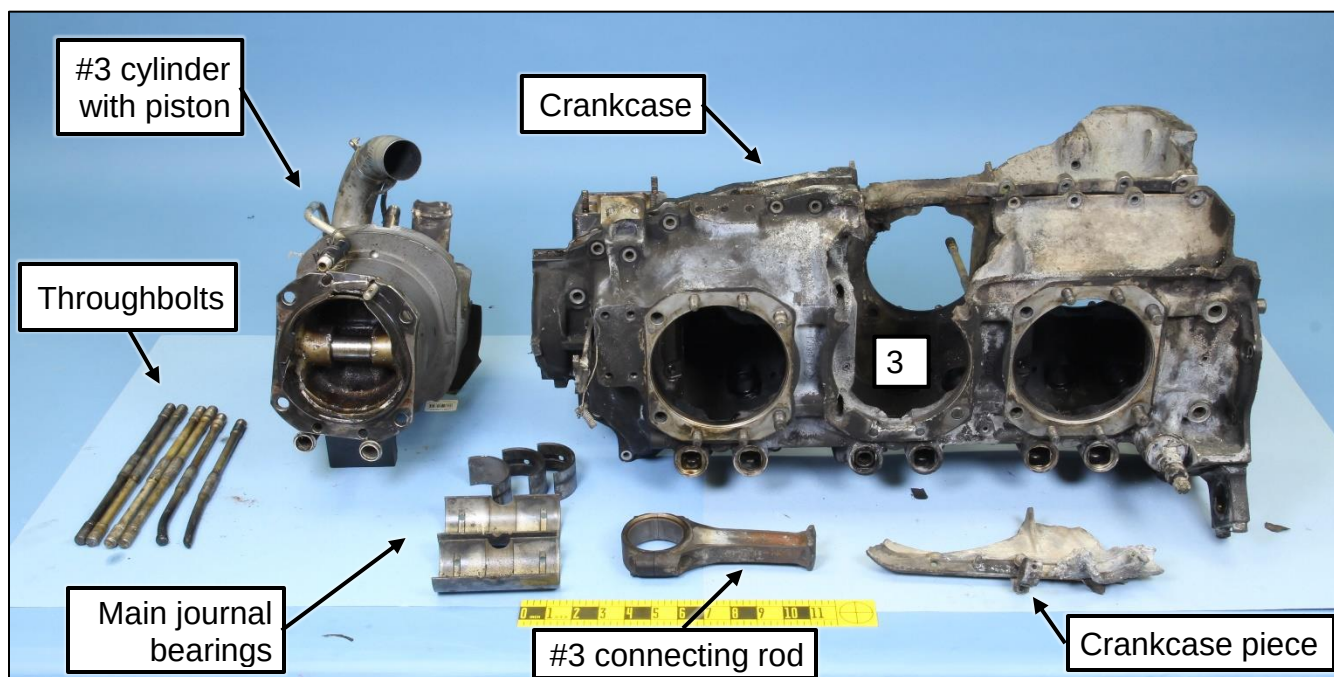


Figure 1. Overall view of the submitted components initially examined by the NTSB Materials Laboratory. The components are oriented to show the lower right side of the crankcase and the inboard end of the number 3 cylinder assembly. The location of the number 3 cylinder port is indicated on the crankcase.

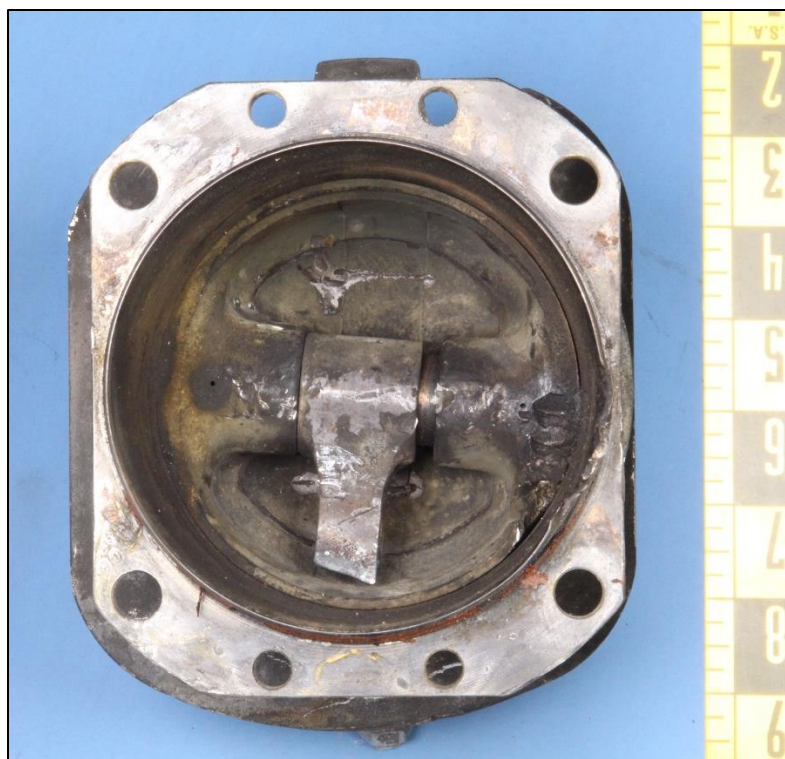


Figure 2. View of the inboard end of the number 4 cylinder assembly showing the piston and cut connecting rod end contained within the cylinder barrel.



Figure 3. Overall view of the numbers 1, 2, 4, 5, and 6 connecting rods.



Figure 4. Wrist pins from the numbers 1, 2, 5, and 6 cylinders.

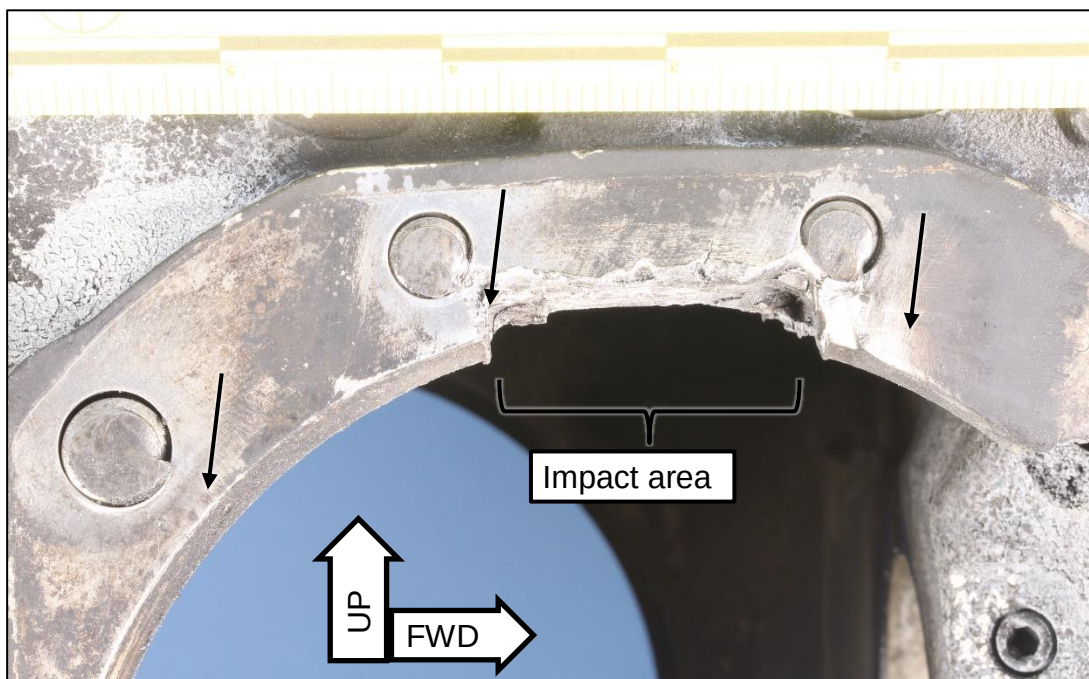


Figure 5. Fractured cylinder attachment studs at the upper side of the number 3 cylinder port on the crankcase. Arrows indicate the relative direction of movement for the mating piece based on deformation to the remaining stud.



Figure 6. Close view of the stud fracture at the upper middle forward attachment location for the number 3 cylinder.



Figure 7. Close view of the stud fracture at the upper middle aft attachment location for the number 3 cylinder.



Figure 8. Close view of the stud fracture at the upper aft attachment location for the number 3 cylinder.

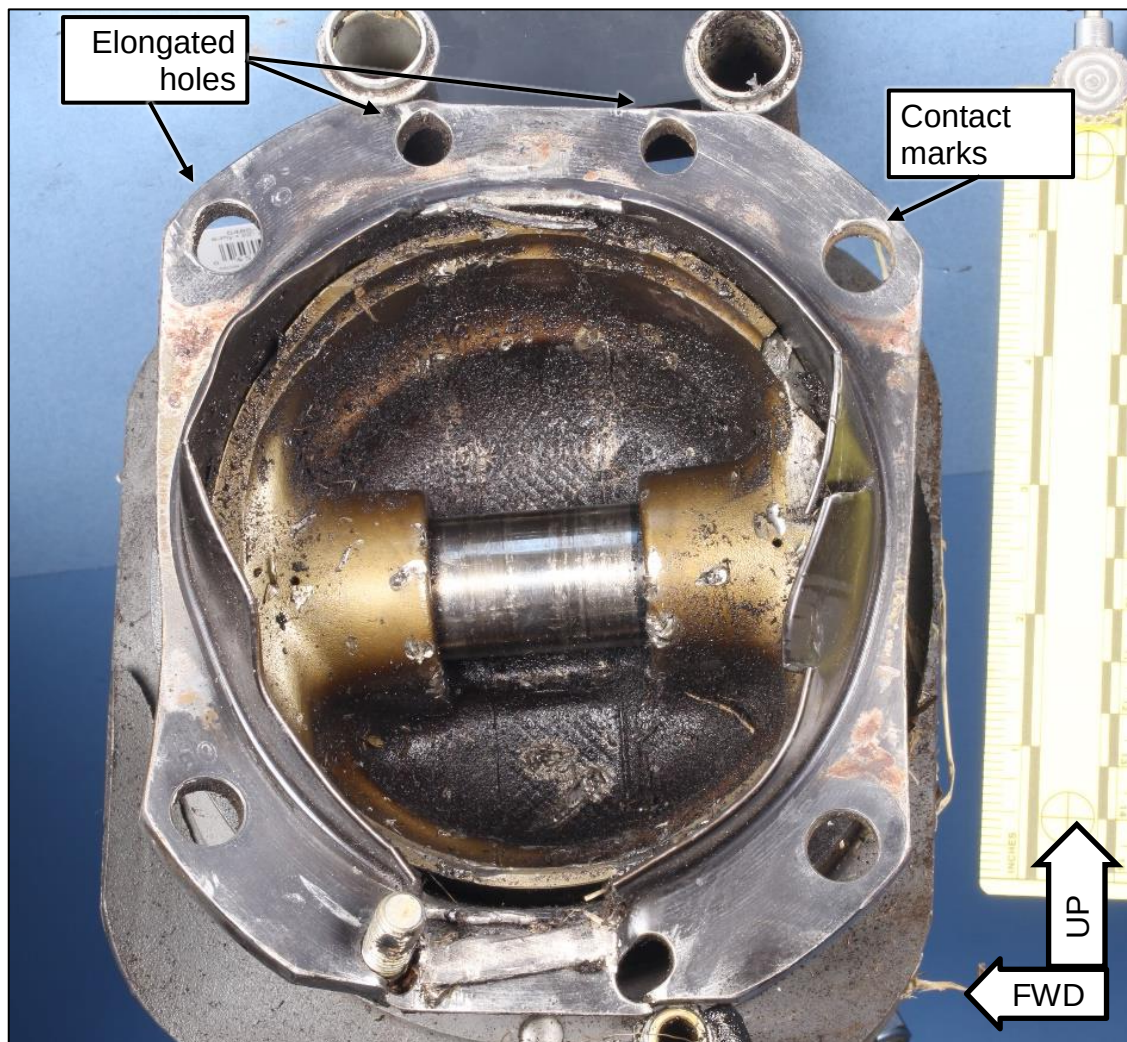


Figure 9. Inboard end of the number 3 cylinder assembly with the mostly intact and trapped piston assembly.



Figure 10. Elongated holes at upper side of the number 3 cylinder flange showing deformation consistent with the cylinder moving downward relative to the attachment studs.

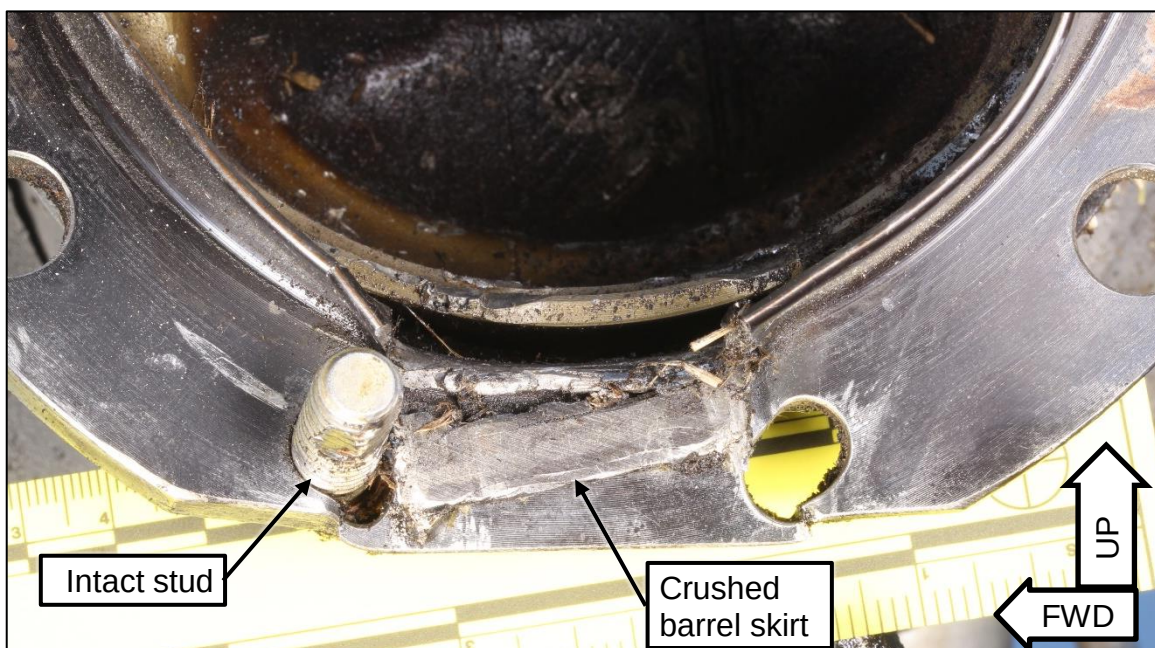


Figure 11. Closer view of damage at the lower side of the number 3 cylinder attachment flange.



Figure 12. Overstress fracture of upper throughbolt at the forward side of the number 3 cylinder.



Figure 13. Overstress fracture of the lower throughbolt at the forward side of the number 3 cylinder.

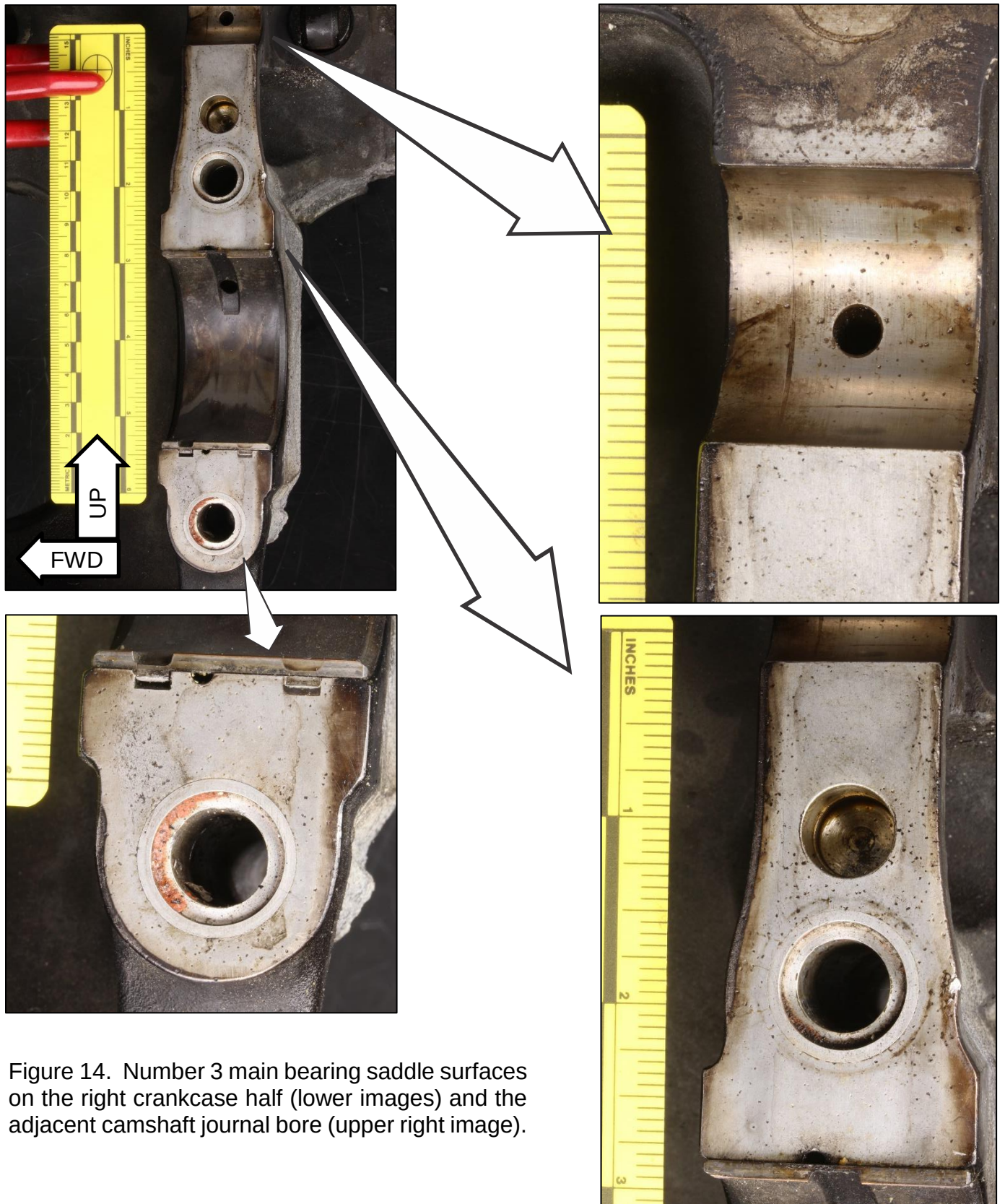


Figure 14. Number 3 main bearing saddle surfaces on the right crankcase half (lower images) and the adjacent camshaft journal bore (upper right image).

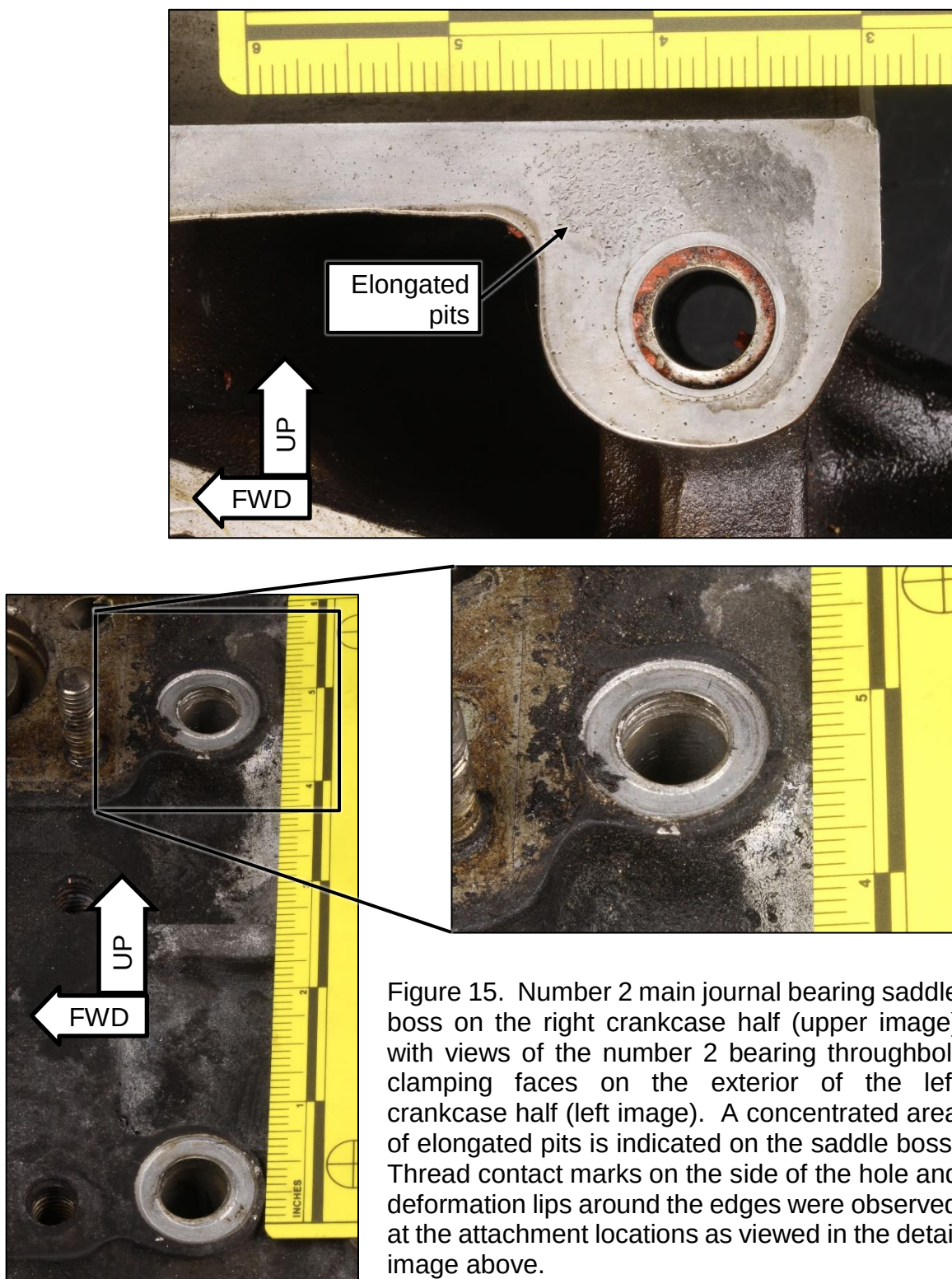


Figure 15. Number 2 main journal bearing saddle boss on the right crankcase half (upper image) with views of the number 2 bearing throughbolt clamping faces on the exterior of the left crankcase half (left image). A concentrated area of elongated pits is indicated on the saddle boss. Thread contact marks on the side of the hole and deformation lips around the edges were observed at the attachment locations as viewed in the detail image above.

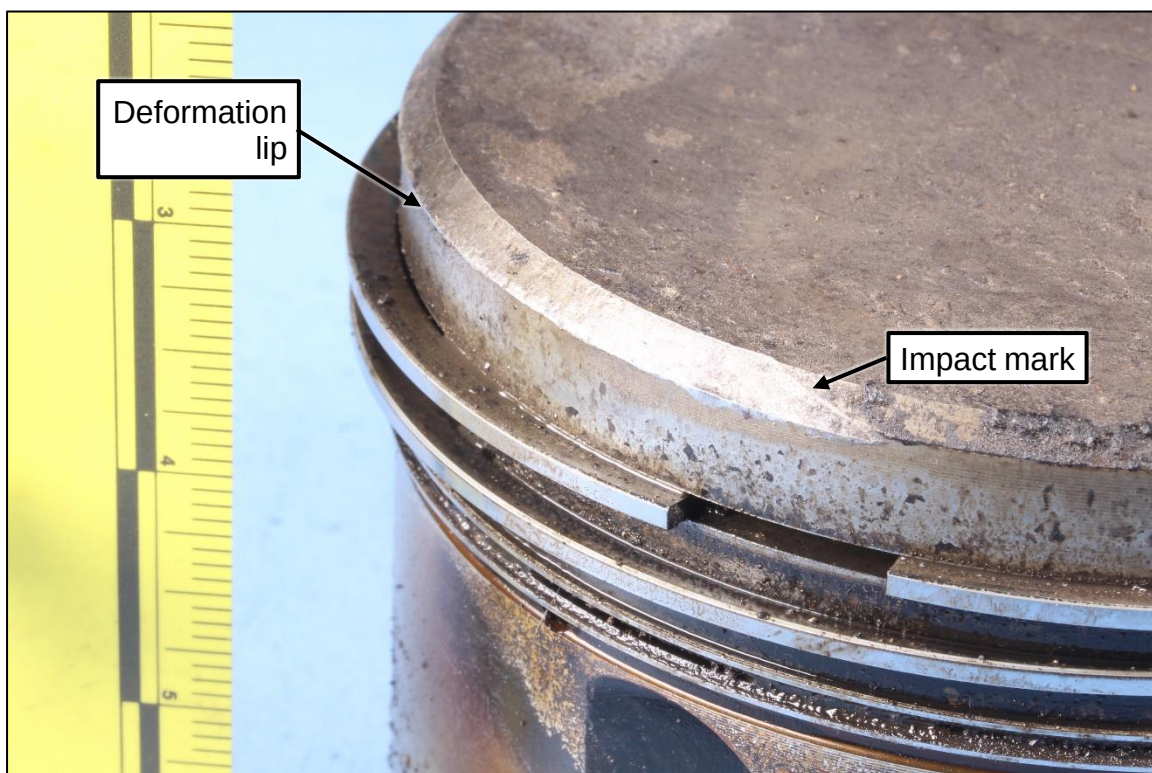


Figure 16. Number 3 piston after removal from the cylinder barrel. Deformation lips and impact marks corresponding to contact with the cylinder head dome were observed around the edges of the piston crown.

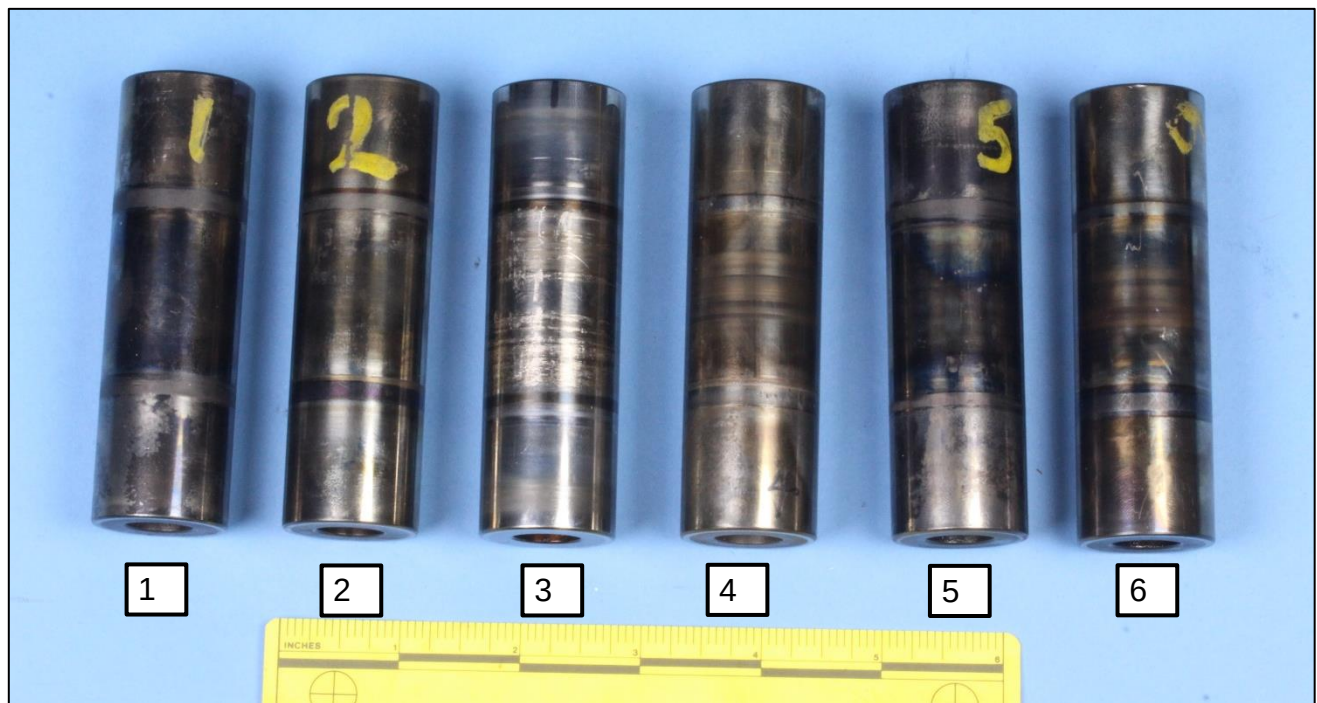


Figure 17. Wrist pins from all cylinders after the cylinders 3 and 4 pins were disassembled from their respective pistons.

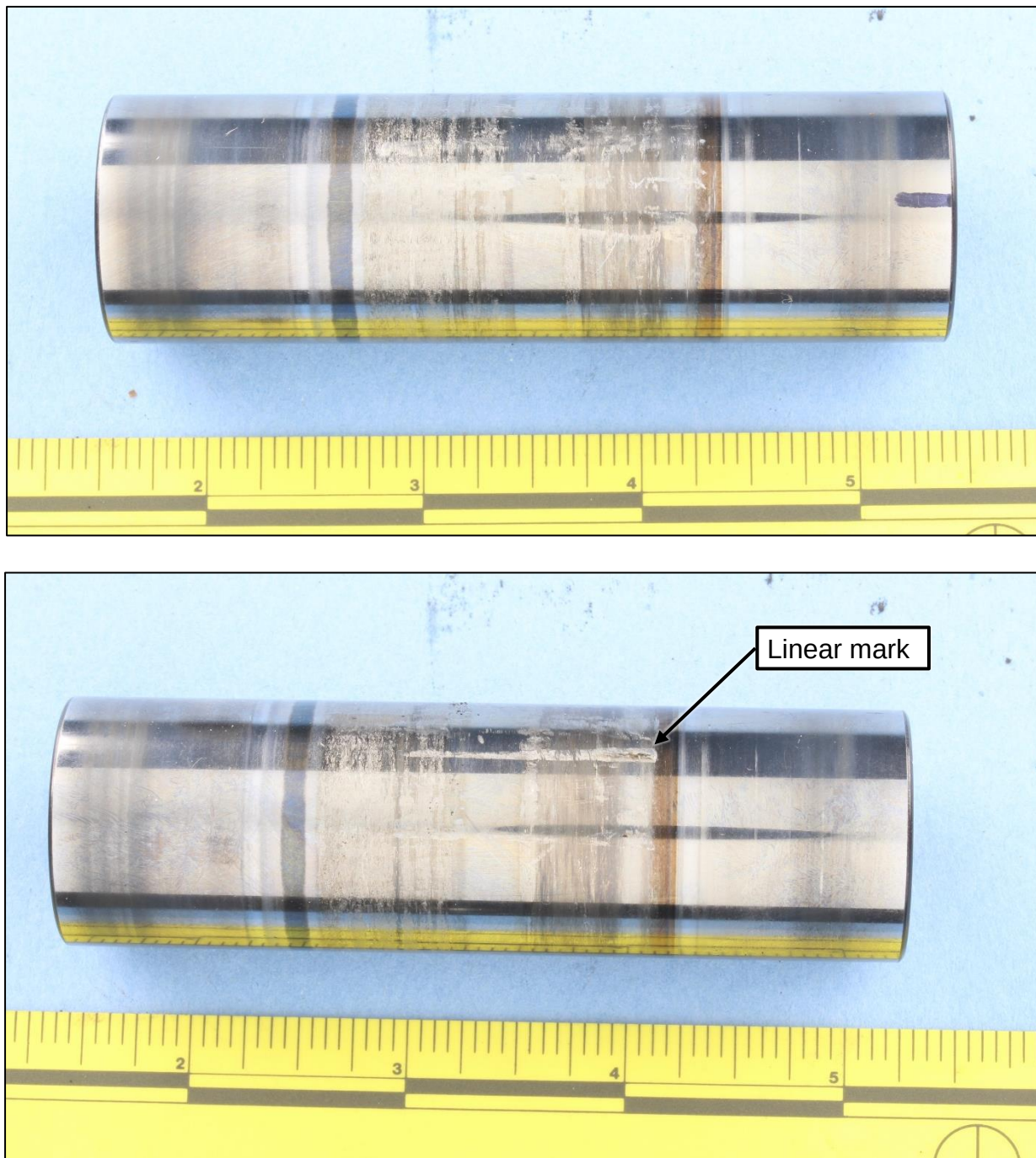


Figure 18. Closer views of the number 3 wrist pin showing the inboard side visible in figure 6 (upper image) and the outboard side (lower image). Circumferential marks with pitting and galled material were present around the circumference. A linear mark with galled material was observed on the outboard side at approximately 180 degrees from the inboard side.

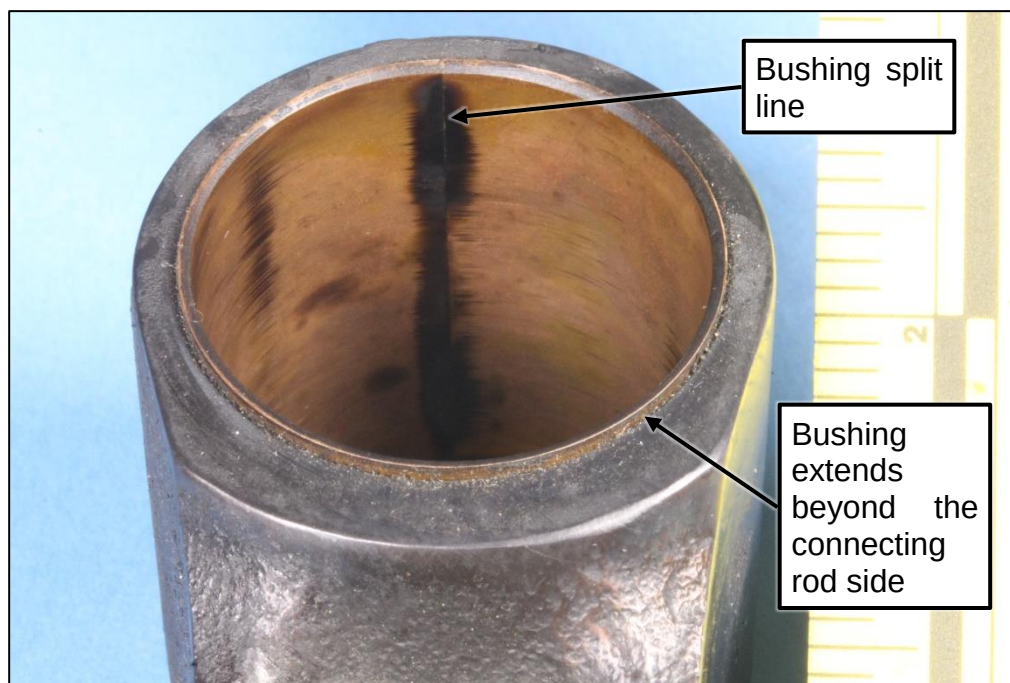


Figure 19. Outboard end of the number 6 connecting rod showing the bearing split line and lateral displacement.

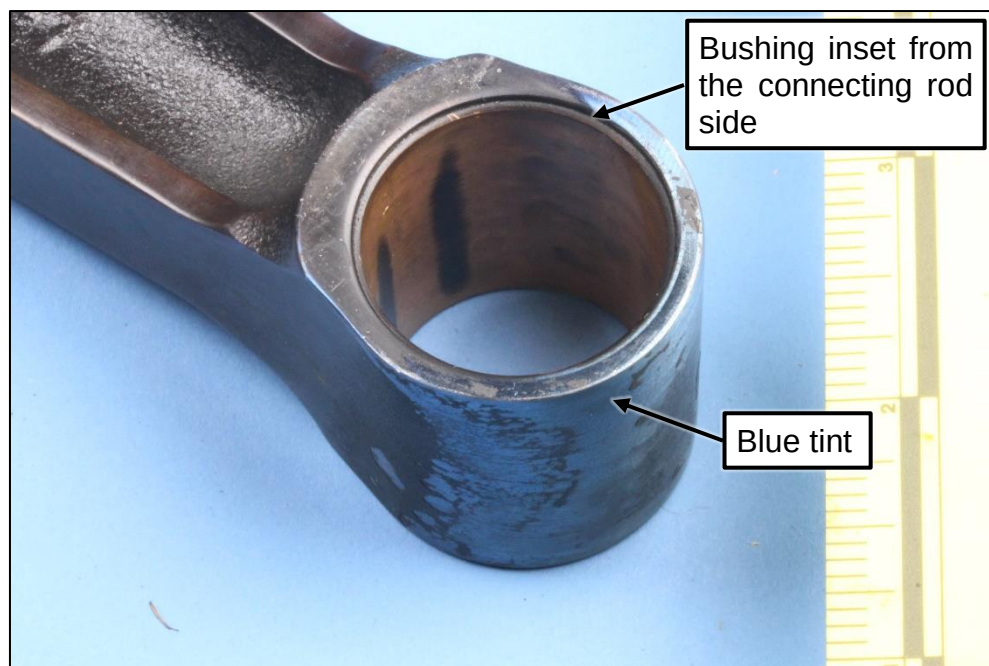


Figure 20. Outboard end of the number 6 connecting rod after cleaning showing blue tint on the surface and lateral displacement of the bushing.



Figure 21. Connecting rod from the number 3 cylinder. The outboard end shown in the lower image had a curved impact mark with a geometry consistent with contact with the inboard end of the cylinder barrel skirt.