

NATIONAL TRANSPORTATION SAFETY BOARD

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



January 21, 2022

MATERIALS LABORATORY FACTUAL REPORT

Report No. 21-101

A. ACCIDENT INFORMATION

Place : Los Angeles, California
Date : February 19, 2021
Vehicle : Piper PA-32-260, N57014
NTSB No. : WPR21FA114
Investigator : Zoe Keliher, ASI-WPR

B. COMPONENTS EXAMINED

Components from a Lycoming O-540-E4B5 engine:

- 1) Multiple pieces from the number 5 cylinder assembly;
- 2) Multiple pieces from the number 6 cylinder assembly;
- 3) Rod of unknown origin.

C. DETAILS OF THE EXAMINATION

Multiple components from the numbers 5 and 6 cylinder-assemblies from a Lycoming O-540-E45B engine were submitted to the NTSB Materials Laboratory for examination, as shown in figures 1a and 1b, respectively. Components without identifying part numbers included: piston pins, piston pin plugs (No. 5 only), rocker arm shafts, intake and exhaust valve springs, intake and exhaust valve spring seats, intake valve keys, exhaust valve keys (No.5 only), exhaust valve rotator caps, push rod socket (No.5 only), and a pushrod shroud tube (No. 6 only). The remaining components and their observed part numbers, if any, are listed in table 1 below.

In addition, an unidentified rod that was found in the oil sump, shown in figure 1c, was submitted to the lab for identification. The rod was hollow, had a gold color, and was coated with a dark brown/black layer. One end of the rod appeared fractured and battered while the other end of the rod had a comparatively flat end. At the flat end, the inner diameter exhibited features similar to thread marks or thread impressions. The rod was cleaned in accordance with standard laboratory protocols and then examined in a scanning electron microscope (SEM) equipped with an energy dispersive x-ray spectrometer (EDS). In the gold-colored regions, the material composition consisted of copper and zinc, consistent with a brass alloy. In the dark regions, the composition was similar, but with the addition of an abundant oxide peak, consistent with the alloy oxide.

Table 1: Examined cylinder-assembly components and their associated part numbers.

Component	Part Number on Number 5 Cylinder	Part Number on Number 6 Cylinder
Cylinder Assembly	LW-12425	74925
Intake Rocker Arm	69443A	69443D
Exhaust Rocker Arm	68520-D	69443DE
Intake Valve	SL 17541T-T	SL 17541T-T
Intake Valve Guide	SL 61681+5	[?] P30
Exhaust Valve	SL19001AQ	Fractured/lost
Exhaust Valve Guide	SL 74230AP005	SL 74230A P10
Tappet Body	72877 M	None found
Plunger Assembly	78290	Not examined
Push Rod	None examined	73435
Piston	None Found	None found

Multiple components from the number 6 cylinder-assembly were mechanically damaged. The number 6 piston was fractured into multiple pieces, two crown pieces being shown in figures 2a and 2b. There were impact marks on the crown, as indicated in figure 2a. Additional impact marks were observed on the interior surface of the cylinder head (figure 3), around the exhaust valve guide through-hole (figure 4a, also compare to the valve guide from the number 5 cylinder-assembly shown in figure 4b), and on the inboard end of the valve guide (also figure 4a). The exhaust valve guide had been extruded outward approximately 0.5 inch, lifting the valve guide boss off its seat on the cylinder head, as shown in figure 5a (also, see the number 5 exhaust valve guide in figure 5b for comparison). The cam follower on the number 6 exhaust tappet body had been worn leaving just the cylindrical shaft (figure 1b).

The number 6 cylinder exhaust valve was fractured through the stem near the stem-to-fillet transition, as shown on the remaining valve head fragment in figure 6a. An arc segment of the stem adjacent to the fracture was deformed radially inward and there were longitudinal tears along the stem on either side. At the base of this segment, in the fillet region, the valve head was gouged. The valve seat face exhibited a shiny metallic appearance (figure 6a), in contrast to the number 5 exhaust valve head, which exhibited a dark heat-tinted appearance (figure 6b). The stem fracture surface (figure 6c) exhibited parallel transverse lines and when viewed from the side (figure 6d) the stem exhibited shear deformation in the same transverse direction. The features were consistent with a shear overstress fracture of the exhaust valve stem. The stem adjacent to the fracture had a pitted/corroded appearance and the combustion face (figure 6e) was comparatively free of combustion products or residues. The valve stem was not located with the wreckage and could not be examined.

The number 6 exhaust valve spring seats exhibited wear and fracture features, as shown in figures 7a and 7b. The lower spring seat exhibited wear of the gold heat tinting on the outer seat, polishing of the inner seat, and wear of the tint on the inboard-facing (cylinder head-facing) side. An approximately 127° arc segment of the outer seat was

fractured, and a crack extended an additional 60° (approx.) beyond one end of the fractured region, as indicated in figure 7b. The fracture was examined by SEM (not shown) and exhibited an intergranular morphology near the inner and outer surfaces. Elsewhere, it exhibited dimple features that were consistent with overstress. The upper spring seat exhibited polishing of the outer and inner seats as indicated in figure 7b. A thumbnail-shaped region had fractured from the seat along its outer circumference. The region was similar in location and size to contact marks observed on the exhaust valve rocker arm, as indicated in figure 8.

In their in-service configuration, the exhaust valve upper spring seats have a recessed cup in the center, with a radially inward-extending flange at the base of the cup. A hole in the center of the flange allows the tip of the valve stem to pass through the base of the seat. Two keys are installed into a groove near the tip of the stem. The keys butt against the seat flange and limit the outward travel of the seat, thereby keeping the valve springs in compression.

The flange at the base of the number 6 exhaust valve spring seat had fractured along an approximately 225° arc segment. The remaining segment is shown in figure 9. The key-facing side of the flange segment exhibited polishing and radially oriented chatter marks. The ends of the segment were beveled and wear was observed into the original flange face. The sidewall of the cup was polished at the level of the keys, as shown in figures 10a – 10d. Approximately 180° (opposite) from the flange segment, there was an additional wear mark and linear mark on the sidewall of the cup closer to the cup's outer entrance, as indicated in figure 10c. For comparison, an image of the number 5 exhaust upper spring seat is shown in figure 11, where no comparable wear marks were observed.

The compression-spring-facing side of the seat is shown in figure 12. The flange fracture had initiated at the fillet radius of the flange to sidewall transition and progressed radially outward and toward the base of the seat. Much of the fracture surface exhibited impact damage and rust-colored wear debris. However, near the edges of the fracture, there were regions that were comparatively undamaged. One region is indicated in figure 12 and shown in figure 13a. The spring seat was cleaned using an alkaline detergent and sonicated in an acetone bath, in accordance with standard laboratory practices. The seat was then examined in the SEM. At the location indicated in figure 13a, the fracture surface exhibited striated features, as shown in figure 13b, consistent with fatigue crack progression. The direction of crack progression, indicated by the yellow arrows, was also consistent with the crack initiating at the fillet transition.

The case hardness depth profile on the number 6 exhaust valve upper spring seat was examined and was found to be in accordance with the material requirements. A wedge-shaped piece of the seat was extracted using a wet abrasive saw and mounted in a block of diallyl phthalate resin with one of the wedge faces oriented downward. The mounted section was then ground and polished in accordance with standard laboratory procedures. Microhardness testing was performed using an automated hardness tester equipped with a Vickers indenter and a 500 g load. Hardness depth profiles were measured along the cup sidewall at three locations. The profiles started at the surface

and proceeded inward at 0.004-inch intervals (the first indent was placed at a depth of 0.004 inch) and the indents were staggered laterally to avoid overlapping one another. The three hardness profiles are shown in figure 14. The measured case depths were in accordance with the material requirement.

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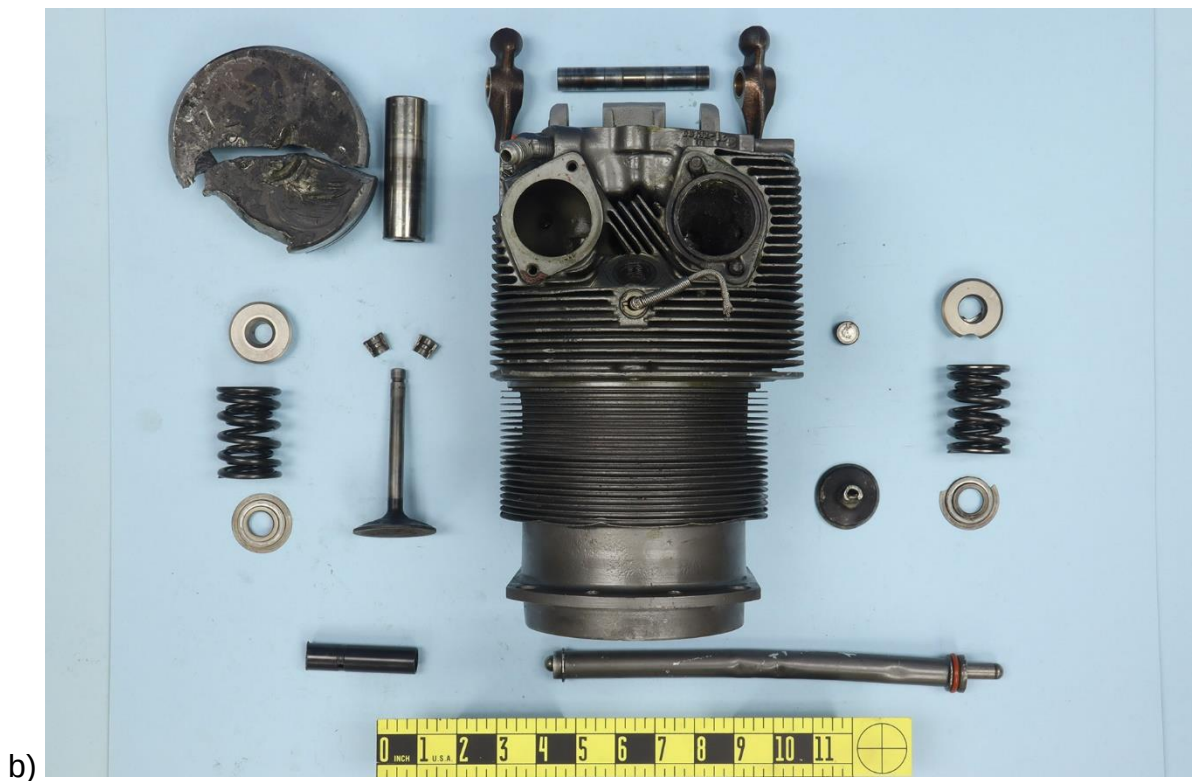


Figure 1: a) Components from number 5 cylinder assembly and associated hardware as received and b) components from number 6 cylinder assembly and associated hardware as received.



Figure 1 (cont.): c) piece of rod found in oil sump.



Figure 2: Images of fractured piston; a) piston-crown side and b) inward side showing fracture in-plane with the pin bosses.



Figure 3: Inside view of number 6 cylinder head showing damage to the exhaust valve seat and surrounding material.

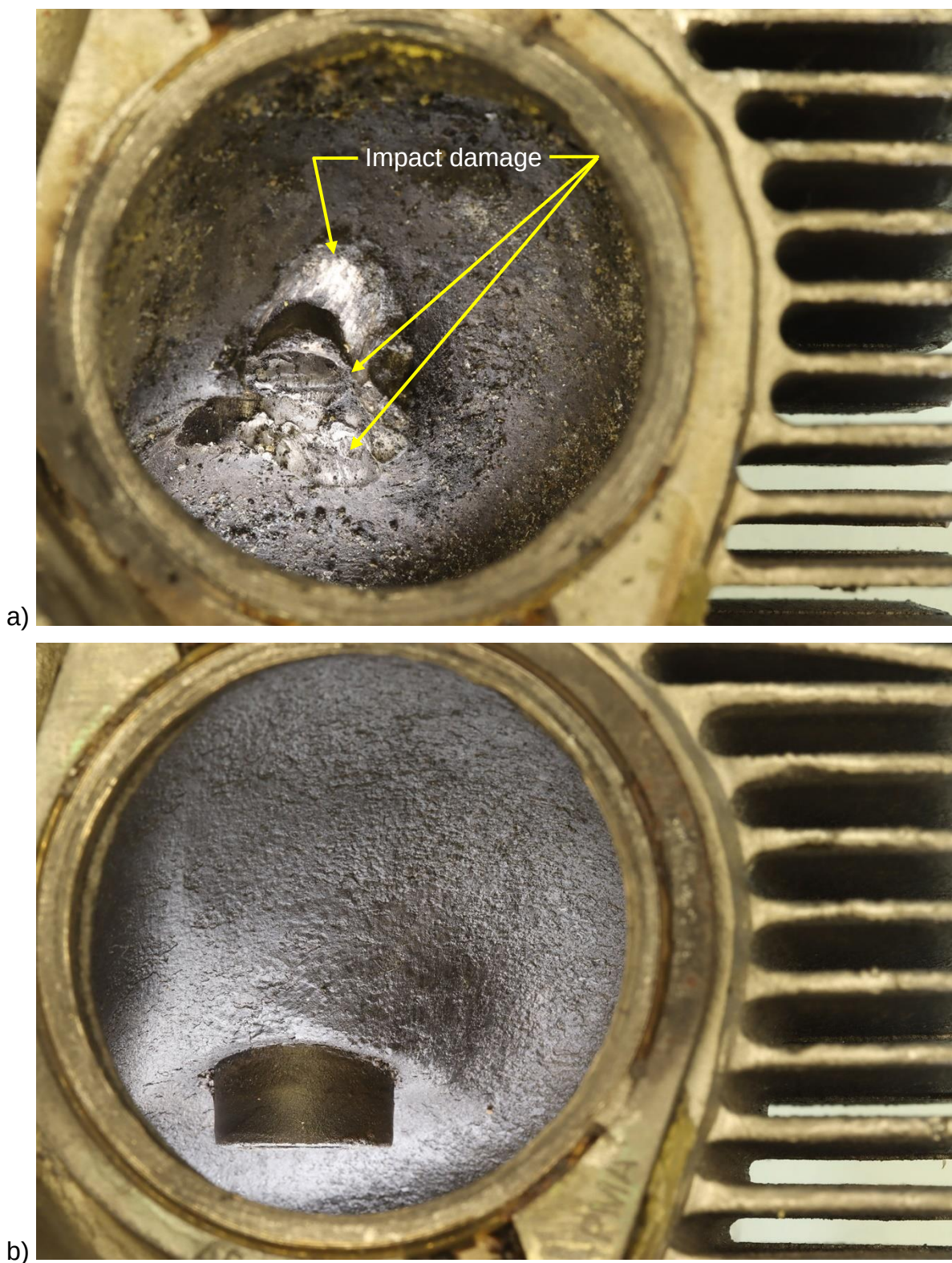


Figure 4: Image of exhaust valve guides as seen from the exhaust port; a) number 6 cylinder and b) number 5 cylinder. The valve guide and surrounding material on the number 6 cylinder exhibited features consistent with impact damage.

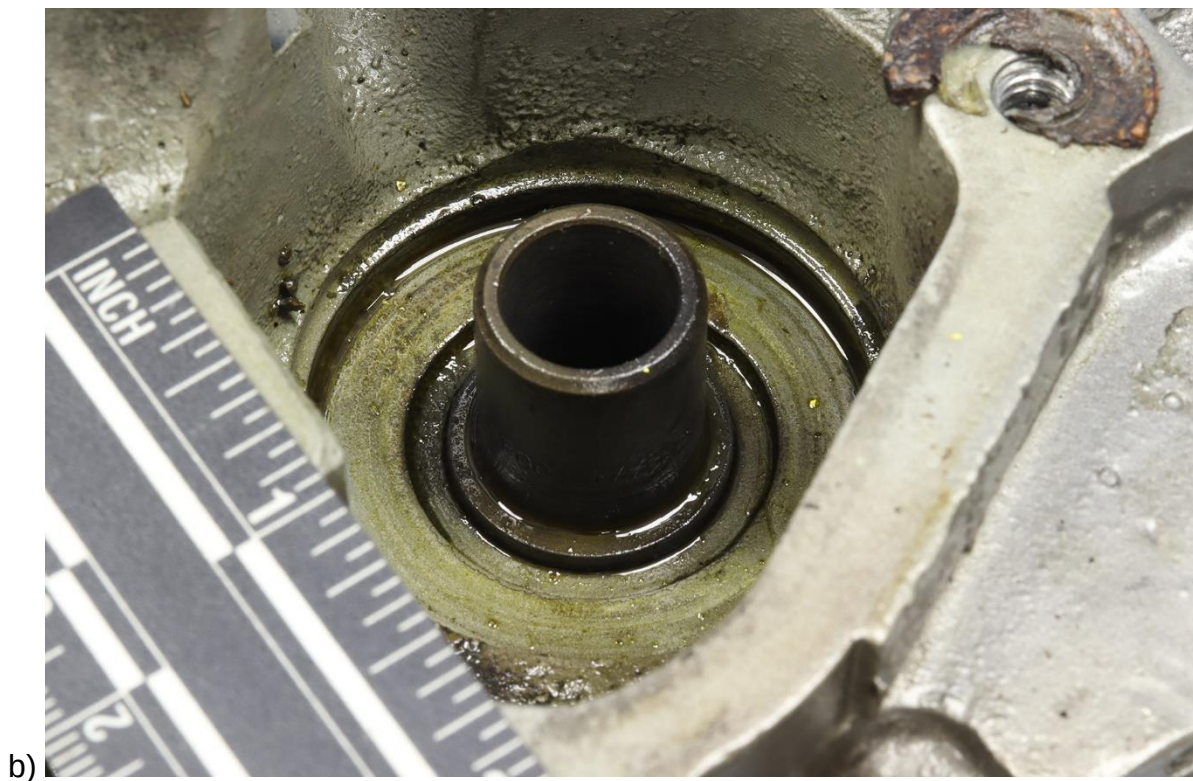


Figure 5: Images of the exhaust valve guides; a) number 6 cylinder and b) for comparison, number 5 cylinder.



Figure 6: a) Image of the number 6 exhaust valve showing the fractured stem, outer face of the valve head and valve seat face; b) image of the number 5 exhaust valve;



Figure 6 (cont.): c) higher magnification image of the stem fracture; d) side view showing shear deformation of stem adjacent to fracture; and



Figure 6 (cont.): e) image showing the combustion face of number 6 exhaust valve.

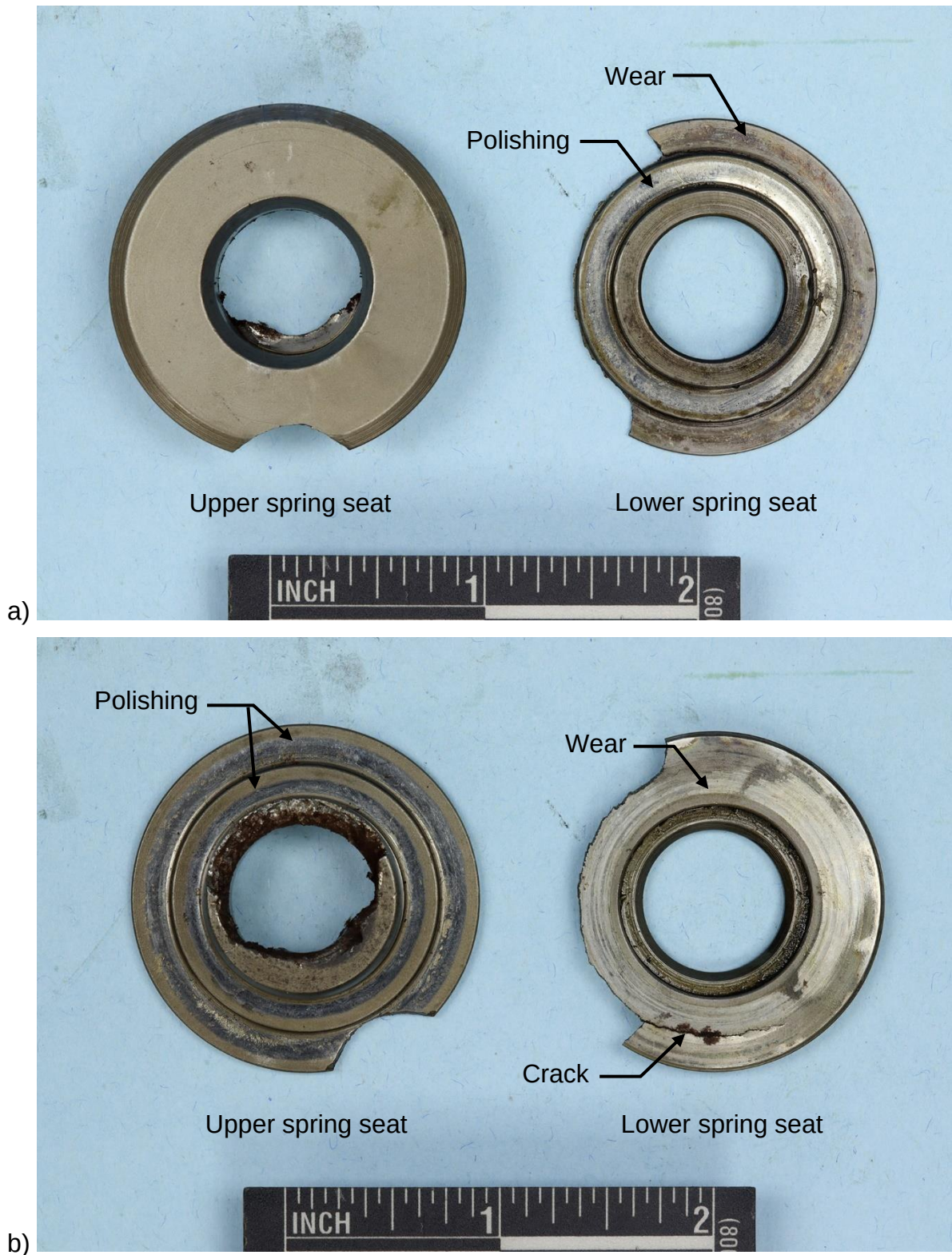


Figure 7: Images of the number 6 cylinder exhaust valve spring seats; a) outboard-facing sides of upper and lower seats and b) inboard-facing sides.

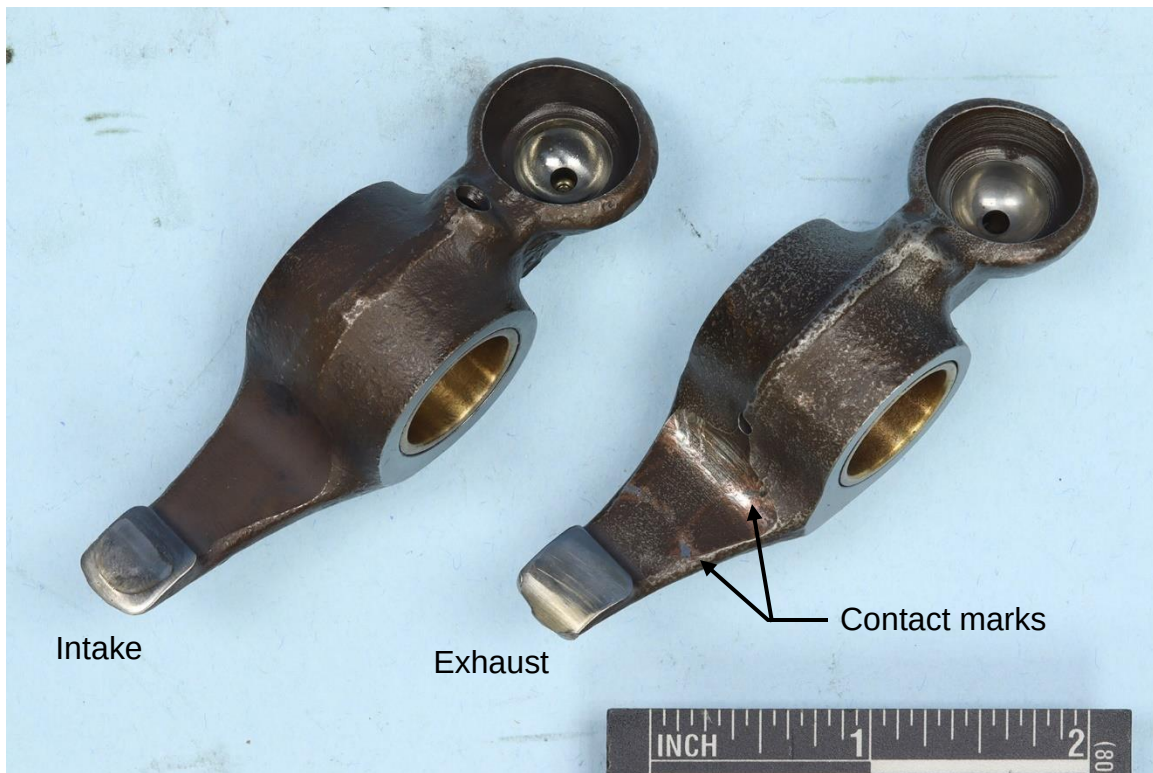


Figure 8: Number 6 cylinder intake and exhaust valve rocker arms. The exhaust valve exhibited contact marks as indicated.

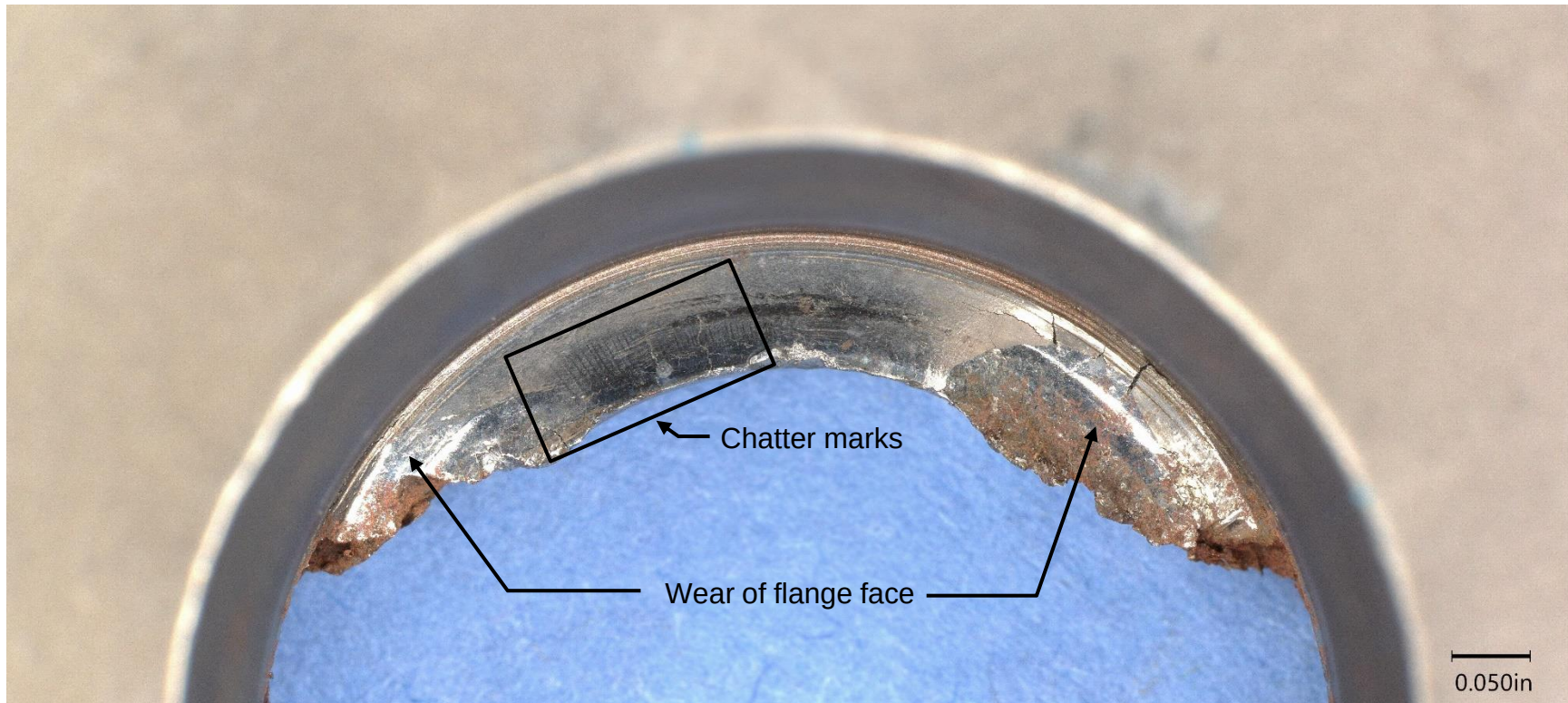


Figure 9: Image showing the remaining flange segment at the base of the number 6 exhaust valve upper spring seat cup.



Figure 10: Images of the number 6 exhaust valve upper spring seat cup sidewall; a) 0°; b) 90°;



Figure 10 (cont.): c) 180°; and d) 270°.

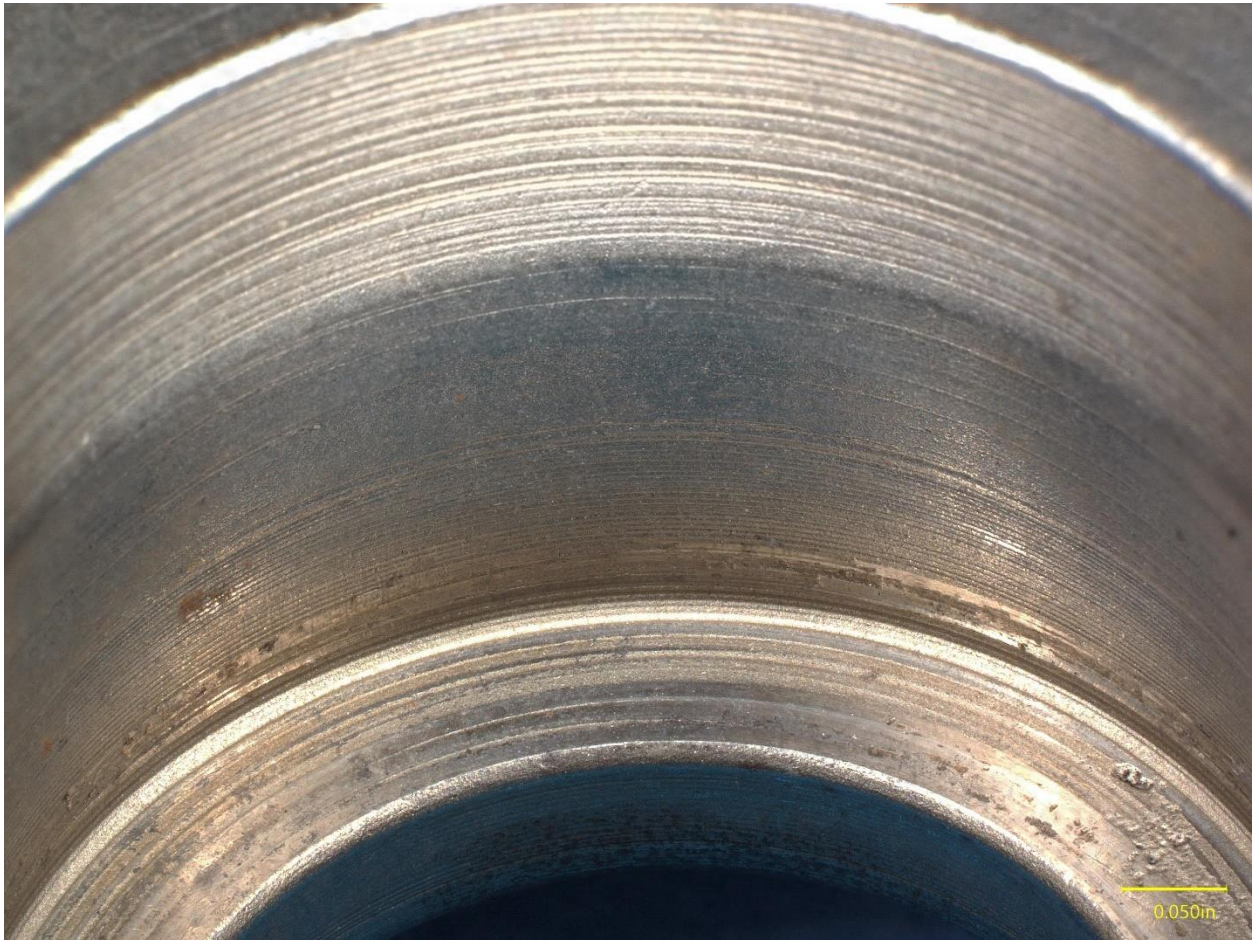


Figure 11: Image of the number 5 exhaust valve upper spring seat cup.

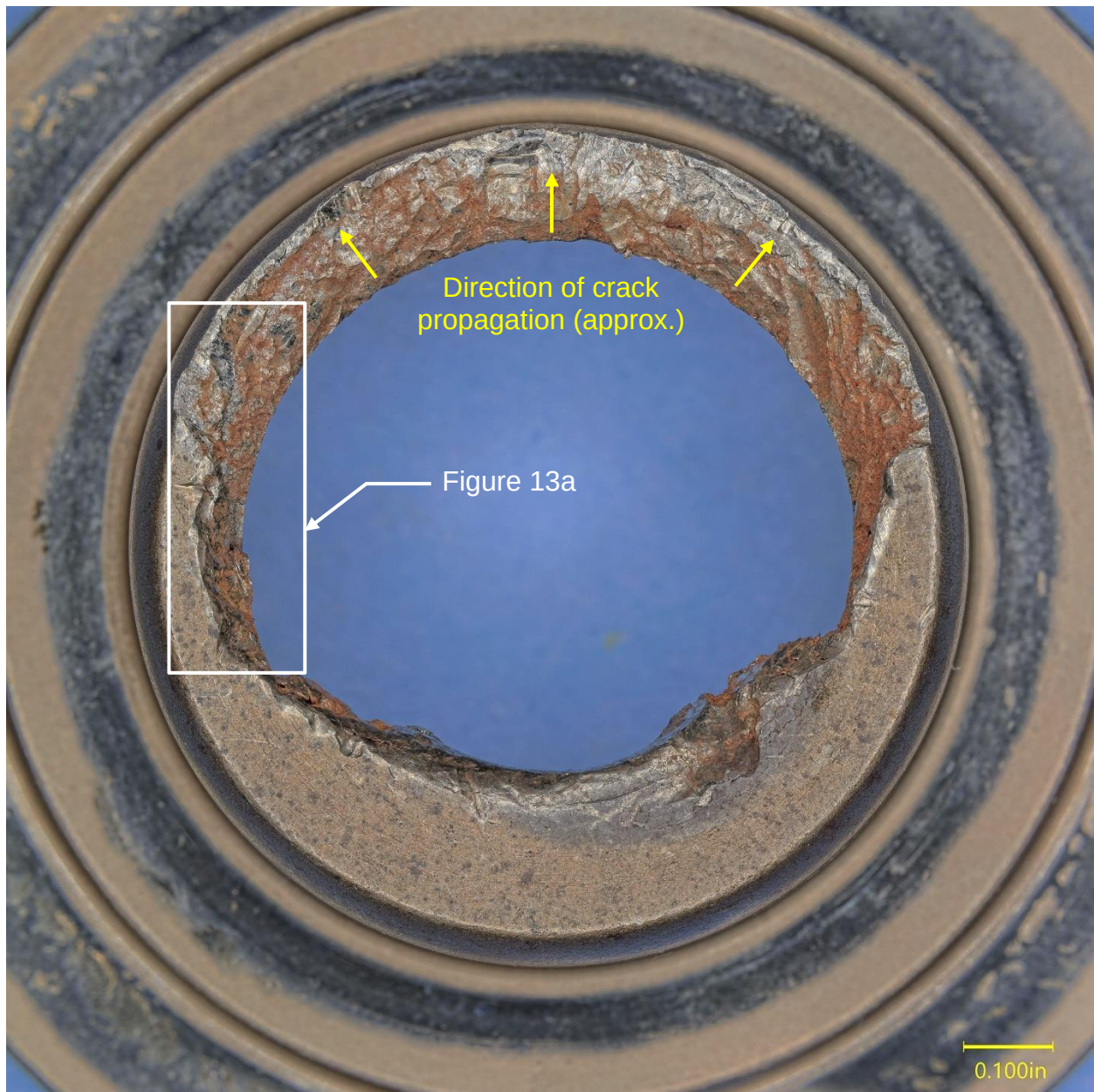


Figure 12: Compression-spring-facing side of number 6 exhaust valve upper spring seat showing extent of fracture at the base of the cup as well as impact damage and rust colored wear debris.

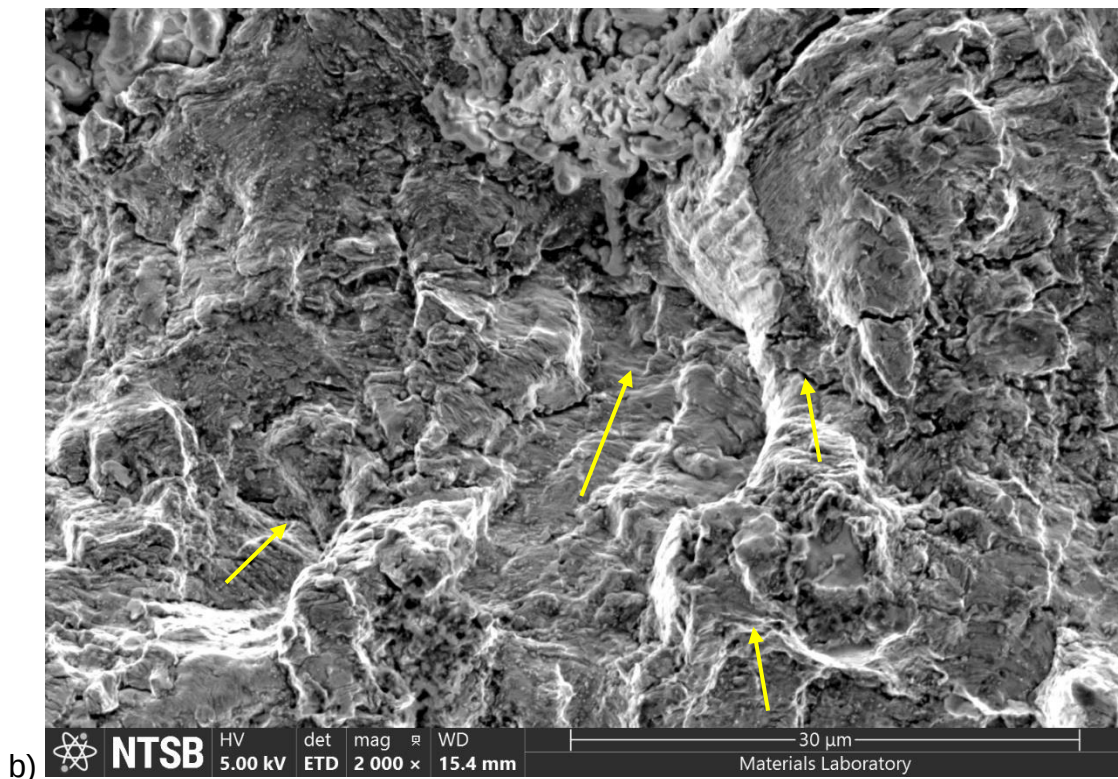


Figure 13: a) Image of fracture as indicated in figure 12 and b) SEM image in the area indicated in figure 13a exhibiting striated features, consistent with fatigue crack propagation.

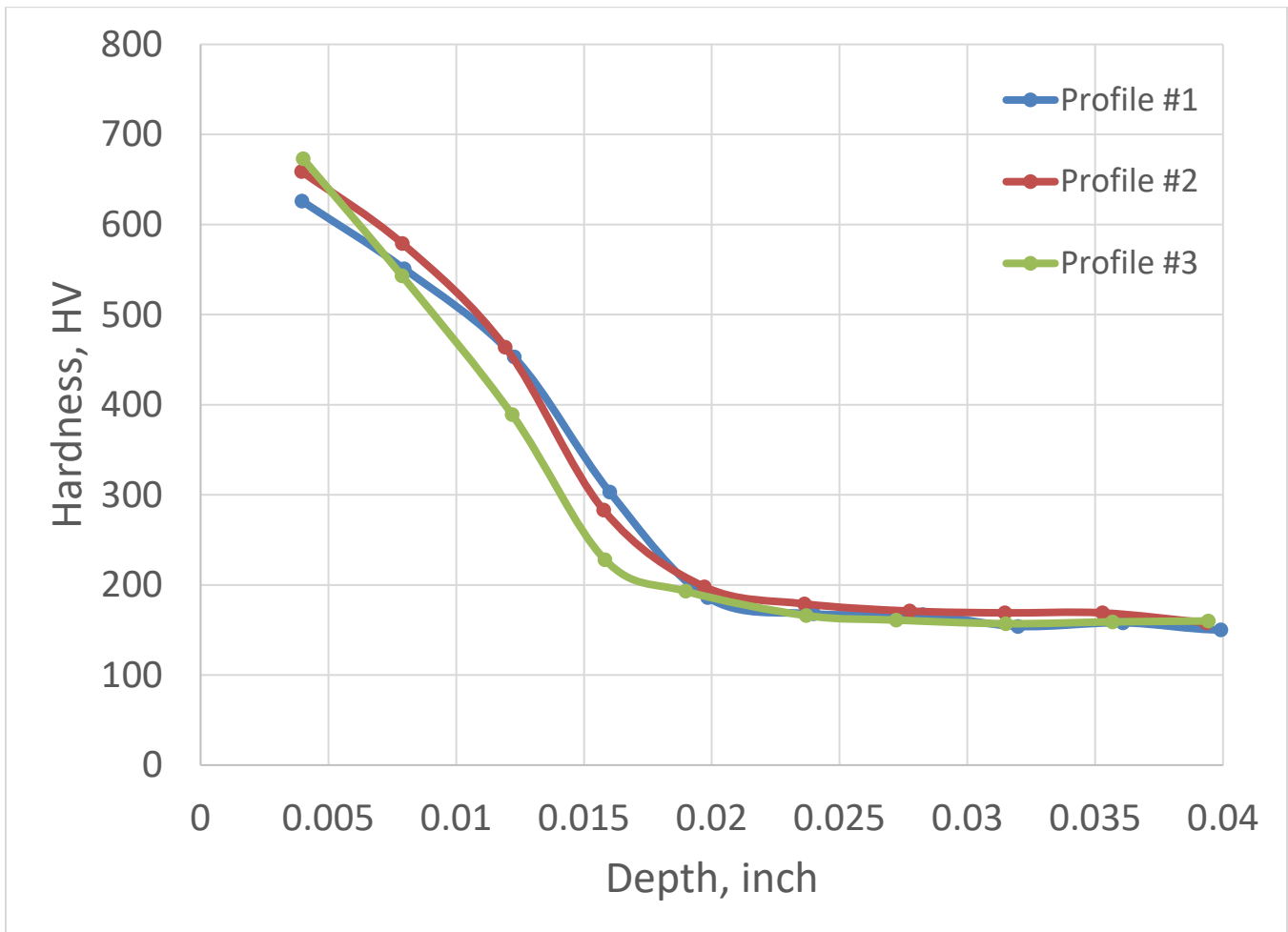


Figure 14: Case depth profiles on the number 6 exhaust valve upper spring seat. Vickers hardness with 500 g load.

APPENDIX A: EXCERPT FROM O-540 ILLUSTRATED PARTS CATALOG

CYLINDER, PISTON AND VALVE TRAIN
VALVE ASSEMBLY AND RELATED PARTS

FIG. REF. 17	PART NUMBER	DESCRIPTION	O N A L L	QUANTITY PER ASSEMBLY									
				B 1 A 5	B 1 B 5	B 2 B 5	B 2 C 5	B 4 B 5	E 4 A 5	E 4 B 5	E 4 C 5	G 1 A 5	G 2 A 5
1	73938	VALVE, Intake	6										
2	LW-19001	VALVE, Exhaust (rotator type)	6										
3	65441	SEAT, Valve spring, lower intake	6										
4	LW-13323	SEAT, Valve spring, lower exhaust	6										
5	LW-10077	SEAT, Valve spring, upper intake	6										
6	LW-16475	SEAT, Valve spring, upper exhaust (rotator type)	6										
7	60009	KEY, Valve, intake	12										
8	17C21191	KEY, Valve, exhaust (rotator type)	12										
9	17C19386	CAP, Valve stem, exhaust (rotator type)	6										
10	LW-11795	SPRING, Valve, inner	12										
11	LW-11800	SPRING, Valve, outer	12										
12	1102	PLUG, 1/8 pipe x 3/8 long	2										
13	LW-18661	SEAL, Shroud tube	12										
14	70310	SEAL, Shroud tube	12										
15	LW-11485	TUBE, Push rod shroud	12										
16	LW-14995	SPRING, Shroud tube	6										
17	LW-12272	LOCKPLATE, Shroud tube	6										
18	STD-1411	NUT, 1/4-20 plain	6										

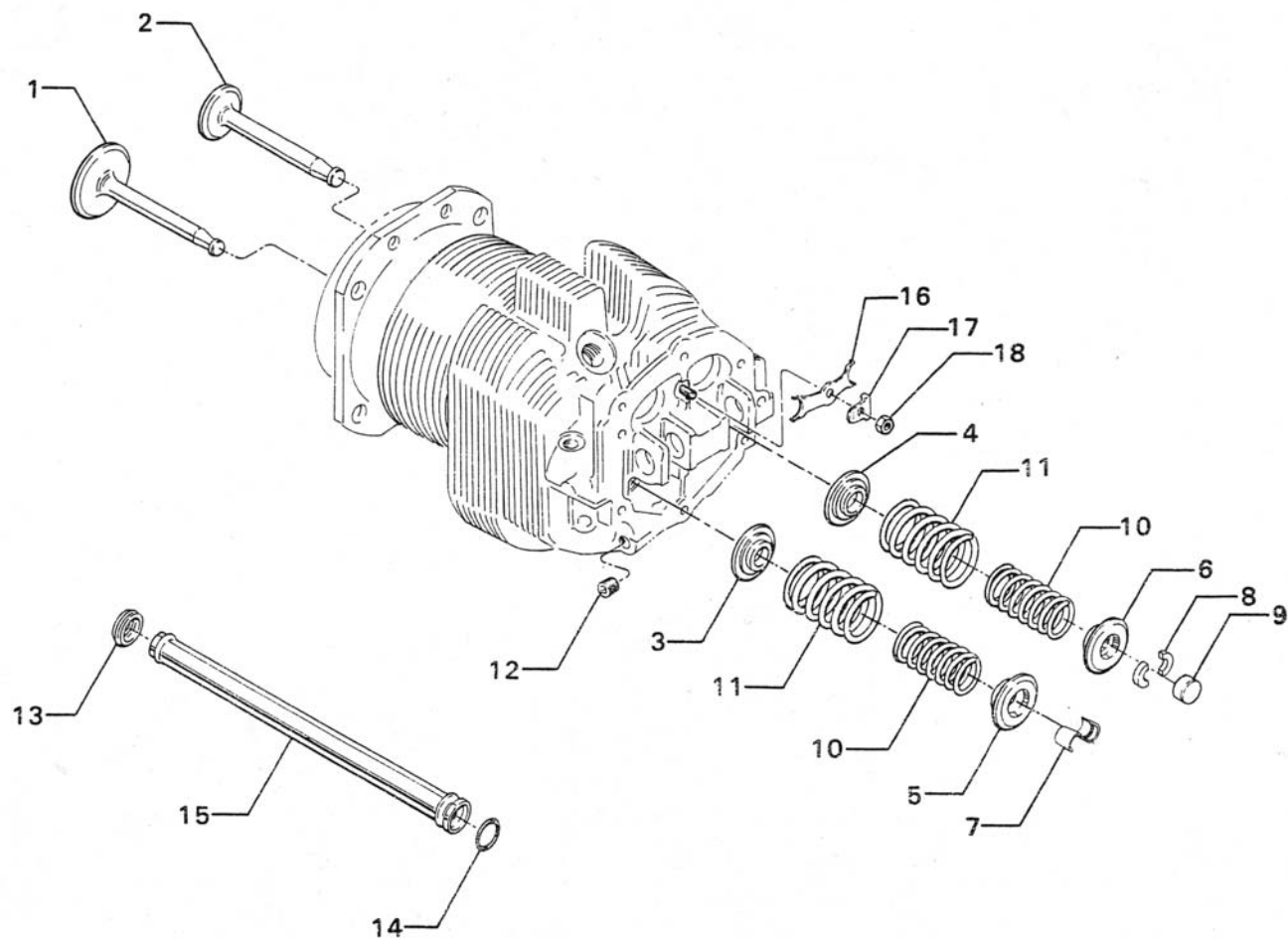


FIGURE 17. VALVE ASSEMBLY AND RELATED PARTS