National Transportation Safety Board
Office of Research and Engineering
Washington, DC 20594

CEN23LA107

MATERIALS LABORATORY

Factual Report 23-076

October 12, 2023

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A. ACCIDENT INFORMATION

Location: Lakeway, Texas
Date: February 12, 2023
Time: 09:58 central daylight time
14:58 coordinated universal time
Vehicle: Mooney M20K, N304MA
Investigator: Michael Hodges, AS-CEN

B. COMPONENTS EXAMINED

Pistons
Cylinders
Connecting Rods
Bags of debris

C. EXAMINATION PARTICIPANTS

Specialist Erik Mueller, Ph.D., P.E.
Office of Research and Engineering – Materials Laboratory Division
NTSB, Washington, DC

D. DETAILS OF THE EXAMINATION

On February 12, 2023, a Mooney M20K airplane sustained substantial damage when it was involved in an accident near Lakeway, TX. The pilot sustained no injuries. The pilot reported that while in flight, the engine exhibited low manifold pressure followed by a total loss of engine power. The pilot forced a landing on a golf course, and the airplane sustained substantial damage to the fuselage and both wings.

The Federal Aviation Administration examination of the site and wreckage reported a large amount of engine oil was observed trailing rearwards on the underside of the fuselage. The engine oil level was checked after the accident, and the oil was not marked on the dipstick. The airplane had a Continental Motors TSIO-360-MB reciprocating engine and a Hartzell metal 3-blade constant-speed propeller. The aircraft service time on the Hobbs meter stated 2763.7 hours. Several components from the engine were sent to the NTSB Materials Laboratory for additional examination.

Figure 1 shows the parts submitted to the Materials Laboratory for examination. These parts included cylinders, pistons, and connecting rods from the #2, 4, and 6 positions, as well as logbooks and various debris collected from the engine.

Figure 2 illustrates the components received from the #2 engine position—these included the cylinder assembly, piston assembly with connecting rod, and a section of the cylinder barrel. As with all the cylinders submitted in this case, the upper housing had been removed prior to receipt. The upper components are shown in Figure 3, illustrating the rockers, retainers, and the underlying springs and valves. There were no visible indications of damage in these component surfaces.

Figures 4 and 5 show the other exterior surfaces of the #2 cylinder assembly. There were no indications of deformation to the cooling fins or overheating, such as discoloration or deposits on the exterior. Figure 6 shows the interior of the #2 cylinder, the crown, and the faces of the intake and exhaust valves as received. This view shows the larger intake valve face on the left, colored brownish-tan with darker edges, and the smaller exhaust valve face on the right, showing a darker color and a rougher surface, consistent with adherence of combustion deposits.

These deposits were present along the cylinder crown surface, particularly around the lower spark plug hole in Figure 6. There were indications of erosion and material loss just below the intake valve seat in the lower left in the figure, as exemplified by the lighter color in the figure. In addition, the opposite sides of the cylinder barrel surfaces exhibited parallel wear streaks along the direction of the piston actuation (on the left and right sides of the bore in Figure 6).

Figure 7 shows the section of the cylinder that had been sectioned from the rest of the barrel. This piece exhibited plastic deformation, consistent with an inward direction. The plastic deformation indicated batter, consistent with impacts against an adjacent metallic component.

Figure 8 shows the piston assembly from opposite sides, as received. While the connecting rod was still affixed to the piston via the pin, the cap and bearings had been disassembled from the rest of the connecting rod. One of the flanges of the connecting rod exhibited minor indentation (Figure 8a) but was otherwise unblemished. The sides of the piston, as exemplified in Figure 8b, show indications of upward plastic deformation near one of the ends of the piston pin.

Figure 9 shows the condition of the connecting rod bearings. The bearings exhibited circumferential streaking consistent with rotational motion against the crankshaft journal. The wear pattern on the bearing interior surfaces revealed a center area of smoother, more reflective material flanked with opposite areas of rougher, duller surfaces.

Figure 10 shows the components from the #4 position—a cylinder and piston assembly. Figures 11 and 12 show the exterior of the cylinder, which exhibited little visual indication of damage outside of nicks in the paint. The opened housing area is

shown in Figure 13, revealing the internal rockers and other components, which were absent visual indications of impact damage or deformation.

Figure 14 shows the interior of the cylinder. The face of the intake valve exhibited a dull gray color, and the smaller exhaust valve face displayed a central dark area with an outer band of maroon-brown coloring consistent with combustion deposits. In addition, white and tan combustion deposits were present along the crown's surface, with the white deposits mainly located around the spark plug holes. In the lower left of Figure 14, some of the deposits had spalled from the cylinder interior surface.

Figure 15 shows opposite views of the piston assembly. The connecting rod, cap, and bearings were still attached and assembled. There were no indications of damage to the outside skirt of the piston or the connecting rod components. However, the crown of the piston, shown in Figure 16, illustrates the heavy deposits present on that surface. The deposits were thick enough to exhibit large protruding chunks, with the one in the upper right consistent with the spalled material on the cylinder in Figure 14. The deposit pattern on the piston matched that of the corresponding cylinder crown and valve faces shown in Figure 14.

Figure 17 shows the components from the #6 position of the engine—the cylinder and piston assemblies along with several pieces of debris from the piston. Figure 18 shows the exposed upper portion of the cylinder assembly, revealing the rockers, retainers, and other components in this space. Figures 19 and 20 illustrate the other exterior surfaces of the cylinder assembly. Of note was the downward plastic deformation and partial fracture of the upper six cooling fins on the intake port side of the cylinder (see Figures 19b and 20b).

Figures 21 and 22 show the interior of the cylinder, which illustrates the condition of the crown and valve face surfaces. Similar to the surfaces of the other two cylinders, there were indications of combustion deposits on many of the surfaces in Figure 22. However, the #6 cylinder also exhibited a surface sheen of oil, along with adherent fines consistent with metal wear abrasives. In addition, the cylinder crown exhibited two hourglass-shaped divots or depressions between the two valve seats. These divots were located next to the spark plug holes, as illustrated in Figure 23 after removing the valves. The valve seat periphery of the exhaust valve contained the same combustion deposits as the rest of the cylinder crown surface. However, the intake valve seat perimeter was absent of such deposits. There were no visible cracks in the edges of either valve seat.

Figures and 25 show the different views of the piston assembly from the #6 cylinder position as received. Of note on the piston skirt were the minor batter marks near the piston pin face on the side in Figure 24b. In addition, the long sides of the piston skirt exhibited longitudinal streaks and gouges, consistent with comparable wear patterns along the barrel of the cylinder. The wear was severe enough to deform and smear

several piston oil rings (lower left in Figure 25a). The flanges of the connecting rod also exhibited minor impact marks (shown in Figure 24a), consistent with contact against adjacent metallic objects.

The most pronounced damage was the hole and missing material on the corner of the piston crown, exemplified in Figure 26. This hole penetrated through the piston cross-section and was consistent with missing material and local fracturing of one of the oil rings. Figure 27 shows a perpendicular view of the corner damage, demonstrating the degree of material loss of the crown in that location.

Figure 28 shows an angled view of the damage to the piston corner after disassembly and removal of the pin and connecting rod. The dimensions of the hole were measured using digital calipers, with the length being upwards of 1.28 inches long and the width up to 0.28 inches. When measured from the interior, the hole width was 0.34 inches wide (the length could not be measured with this technique from inside). The chord length of the crown damage in Figures 28 and 29 was 2.52 inches long, with 0.26 inches of crown height absent above the ring.

The corner of the damage and hole exhibited discoloration, darkening, and heat tinting. The periphery of the hole exhibited material thinned to an edge. These features were consistent with a high-temperature burn-through of the part. There were also longitudinal wear marks and streaks near the hole, consistent with material rubbing between the piston and the adjacent cylinder barrel. This rubbing and deformation extended to the ring material near the piston hole.

The rest of the piston crown exhibited white deposits, consistent with combustion deposits. The degree of deposition was less than on the top of the #4 piston.

Figures 30 and 31 show the interior of the #6 piston. Figure 30 shows the hole in the corner, which exhibited a greater width than the exterior measurements. Figure 31 demonstrates the deposits in the surfaces of the piston, along with the varnishing of the surfaces.

The #2 and #6 cylinders were completely disassembled, and the intake valves from each, shown in Figure 32, were measured to determine any differences in dimensions. The dimensions are listed in Table I. While the length of the #6 intake valve was longer by over 0.01 inches, this valve also exhibited more combustion deposits.

Figures 33 and 34 show different views of each valve, demonstrating the difference in surface deposits. Those on the #2 valve were browner in color and flatter over the exposed surfaces on the face, seat, and stem. In contrast, the combustion deposits on the #6 intake valve were darker and more globular and tortuous, with a reflective sheen consistent with engine oil and metal fine deposits.

Examination of the spark plugs performed outside of the Materials Lab showed that the #6 spark plugs exhibited more surface deposits than those of the number 2 and 4 cylinders (see Figures 35 and 36). While all the spark plugs exhibited combustion deposits to some degree, the #6 plug in Figure 36 exhibited dark deposits enough to obscure the electrode surfaces. Further, the #6 spark plug in Figure 35 revealed more deposits, showing engine oil and protruding debris on all the exposed surfaces.

A review of recent maintenance logs of the three years prior to the February 12 accident are detailed in Table II. These records show that there had been no noted issues concerning a lack of compression or leaking oil during the maintenance performed. Further, there was no notation regarding combustion deposits or piston damage.

Submitted by:

Erik M. Mueller
Materials Research Engineer

Table I – Various measurements of the #2 and #6 intake valves.

Intake Valve Number	Length (in)	Stem Diameter (in)	Face Diameter (in)
2	4.366	0.374	2.042
6	4.377	0.374	2.045

Table II – Recent logged maintenance of the airplane engine for the three years prior to the accident that occurred in February 12, 2023 (2763.7 hours).

Date	Service Time (hrs.)	Time Prior to Accident (hrs.)	Maintenance Details
February 10, 2023	2757.9	5.3	Turbocharger overhauled; engine leak test performed with no noted issues
October 8, 2022	2732.4	31.3	Engine compression checked, spark plugs cleaned and re-gapped with a new plug installed in #2 position, fuel injectors serviced, oil changed, and new oil and air filters installed
July 11, 2022	2691.6	72.1	Oil and filter change, no cuttings or leaks found
April 4, 2022	2669.0	94.7	Changed oil and installed new filter with leak check
September 18, 2021	2641.3	122.4	Engine compression checked, spark plugs cleaned and gapped, fuel injectors serviced, engine oil and new filter installed
April 21, 2021	2604.6	153.3	Oil and filter change, no cuttings or leaks found
August 25, 2020	2559.4	204.3	Engine compression checked with magneto timing, spark plugs cleaned and gapped, fuel injectors serviced, engine oil and new filter installed after oil sample tested. Service also replaced the aft alternator belt and repaired the alternator cooling duct attach point while adjusting manifold pressure
June 24, 2020	2537.9	225.8	Oil and filter change, no cuttings or leaks found
December 2, 2019	2512.0	251.7	Changed oil and installed new filter, cleaning pressure, and suction screens

Figure 1. The piston assemblies and cylinders from the #2, 4, and 6 positions, with miscellaneous debris and small remnants.

Figure 2. The cylinder and the piston with connecting rod from the #2 position. The connecting rod had been partially disassembly, and a section of the cylinder skirt had been removed.

Figure 3. View of the top of the #2 cylinder, showing the rockers and retainers.

Figure 4. View of the exhaust port side of the #2 cylinder, as received.

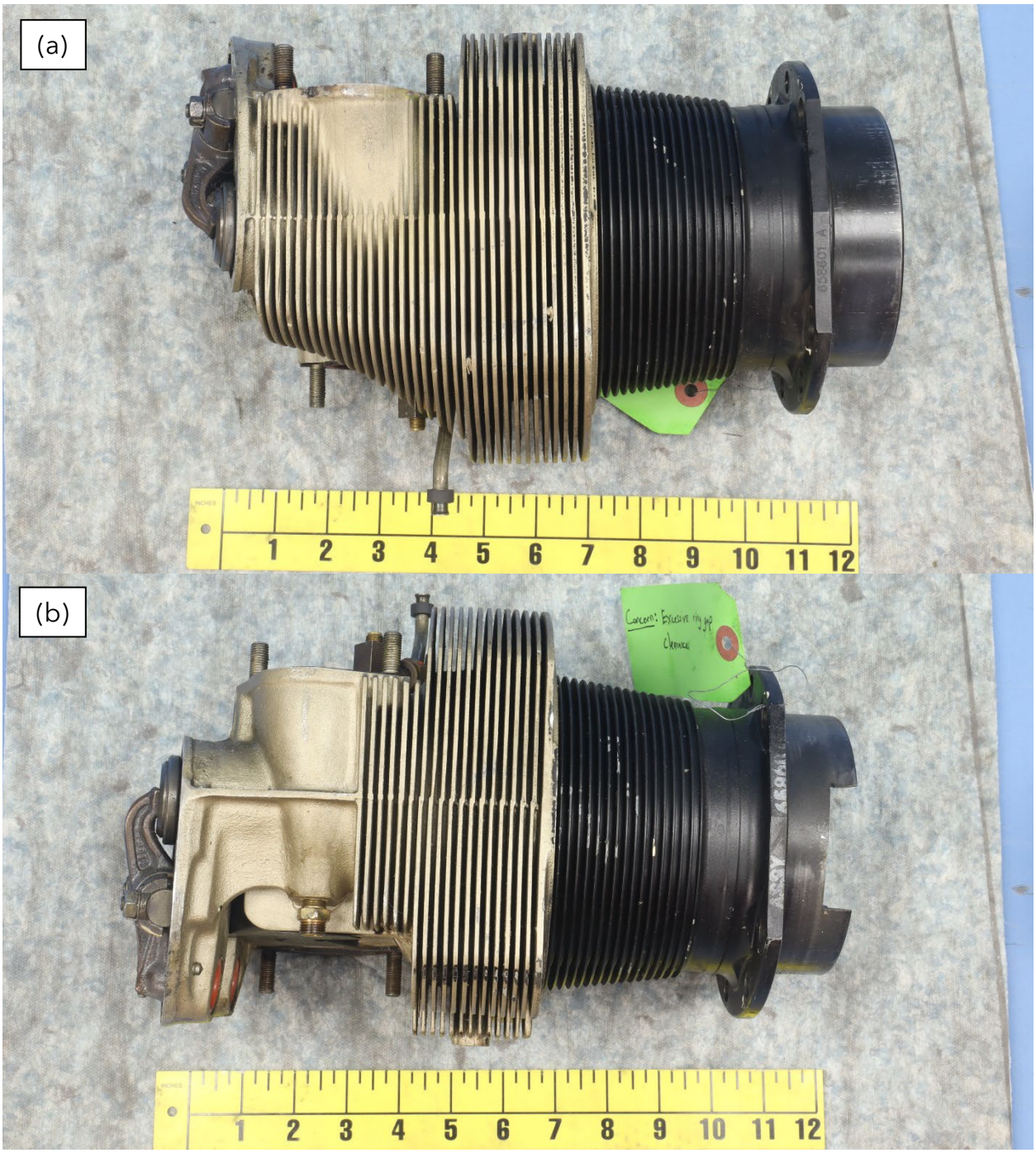

Figure 5. Opposite view of the sides of the #2 cylinder exterior.

Figure 6. The interior of the #2 cylinder, showing the crown and valve faces.

Figure 7. View of the piece sectioned from the #2 cylinder skirt.

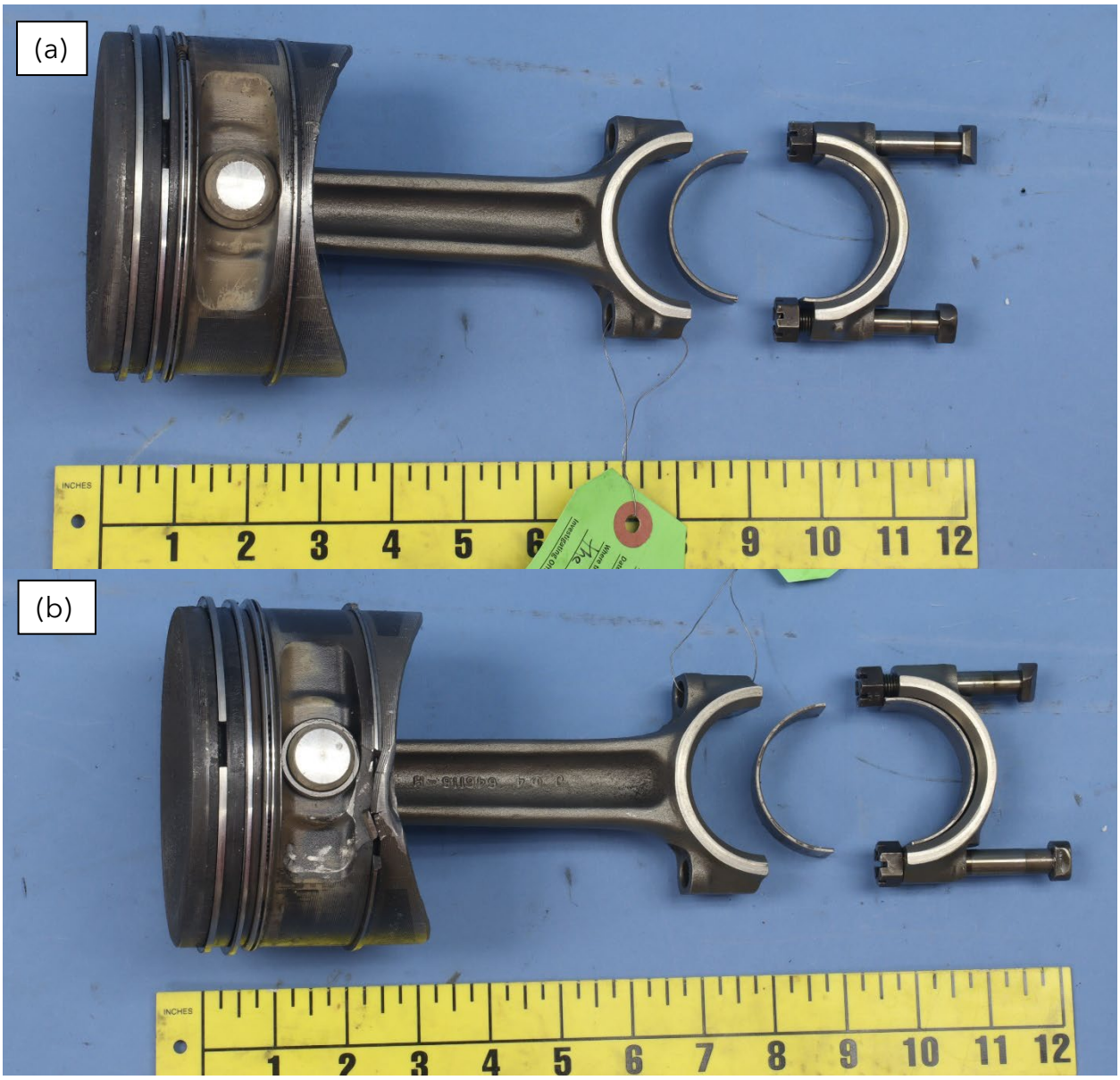

Figure 8. View of the opposite side of the #2 piston and connecting rod assemblies.

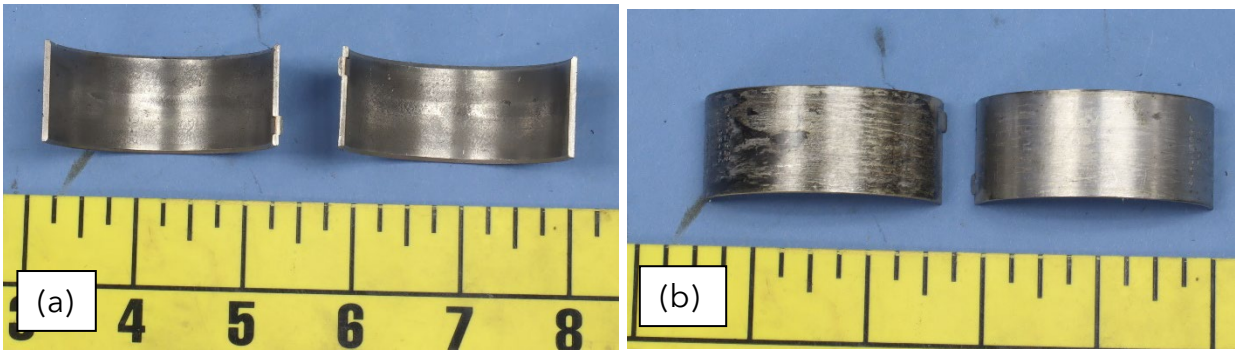

Figure 9. Views of the (a) interior and (b) exterior surfaces of the conrod bearings.

Figure 10. The #4 cylinder, piston and connecting rod assemblies, as received.

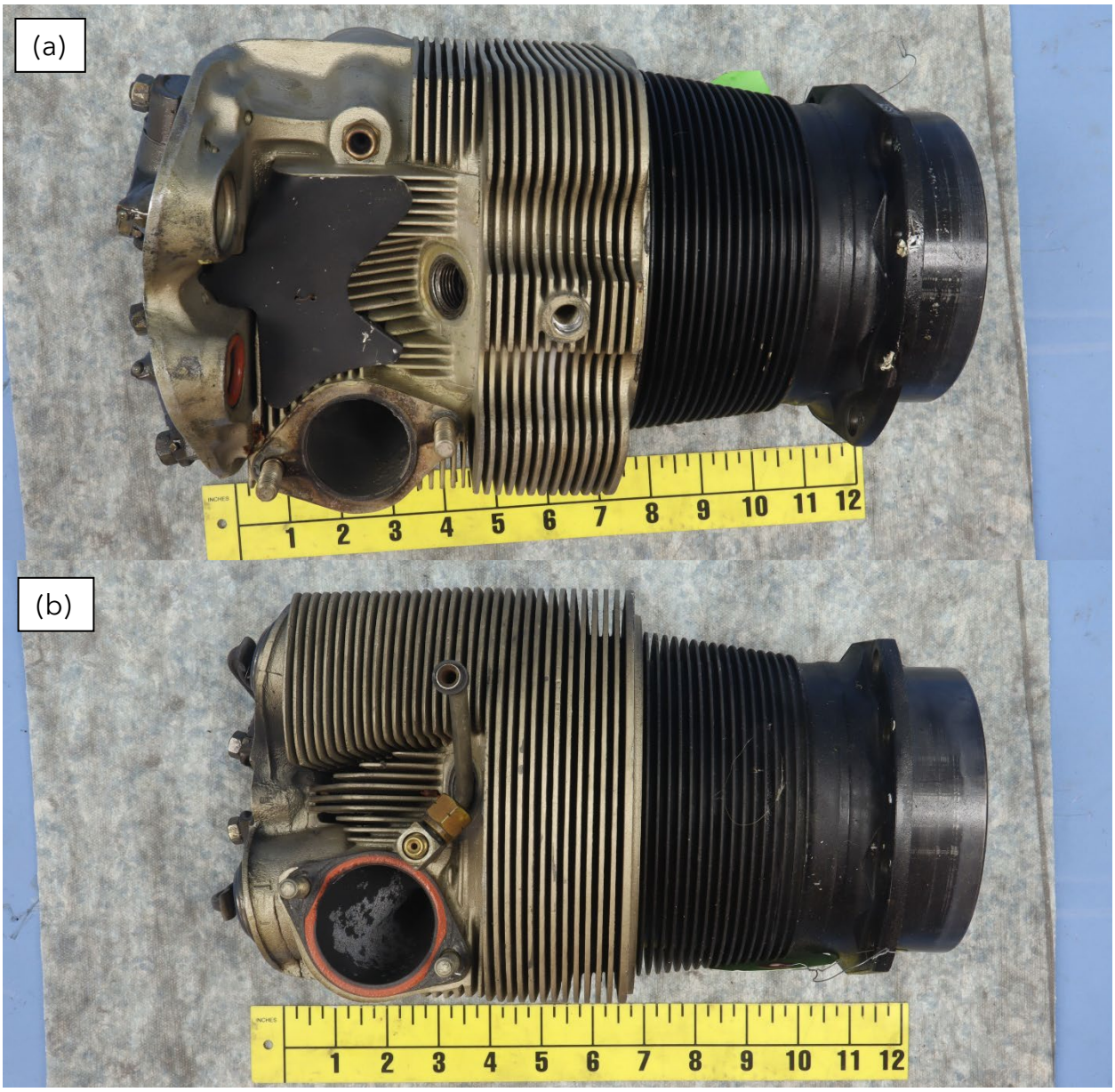

Figure 11. Opposite views of the #4 cylinder from (a) exhaust and (b) intake port sides.

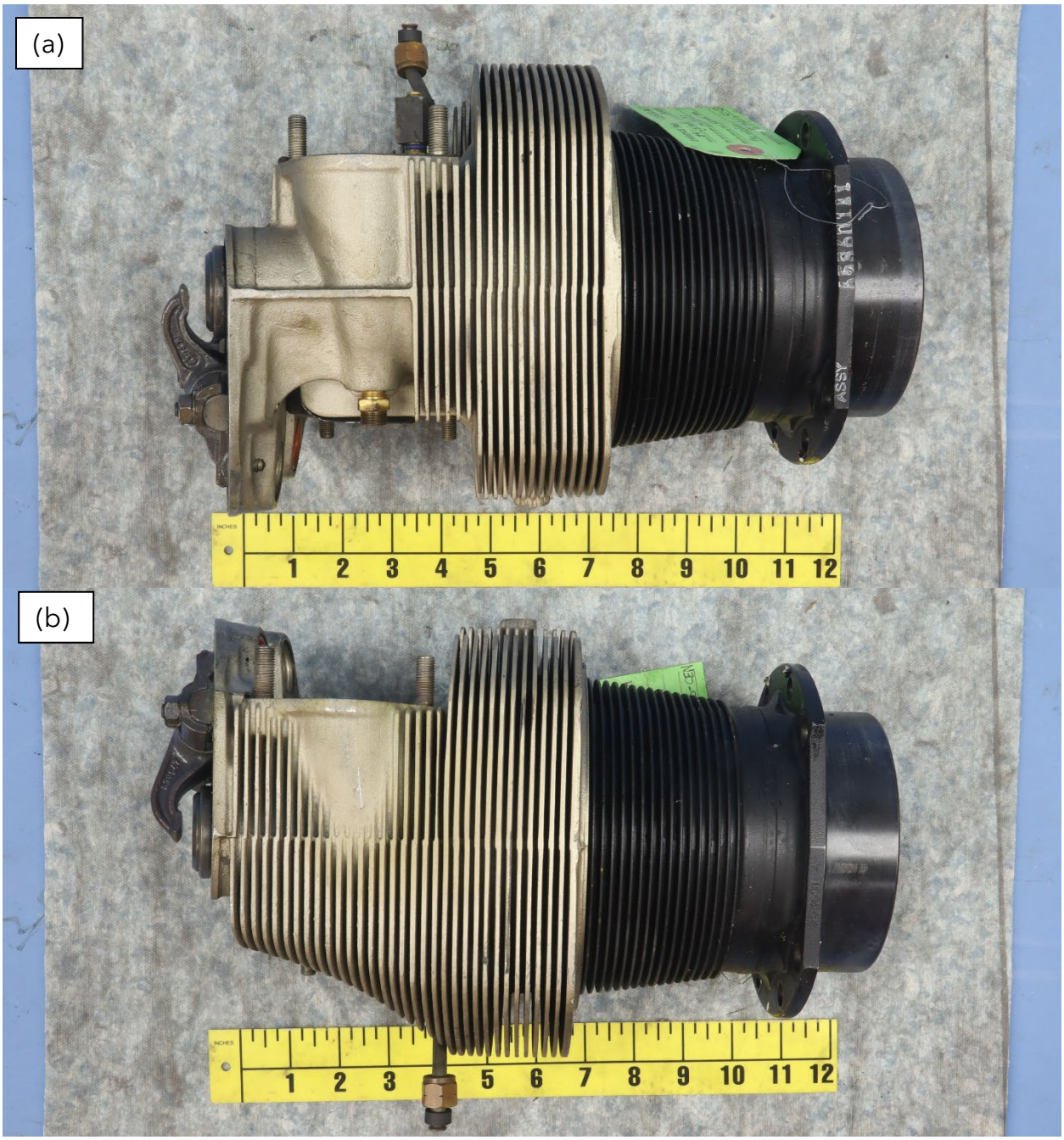

Figure 12. View of the other two sides of the #4 cylinder, as received.

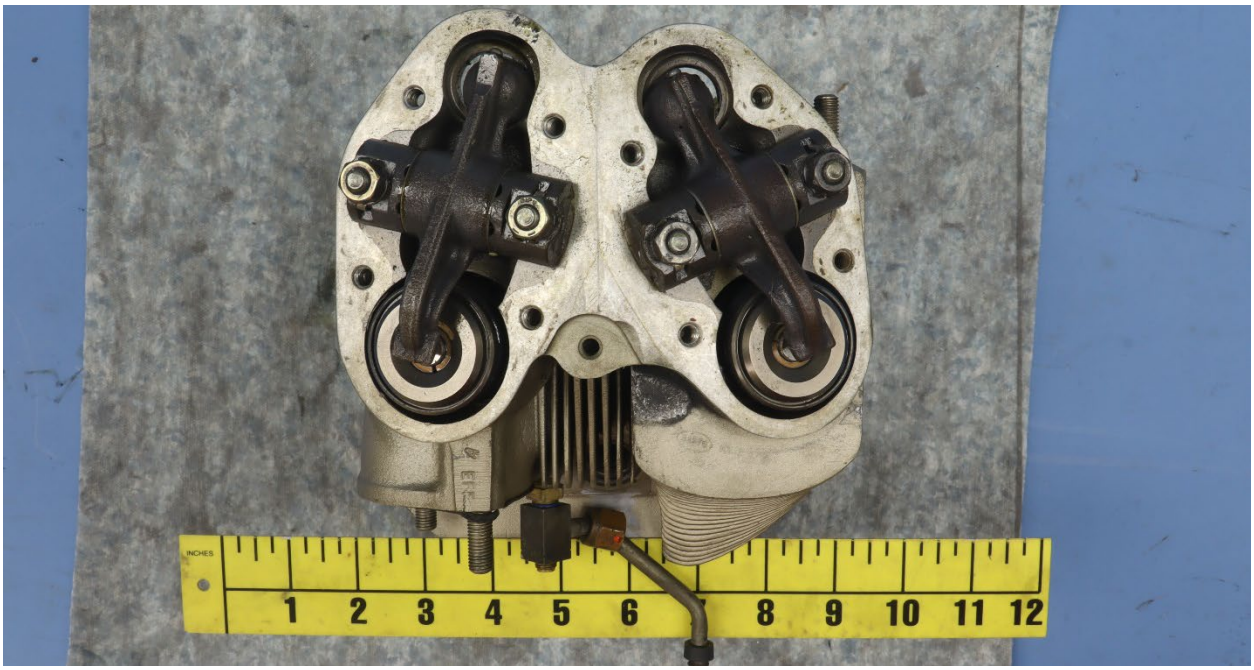

Figure 13. View of the top of the #4 cylinder, as received, showing the rockers and retainers.

Figure 14. View of the interior of the #4 cylinder, showing the crown and valve faces.

Figure 15. Opposite views of the #4 piston and connecting rod assembly.

Figure 16. View of the deposits on the #4 piston crown.

Figure 17. The #6 cylinder and piston assemblies, as received.

Figure 18. View of the opened top of the #6 cylinder showing the rockers and retainers.

Figure 19. Opposite views of the two sides of the #6 cylinder, as received.

Figure 20. Opposite views of the #6 cylinder from (a) exhaust and (b) intake port sides.

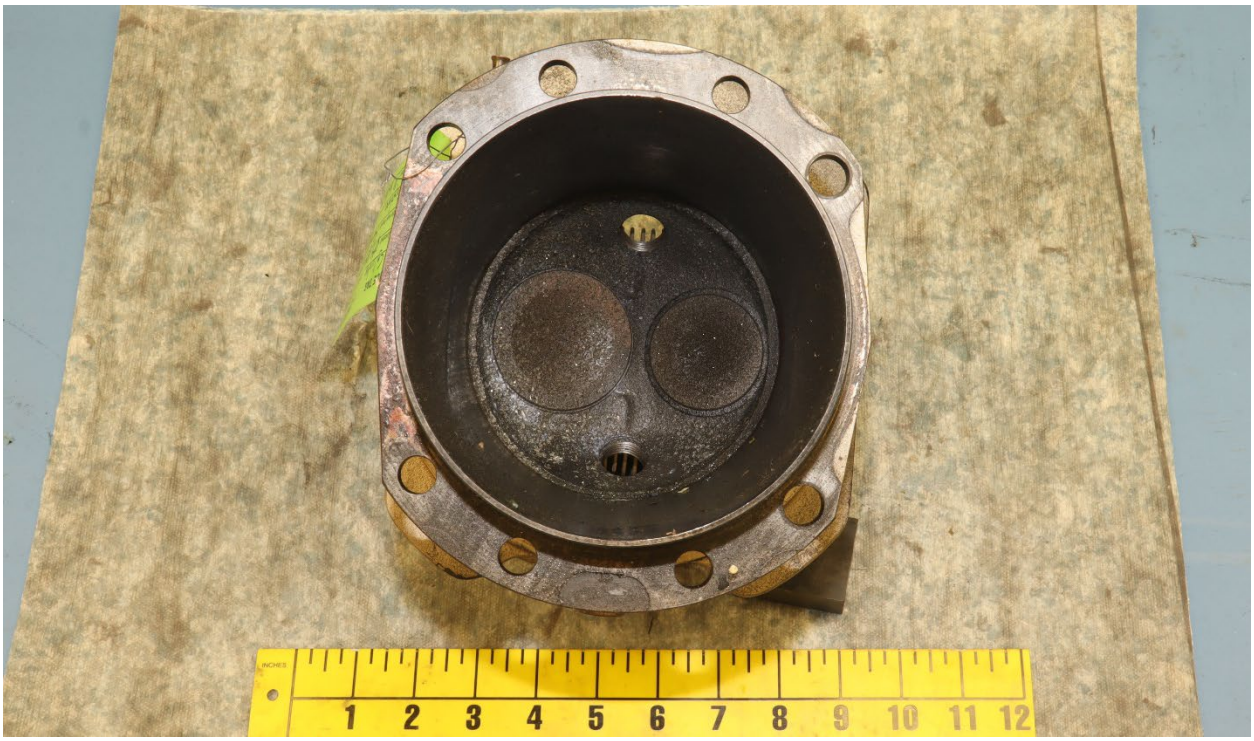

Figure 21. View of the interior of the #6 piston cylinder, as received.

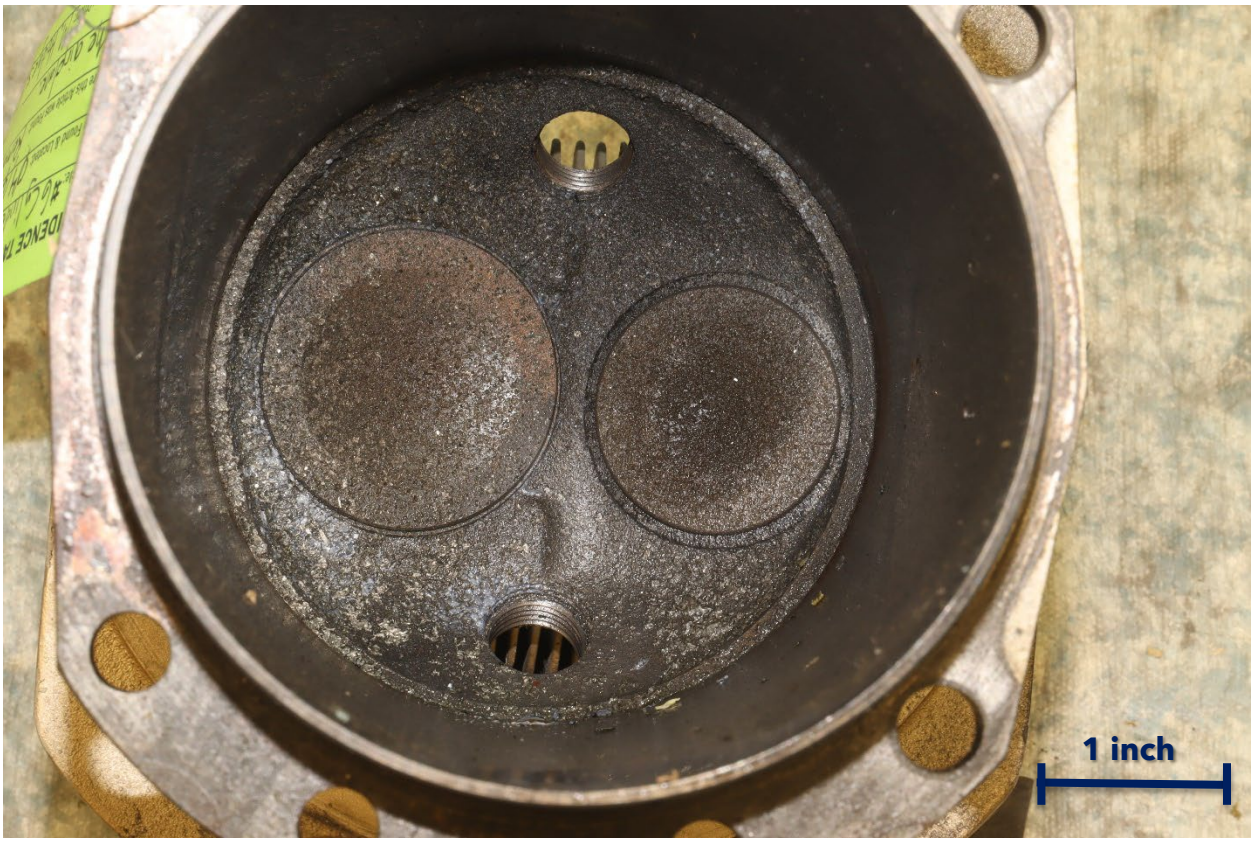

Figure 22. Closer view of the crown and valve faces of the #6 cylinder, as received.

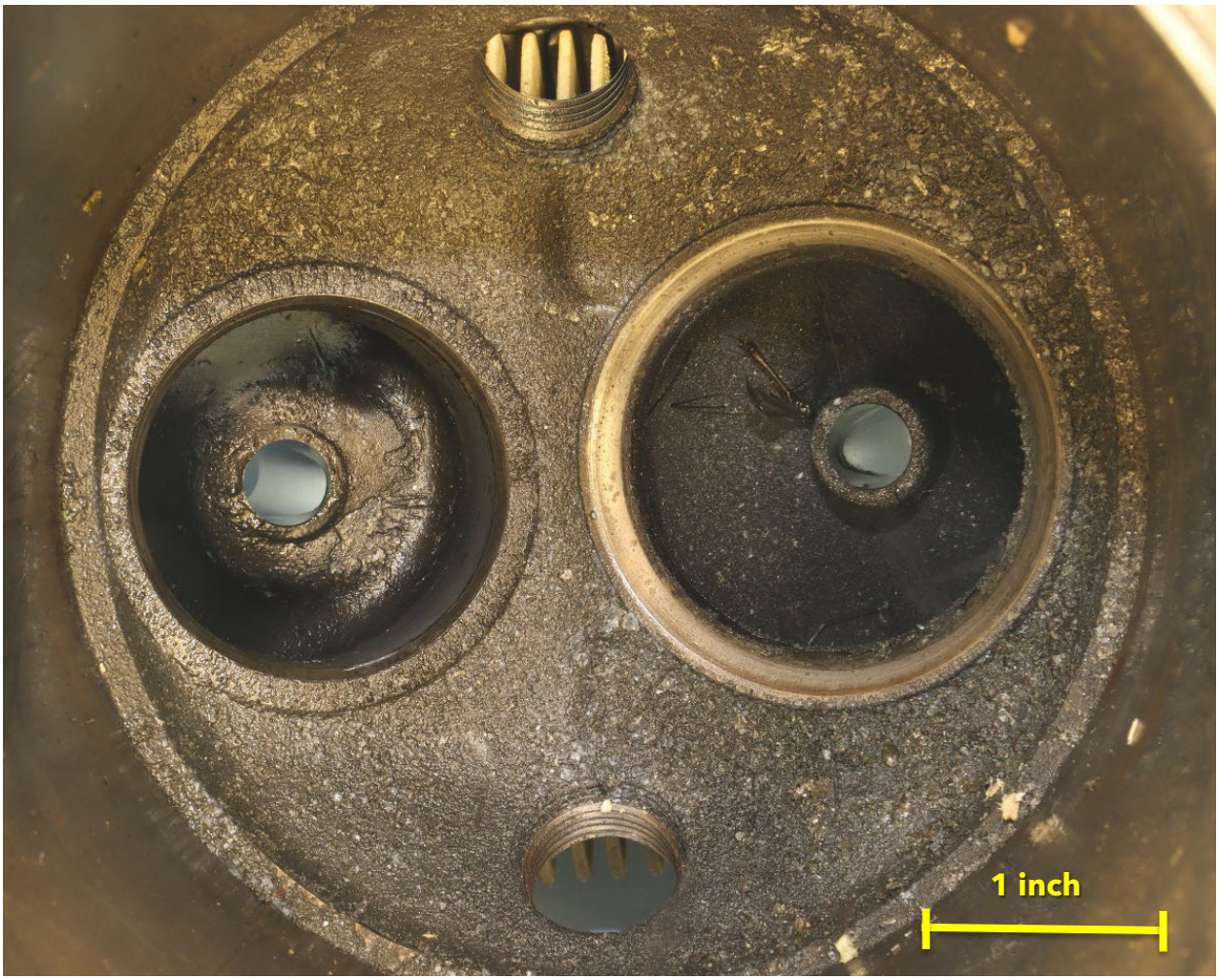

Figure 23. View of the #6 cylinder crown after removal of the valves, showing the condition of the seats.

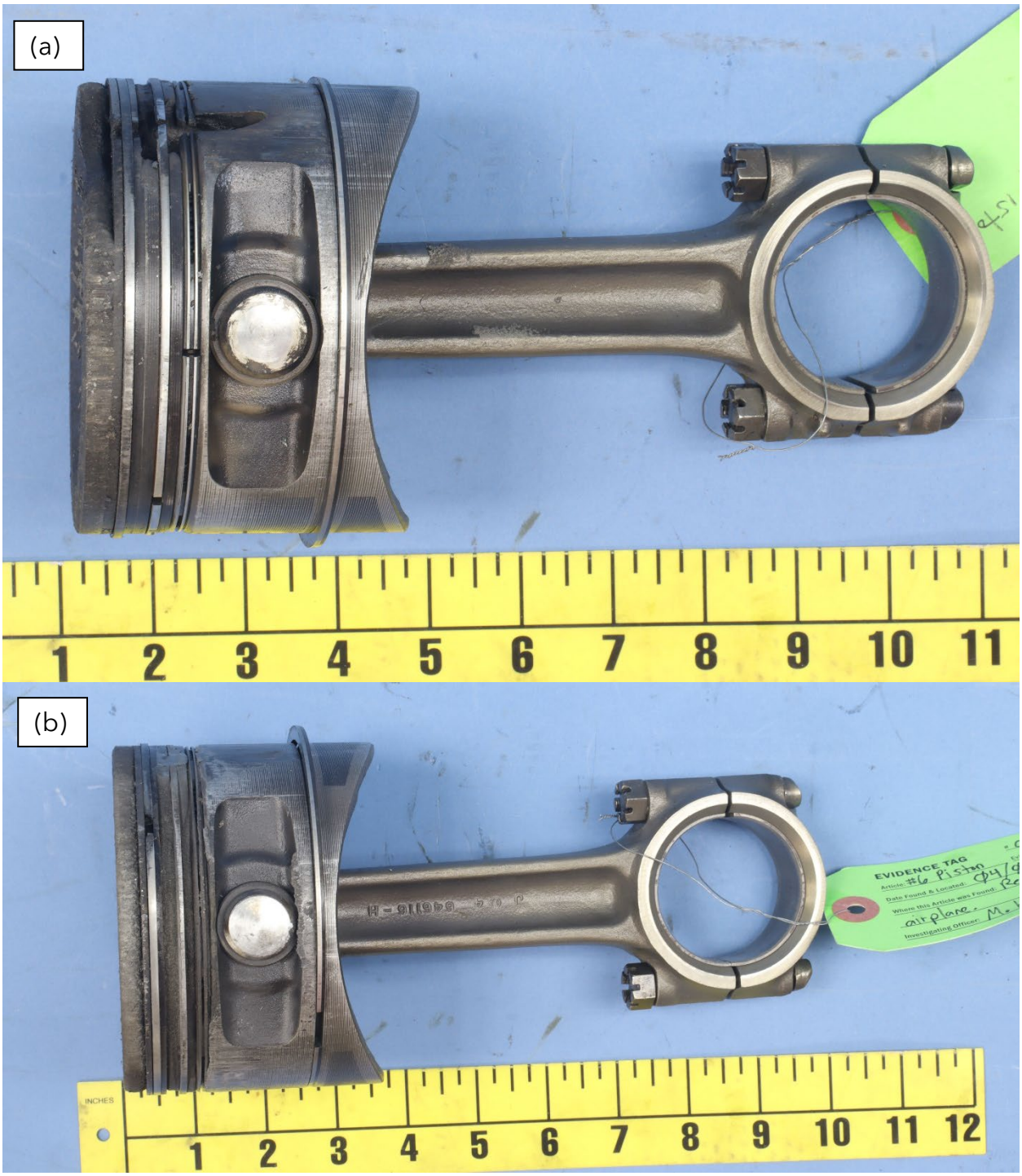

Figure 24. Opposite sides of the piston assembly from the #6 cylinder, on the piston pin faces.

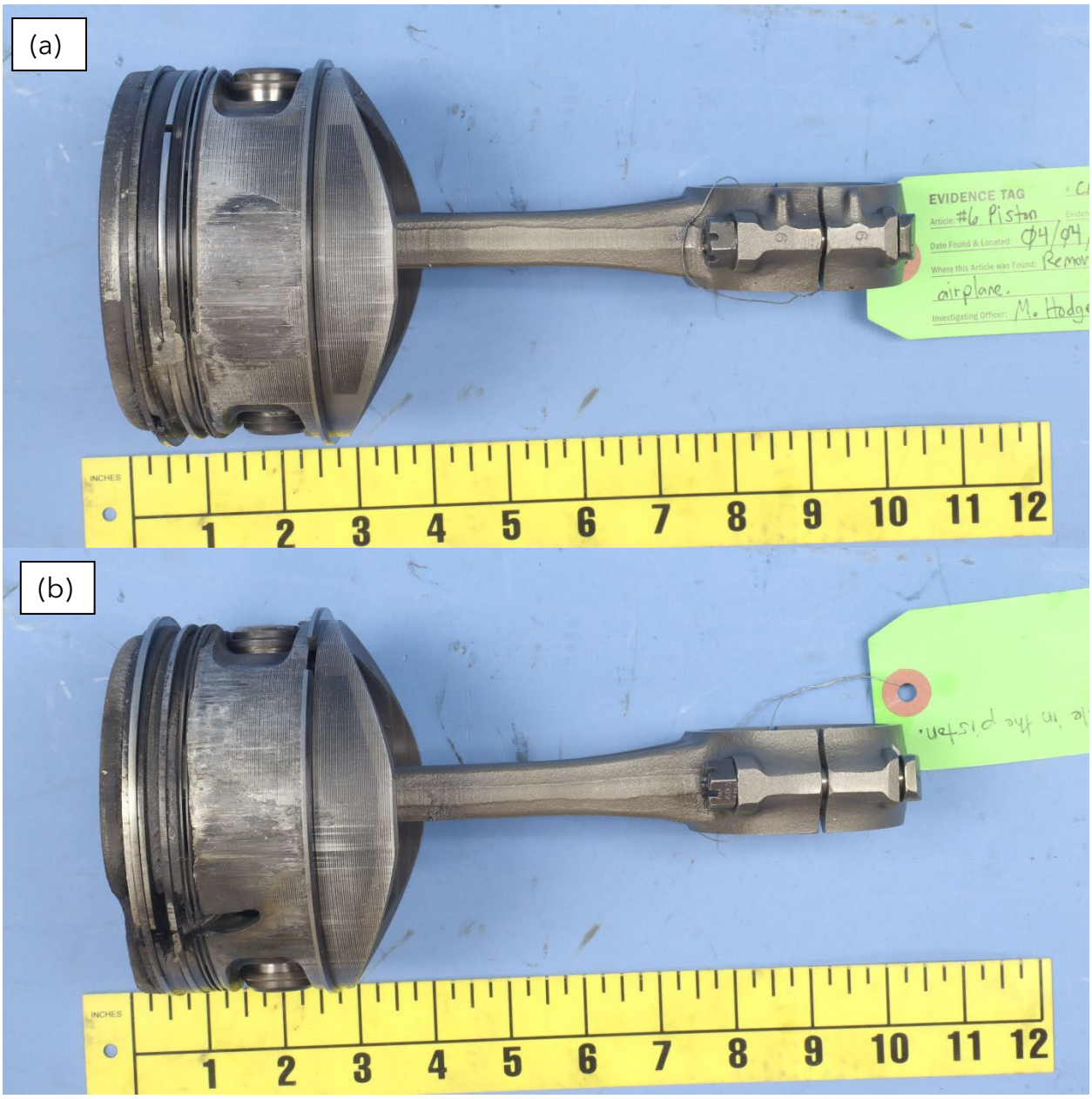

Figure 25. View of the piston and connecting rod, from 90° of the views in **Figure 23**, showing sliding wear along the piston skirt surfaces.

Figure 26. View of the corner of the piston skirt, showing an elongated hole in the piston.

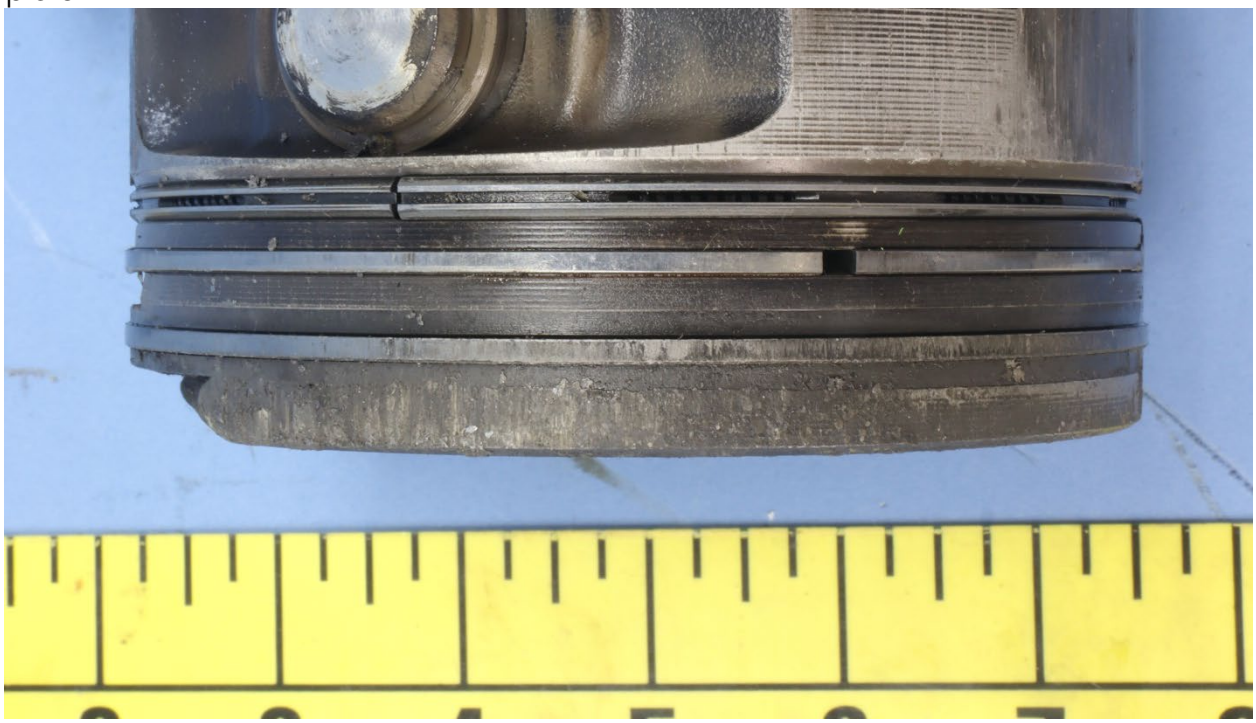

Figure 27. Perpendicular view of the #6 piston hole (on the left), demonstrating the degree of material loss in the piston crown corner.

Figure 28. Angled view of the #6 piston hole, after removal disassembly and removal of the connecting rod.

Figure 29. Oblique view of the piston crown surface, after disassembly.

Figure 30. The hole on the #6 piston, viewed from the interior of the piston.

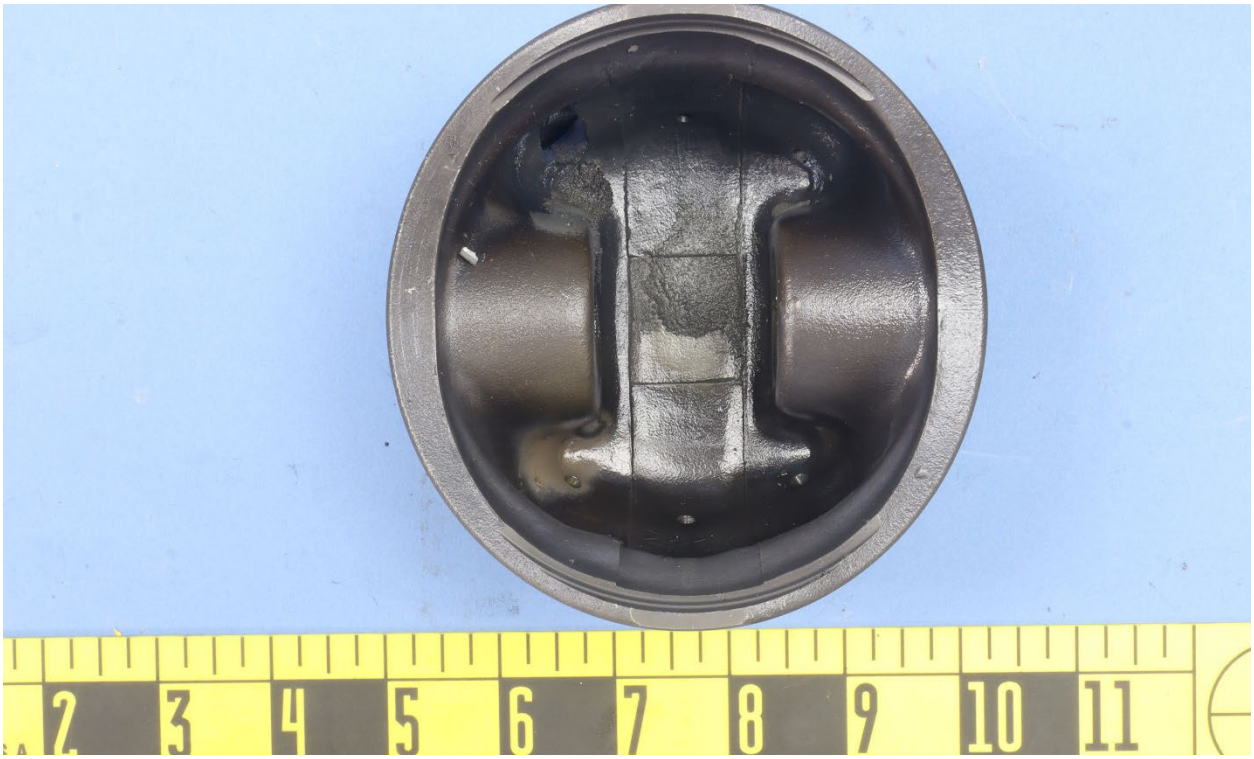

Figure 31. Oblique view of the #6 piston interior, showing deposits and varnishing of the interior surfaces.

Figure 32. View of the intake valves from the #2 and # cylinder positions.

Figure 33. Top-down view of the #2 and #6 intake valves.

Figure 34. Side views of the #2 and #6 intake valves.

Figure 35. Views of the bottom spark plugs from the #2, 4, and 6 cylinders (courtesy Michael Hodges, AS-CEN).

Figure 36. Views of the opposite top spark plugs from the #2, 4, and 6 cylinders (courtesy Michael Hodges, AS-CEN).