

NATIONAL TRANSPORTATION SAFETY BOARD

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



October 14, 2022

MATERIALS LABORATORY FACTUAL REPORT

Report No. 22-067

A. ACCIDENT INFORMATION

Place : Coalinga, California
Date : August 19, 2020
Vehicle : UH-1H, N711GH
NTSB No. : WPR20LA280
Investigator : Van McKenny (AS-40)

B. COMPONENTS EXAMINED

Left lateral servo; right lateral servo and hydraulic irreversible valve assembly for the right lateral servo; and collective servo for the main rotor of the helicopter.

C. DETAILS OF THE EXAMINATION

1. As-received

Figure 1 show photographs of the as-received left lateral servo; right lateral servo and irreversible valve assembly for the right lateral servo; and collective servo. The servos could not be moved up and down by hand relative to their respective rods. The as-received pieces were disassembled to document their condition, such as for evidence of heat damage and fracture.

2. General Description of a Servo

Figure 2 show reconstructed X-ray computed tomography (CT) images of the right lateral servo assembly. The left and collective servos are made from the same parts (configuration) as those from the right lateral servo. A servo assembly contains a center¹, upper and lower housing. The ends of the center housing are attached to the upper and lower housing. The upper housing contains a reduced inner diameter portion that functions like a bushing or guide for the rod portion.² The bottom end of the center housing is attached to a fitting and, in turn, the inner diameter portion of the fitting functions like a bushing or guide for the rod portion. A ball bearing assembly is installed inside the lower housing and the bore for the inner race portion of the ball bearing is attached to the outer surface of the center housing. The rod and piston portion are manufactured as one piece. The piston portion of the rod contains a groove that extends all around its circumference that

¹ The center housing is also referred to as the actuating cylinder.

² Bushings are shaped like a tube or sleeve, and help with motion by sliding, as opposed to the rolling motion of most bearings.

incorporates a ring seal. During operation of the main rotor blades, the piston with its incorporated ring seal slides up and down against the inner wall of the center housing. Circumferential spring seals are installed within the upper housing and fitting and they are intended to prevent debris from entering the bushing areas.

3. Examination of the Right Lateral Servo

Visual examination of right lateral servo revealed the outer surfaces of the center, upper and lower housings, and those of the hydraulic servo cylinder, contained multiple indications of exposure to severe heat from a fire. These indications include one or more of the following visual observations: oxide layer on the outer surface (tint or color varied throughout the part); oxide layer that contained micro-cracks; resolidified metal; and deformation damage. The exposed portion of the rod appeared straight with no evidence of deformation or gouge damage but in several areas showed variations in tint. The safety wires in the servo assembly were intact. The inner and outer surfaces of the servo assembly were dry and contained no evidence of hydraulic fluid (liquid).

3.1 Upper Housing for the Right Lateral Servo

The tube (link) structure that was attached to the upper end of the rod (including nut and safety wires) were disassembled, clearing a path for the upper housing to be removed from the rod. As shown in the X-ray CT images of the servo (Figure 2), the inner surface of the upper housing in the areas of the reduced inner and larger diameter portions contained ring seals. The circlip and circumferential spring seal were intact and covered with debris. The circlip, circumferential spring seal, and nut were removed from the upper housing (while the housing was attached to the rod). The upper housing did not slide off the rod. The lower end of the upper housing was lightly struck multiple times with a hammer to assist with removal of the upper housing from the rod.³ As the upper housing was removed from the rod, fractured pieces of the ring seals fell out of the housing. All the ring seals fractured into multiple pieces (none of ring seals were intact).

Examination of the disassembled upper housing (see Appendix 1A) revealed the outer surface exhibited evidence of localized re-solidification and micro-cracks in the oxide layer. The surface in the general area of re-solidification contained wrinkles. The inner wall was covered with dry black soot and exhibited evidence of re-solidification (including wrinkles on the surface), as shown in Appendix 1B, consistent with exposure to severe heat from a fire. The bushing area (reduced inner diameter portion) of the housing and corresponding surface on the rod contained no evidence of embedded metal fragments, corrosion, gouge, or wear damage.⁴

³ As a general comment, the upper and lower housings were extremely difficult to disassemble from the center housing. WD-40 lubricant was applied to several threaded joints to facilitate with the disassembly. At several stages of disassembly, a pipe wrench was used to help with disassembly when standard wrench was not able to accomplish the task.

⁴ For the purpose of this report, general corrosion is defined as any area that has a reduced thickness or cross section as a result of a corrosion mechanism. Pitting corrosion is a form of localized corrosion that causes small cavities on the metal surface.

3.2 Lower Housing for the Right Lateral Servo

The hydraulic servo cylinder was disassembled and removed from the lower end of the rod portion – making room for the lower housing to slide off the rod portion. The circlip and circumferential spring seal were removed from the lower end of the lower housing (while the housing was on the rod). The circlip and circumferential spring seal were intact. Circlip and circumferential spring seal were also covered with debris. After unscrewing the fitting from the bottom end of the center housing the lower housing easily slid off the center housing.

To facilitate disassembly, an axial saw cut was made at diametrically opposite sides of the lower housing. The diametrically opposite saw cuts partially penetrated the outer race portion of the bearing assembly. The diametrically opposite saw cuts were completed with a portable pneumatic operated cutting wheel and this cutting operation allowed the ball portion to be exposed (see Attachments 1C through 1E). The area between the outer race and ball contained two circumferential inserts. The inner surfaces of the two circumferential inserts functioned as raceways (they slide against the ball portion). The inner surface of the inserts and mating outer face of the ball contained no evidence of embedded metal fragments, general corrosion, pitting corrosion, gouge, or wear damage.

3.3 Center Housing for the Right Lateral Servo

Several saw cuts were made through the wall of the center housing to expose the piston portion of the rod. The rod with the piston portion was removed (slid off) from the center housing. As indicated earlier, the piston contained a groove that extends all around its circumference and this groove incorporated a ring seal. As the piston was removed from the center housing, fractured pieces of the ring seal fell out of the piston portion. All the ring seals fractured into multiple pieces (none of them were intact).

Examination of the inner surface of the center housing revealed evidence an oxide layer that contained micro- cracks consistent with exposure to severe heat from a fire (see Appendix 1F). The inner face of the center housing was covered with a black soot; and showed no evidence of axial marks that would have indicated the extent of piston travel within the center housing. No evidence of embedded metal fragment, corrosion, gouge, or wear damage was found at the inner face of the center housing.

3.4 Hydraulic Servo Cylinder for the Right Lateral Servo

Appendix 1G shows a side view of the hydraulic servo cylinder for the right lateral servo. The hydraulic servo cylinder contained an internal spool and sleeve assembly. A push-pull rod is attached to the spool portion. Several external links to the push-pull rod were cut in the laboratory to prepare for extraction of the spool. Four screws were removed from the cover. The exposed end of the push-pull rod was secured to the end of a needle-nose pliers. An attempt was made to pull the push-pull rod out of the port. The internal spool and sleeve could not be extricated from the port.

3.5 Connector Fittings between Hydraulic Servo Cylinder and Irreversible Valve for the Right Lateral Servo

The pressure and return ports for the hydraulic servo cylinder and their respective ports on the irreversible valve are connected to each other by connector fittings (see Attachments 1G through 1I). A connector fitting resembles a bolt but it contains a hollow shank. The hollow portion of the shank is axial oriented and extended along the length of the shank and threaded portion. A transverse hole is located within the shank portion of the connector fitting that intersects the axial hollow portion. The hollow passages within the connector fitting allows hydraulic fluid to transfer between the hydraulic servo cylinder and the irreversible valve assembly. The diameter of the connector fitting for the cylinder return port was greater compared to the one for the cylinder pressure port. The connector fittings were fractured. Bench binocular microscope examination of the connector fittings for the right lateral servo revealed the fractured ends exhibited a rough texture on a slanted planes consistent with overstress separation.

4. Left Lateral Servo

The left lateral servo was disassembled in a manner that was similar to the right lateral servo. The observations made on the left lateral servo were similar to those found on the right lateral servo. Appendix 2A through 2G show photographs of the left lateral servo in various conditions of disassembly.

5. Collective Servo

The collective servo was disassembled in a manner that was similar to the right lateral servo. The observations made on the collective servo were similar to those found on the right lateral servo. Appendix 3A through 3C show photographs of the left lateral servo in various conditions of disassembly.

6. Materials Analysis of Parts from the Right Servo Valve

Various parts of the valves were analyzed with an Olympus Vanta X-ray fluorescence (XRF) portable alloy analyzer to determine their material grade. Table 1 shows the materials that were identified by the portable alloy analyzer.

TM55-1520-210-23P, titled "Technical Manual, Aviation Unit and Intermediate Maintenance, Repair Parts and Special Tool List, (Including Depot Maintenance Repair Parts and Special Tools), For Helicopter – Utility – Tactical Transport UH-1B, UH1C, UH-1H, UH-1M, EH-1H (Bell), UH-1V", dated 27 Feb 1981, provides illustrations (parts breakdown) and parts lists for the respective helicopters. The part's name and part number, and national stock number (NSN) are listed and they refer back to an item number in an illustration within the manual. The ring seals in this report are referred to in the TM55 technical manual as packing preform. Most of the packing preforms for the irreversible valve assembly are listed as made from materials that conform to specification MS28775, titled Packing, Preformed, Hydraulic, +275°F ("O" Ring). According to MS28775, the packing preform materials are procured to

MIL-P-25732 specification, titled Performance Specification, Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Limited Service at 250 °F (121 °C). MIL-P-25732 specifies an Acrylonitrile-Butadiene (NBR) rubber in the form of molding rings, compression seals, O-ring cord, and molded-in-place gaskets for aeronautical and aerospace applications.

The circumferential inserts and ring seal for the piston rod from the right servo valve were black and their outer surfaces exhibited a smooth texture. These pieces were placed next to a magnet and they were not attracted to the magnet. To determine whether these pieces were flexible or brittle, they were intentionally bent with a needle-nose pliers. These pieces fractured easily and showed no evidence of flexibility. The fracture face of all these pieces exhibited a brittle fracture feature. This XRF alloy analyzer cannot detect the element carbon, so a sample of the circumferential insert and ring seal for the piston portion of the rod was analyzed by other analytical method to determine whether carbon was present. Energy dispersive spectroscopy (EDS) analysis of each sample produced a spectrum that contained one major elemental peak of carbon. Fourier Transform Infrared (FTIR) spectroscopy was used to analyze these two materials. The FTIR spectra of each sample showed no hydrocarbon peaks and each contained only a single peak ($\sim 2100\text{ cm}^{-1}$) consistent with carbon. The FTIR spectra is indicative of either a carbon-based material such as graphite or the material was significantly heat damaged leaving only carbonize⁵ residue (Appendix 4 shows a typical FTIR spectrum).

Prepared by:

Frank Zakar
Senior Metallurgist

⁵ Carbonize – when a carbon containing material is converted into carbon, typically by heating or burning.

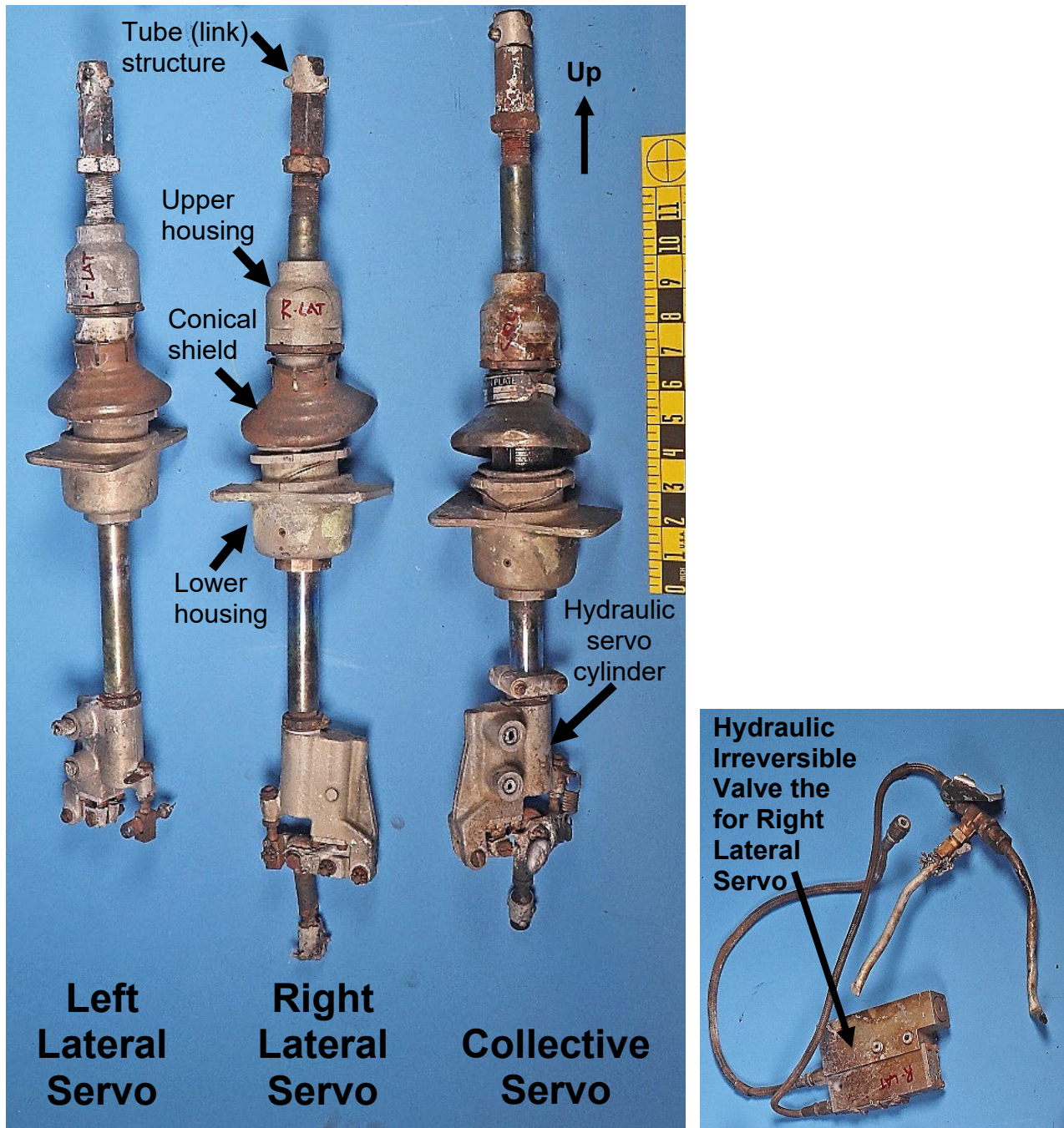


Figure 1. As-received left lateral servo; right lateral servo and hydraulic irreversible valve for the right lateral servo; and collective servo.

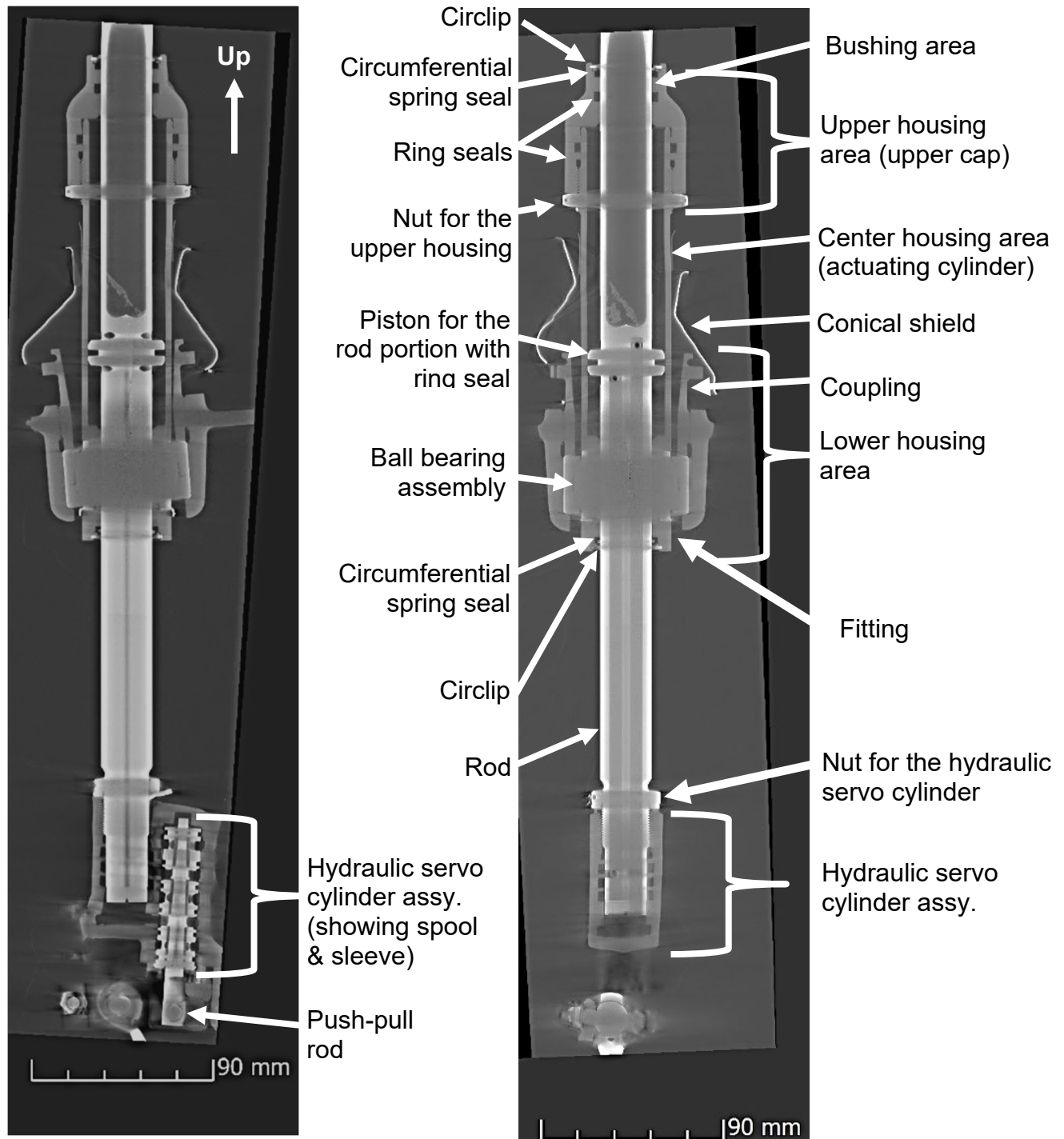


Figure 2. Two reconstructed X-ray CT images of the right lateral servo assembly. The image on the right side of the page was rotated 90 degrees about the axial length of the rod, relative to the image on the left side of the page.

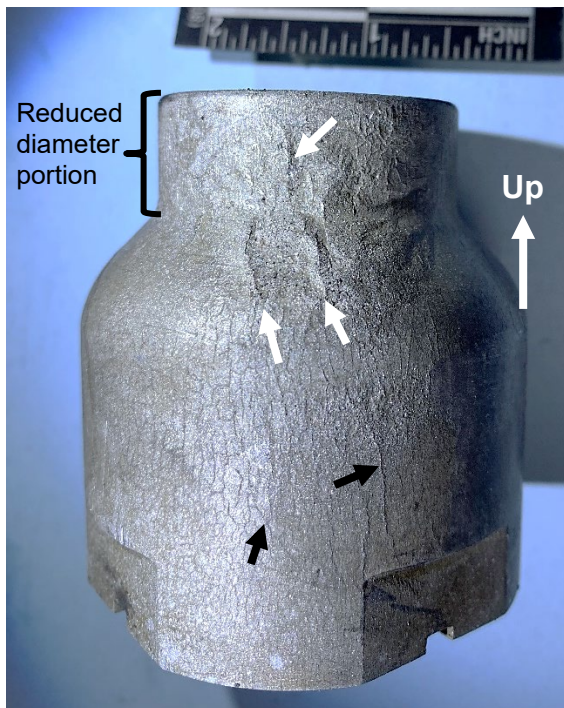
Table 1 Materials Identified by the Alloy Analyzer for the Right Lateral Servo	
Part	Identified Material
Upper housing	2014 aluminum alloy
Center housing	2014 aluminum alloy
Lower housing	2014 aluminum alloy
Fitting	2014 aluminum alloy
Coupling	2014 aluminum alloy
Housing for the hydraulic servo cylinder	2014 aluminum alloy
Housing and covers for the irreversible valve assembly	2014 aluminum alloy
Connector fitting	2014 aluminum alloy
Rod	4340 steel*

Note: (*) The rod was identified as 4340 steel and the non-threaded shank portions (sliding surfaces) were detected as having nickel plating.

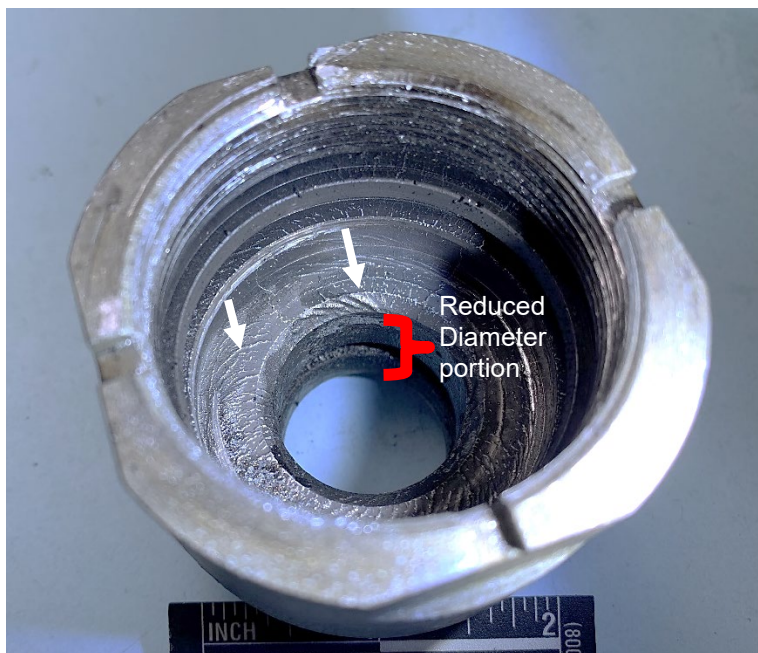
APPENDICES

APPENDIX 1

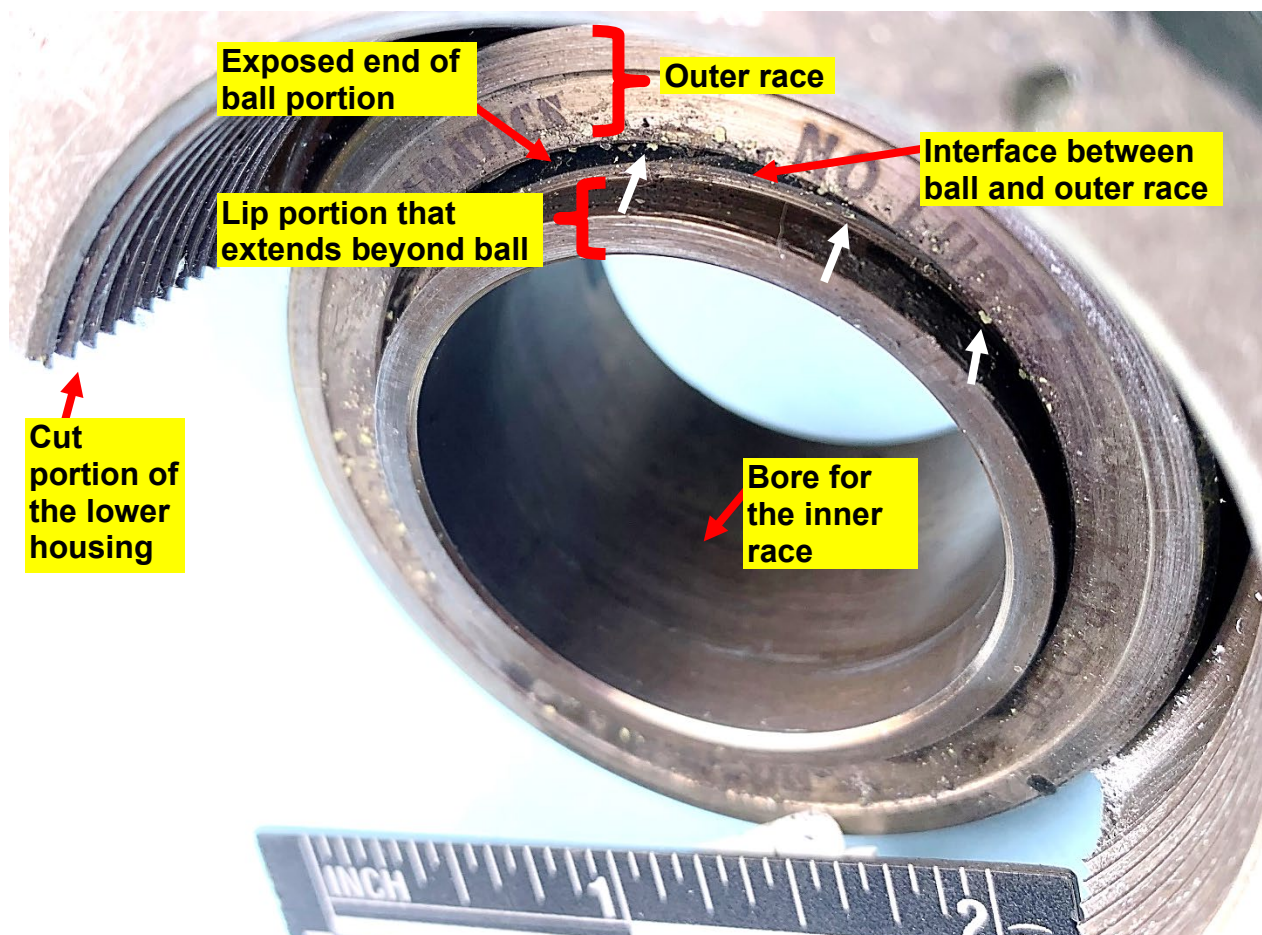
Right Lateral Servo



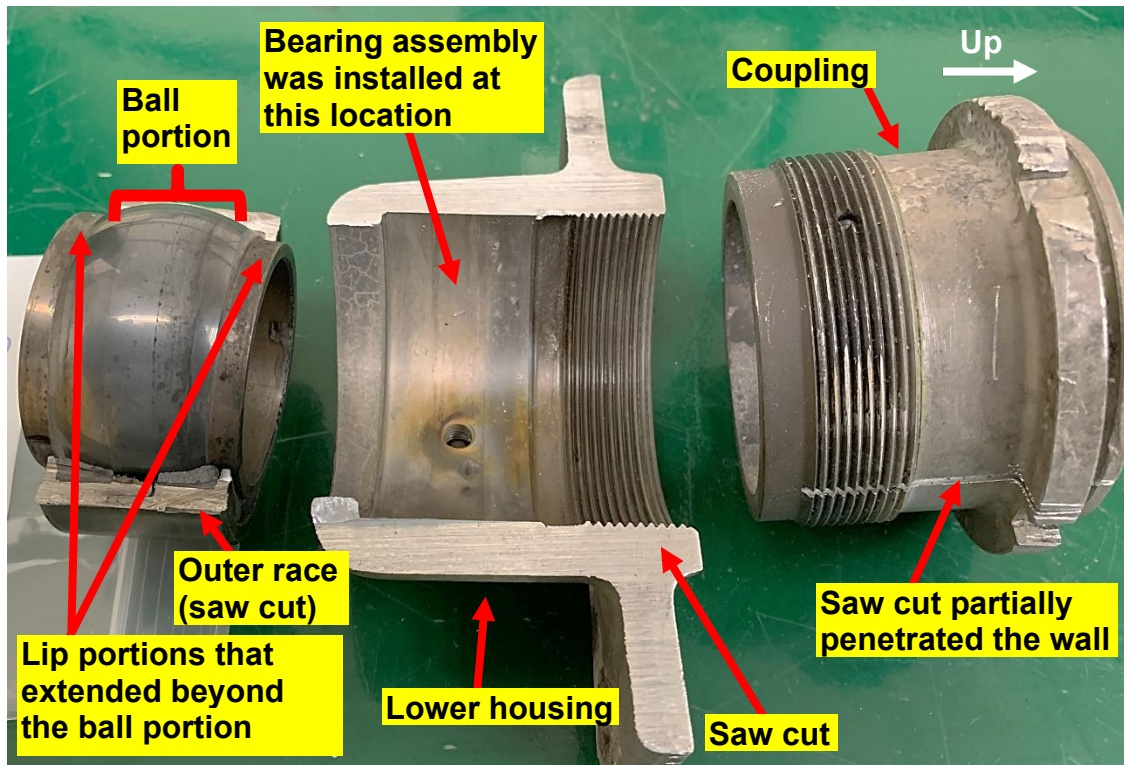
Appendix 1A. Outer surface of the upper housing for the right lateral servo after disassembly showing wrinkle marks (white arrows) and micro-cracks (black arrows).



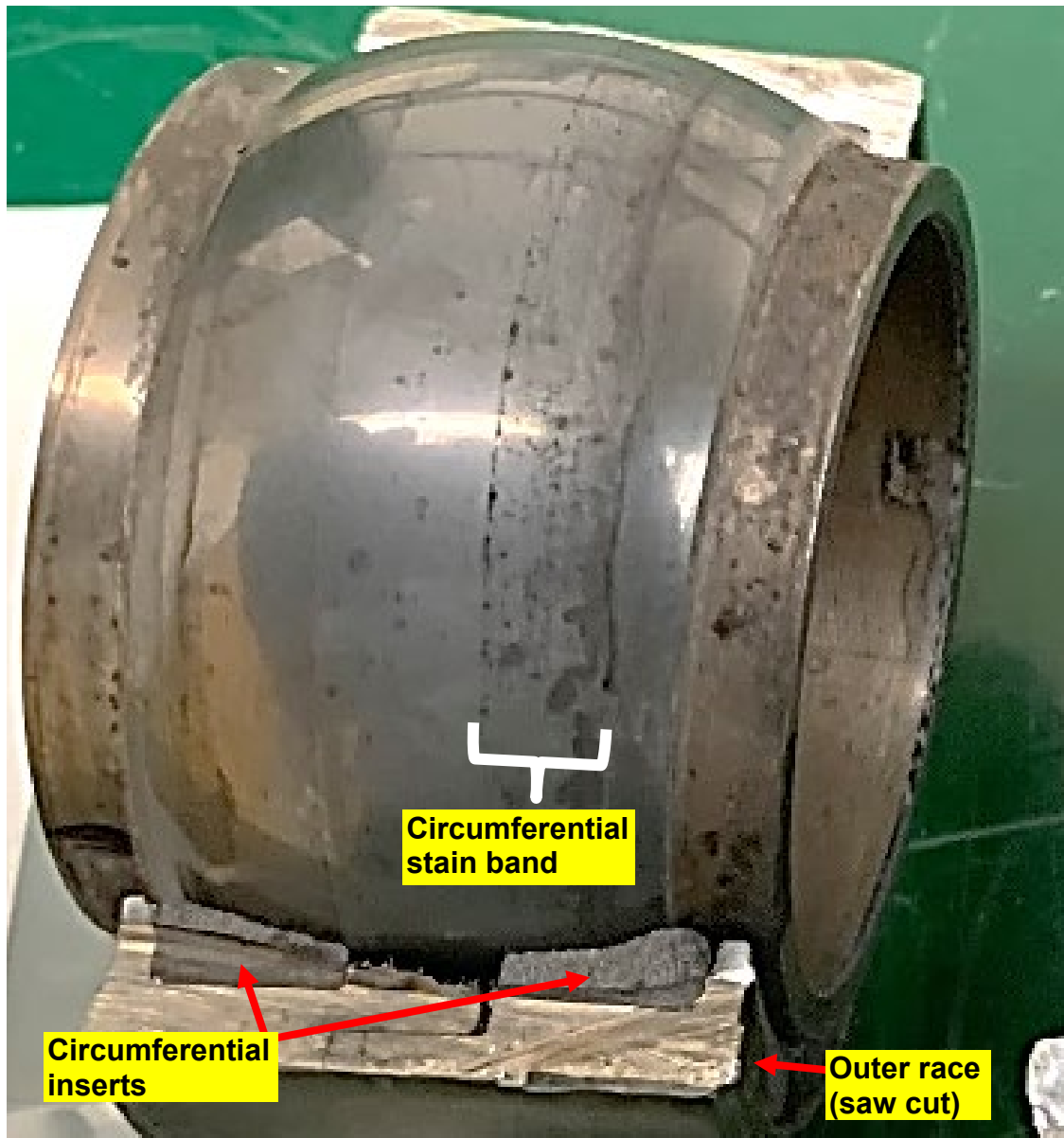
Appendix 1B. View looking up at the inner surface of the upper housing after disassembly showing wrinkle marks indicated by arrows and reduced inner diameter portion.



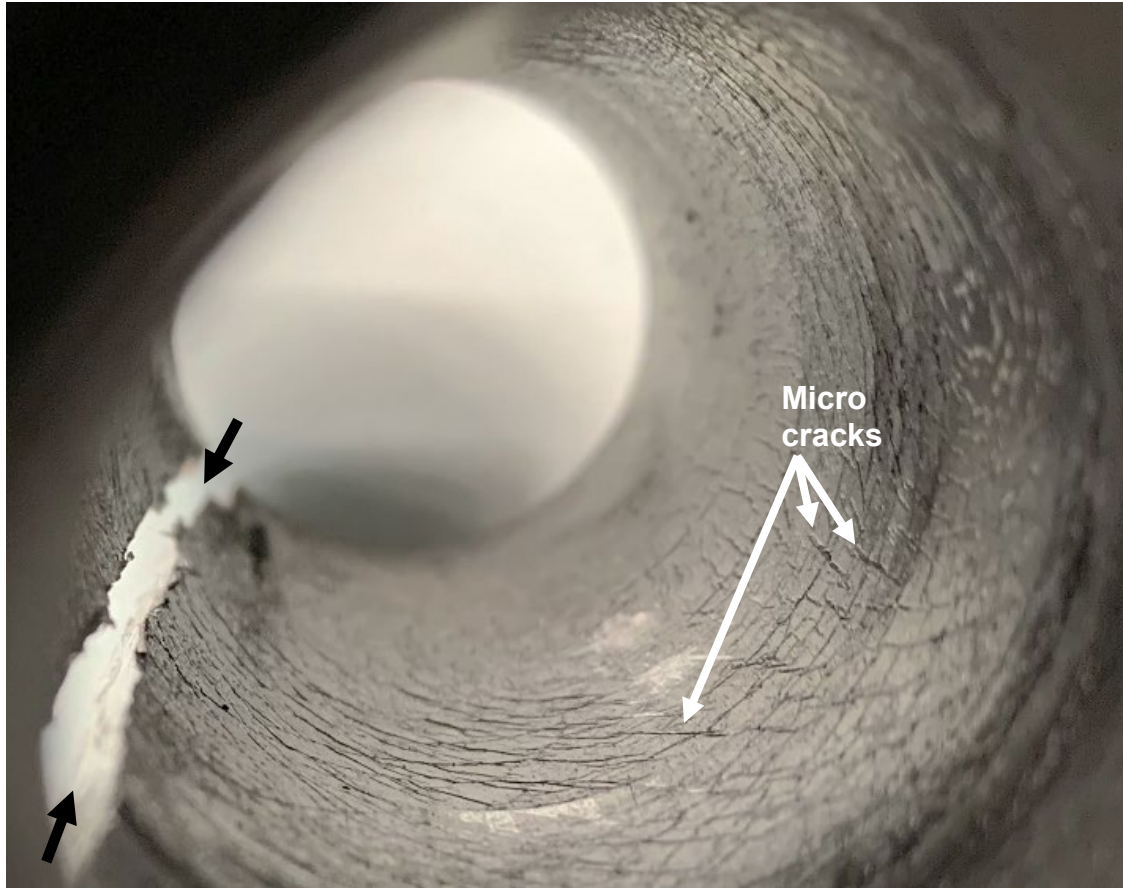
Appendix 1C. Oblique view of the bottom surface of the ball bearing assembly for the right lateral servo showing debris outside of the ball portion, such as in the areas indicated by arrows. The ball contains a bore through the center portion. The lip portion is part of the ball and extended beyond the ball. See appendix 1E for a view of a fully disassembled and exposed ball. The bore portion of the ball is attached to the bottom end and outer face of the center housing.



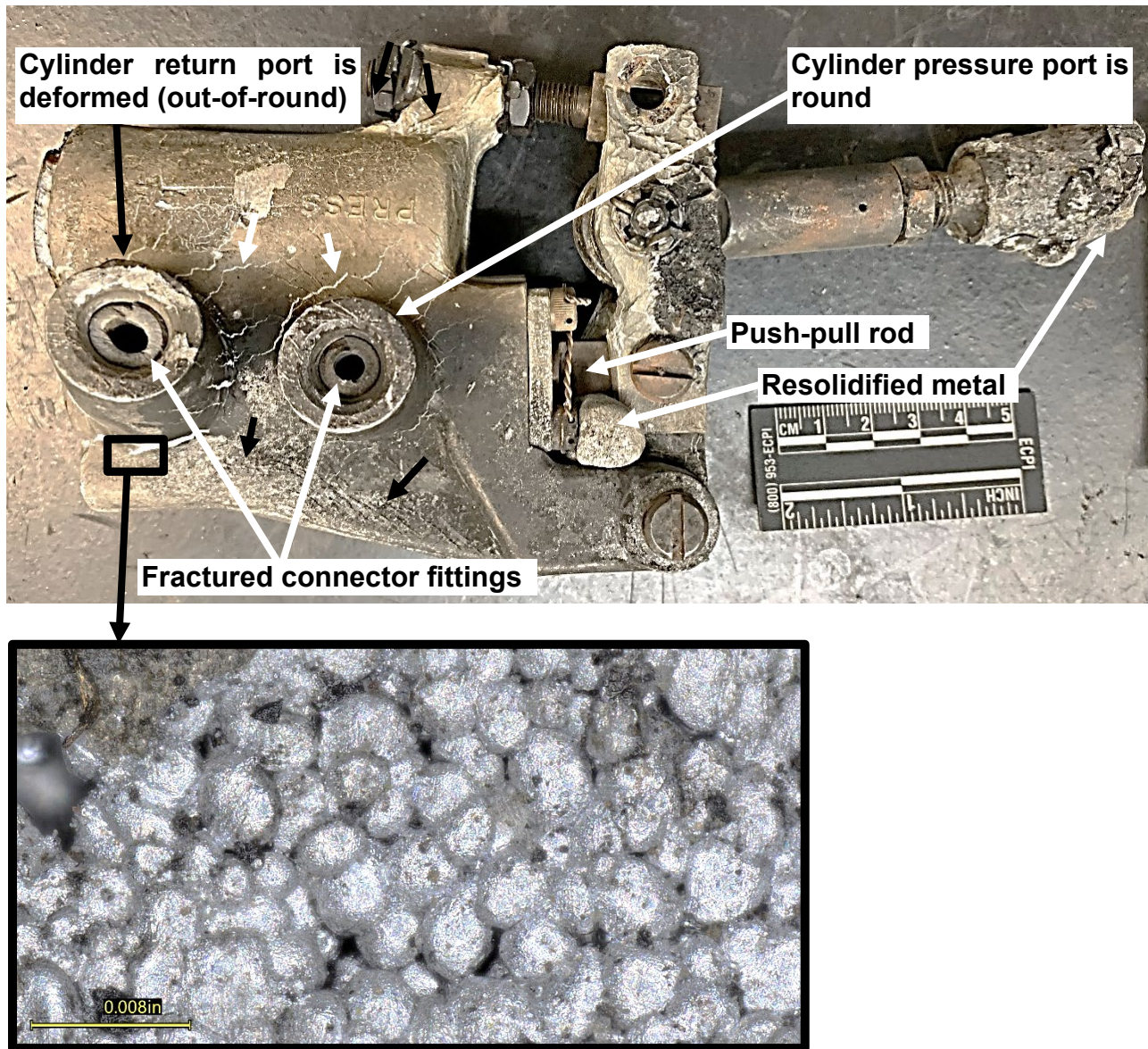
Appendix 1D. Inner surface of the lower housing for the right lateral servo after disassembly and exposed ball bearing assembly. Saw cuts were made through diametrically opposite sides of the outer race and circumferential inserts to expose the outer face of the ball portion.



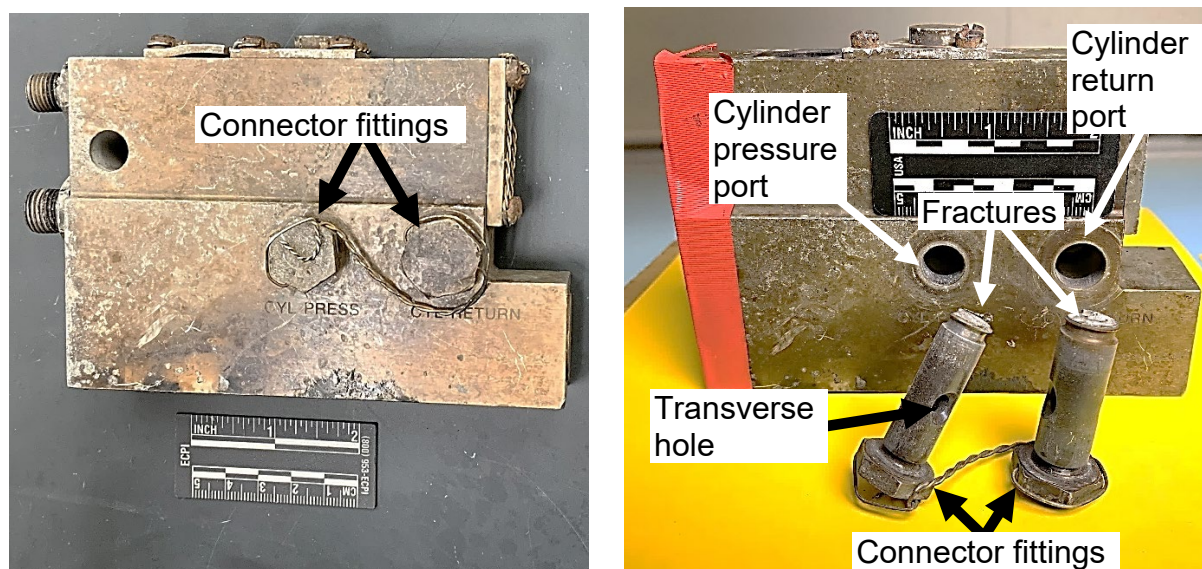
Appendix 1E. Exposed ball portion for the right lateral servo showing a dark stain band that extended all around the ball. The band coincided with the location of one of the inserts. The surface of the ball showed no evidence of scratch, gouge, or wear damage. Dark stain spots were noted in other areas of the ball and lip portions.



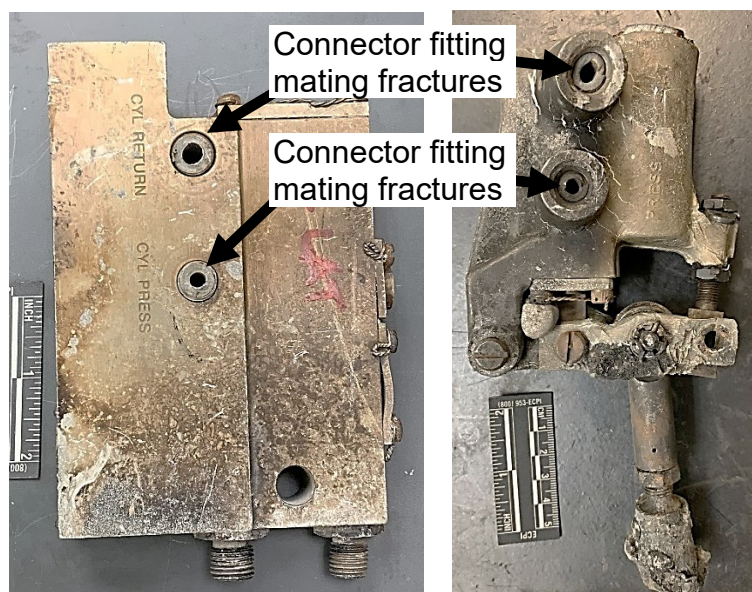
Appendix 1F. Inner surface of the center housing for the right lateral servo after disassembly showing a severely oxidized surface with micro-cracks that extended all around the inner surface. Axial saw cut was made through the center housing to facilitate disassembly (between arrows).



Appendix 1G. Outer surface of the hydraulic servo cylinder (upper side of page) showing micro-cracks in the oxide layer indicated by white arrows; and wrinkle marks indicated by black arrows. Upon closer examination with a bench binocular microscope, the re-solidified areas exhibited adjoining micro-spheres or micro-globules (lower side of page) which are consistent with re-solidification. The cylinder return port and respective fractured connector fitting are deformed (out-of-round) compared to those from the cylinder pressure port which are round.



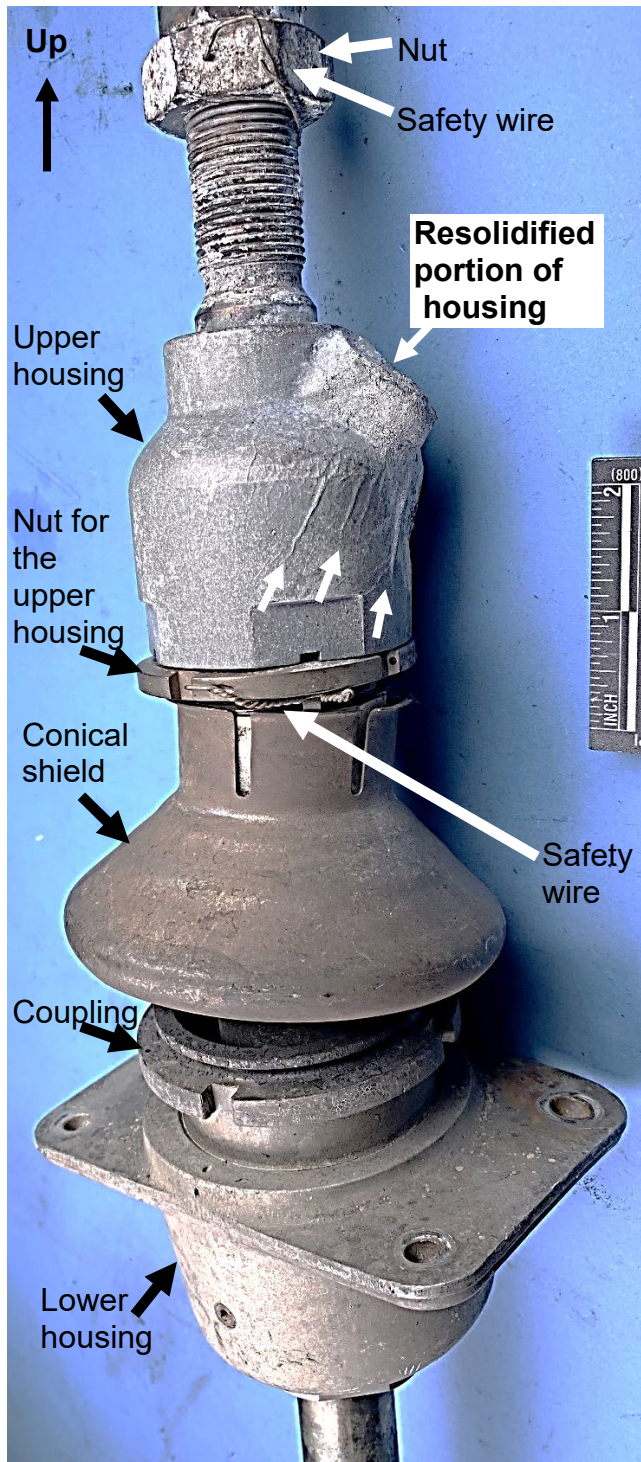
Appendix 1H. Views of the irreversible valve from the side containing the head portion of the connector fittings before and after removal of the connector fittings, left side and right side of page, respectively.



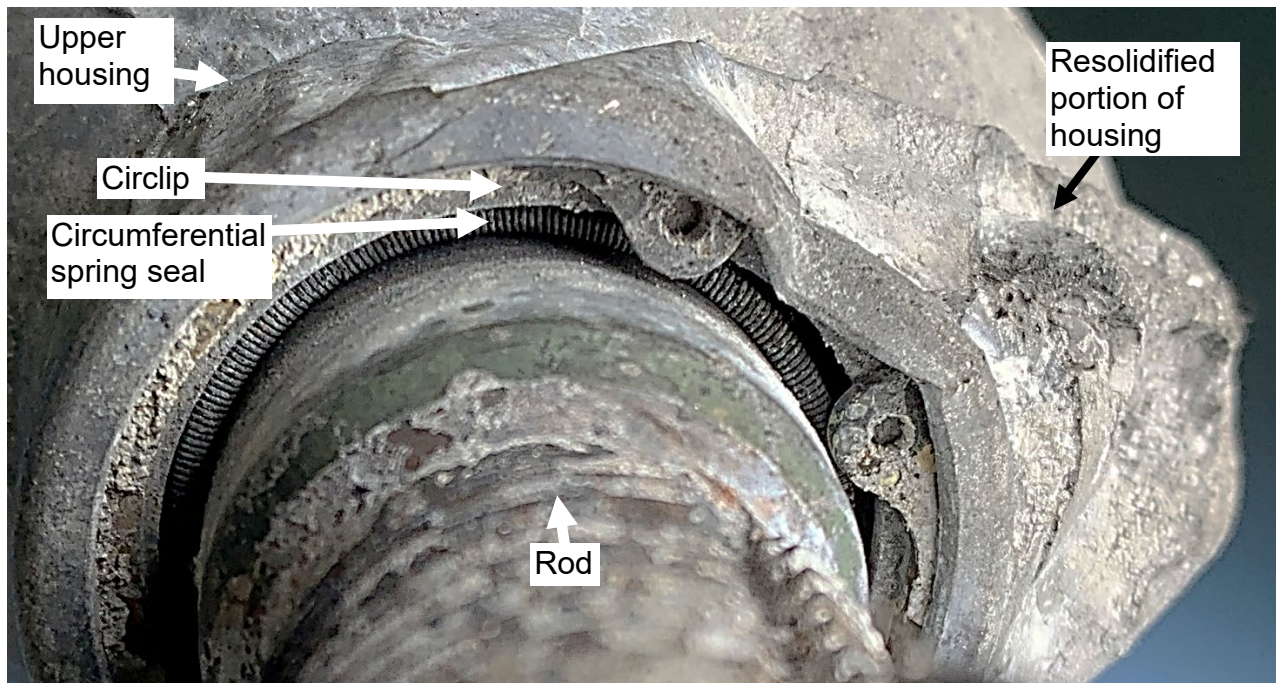
Appendix 1I. View of the irreversible valve (left side of the page) and the hydraulic servo cylinder (right side of the page) showing the mating ends of the fractured connector fittings.

APPENDIX 2

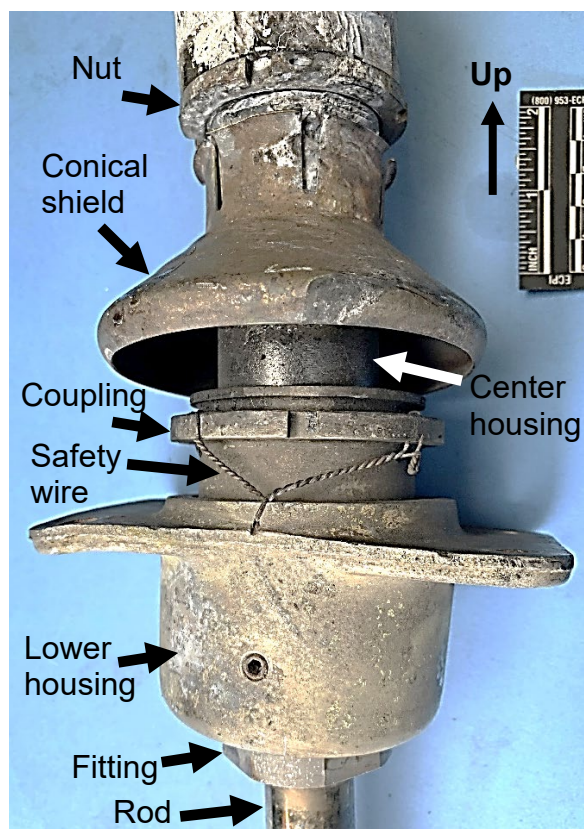
Left Lateral Servo



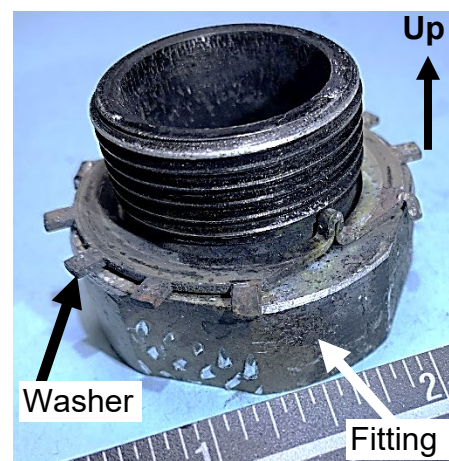
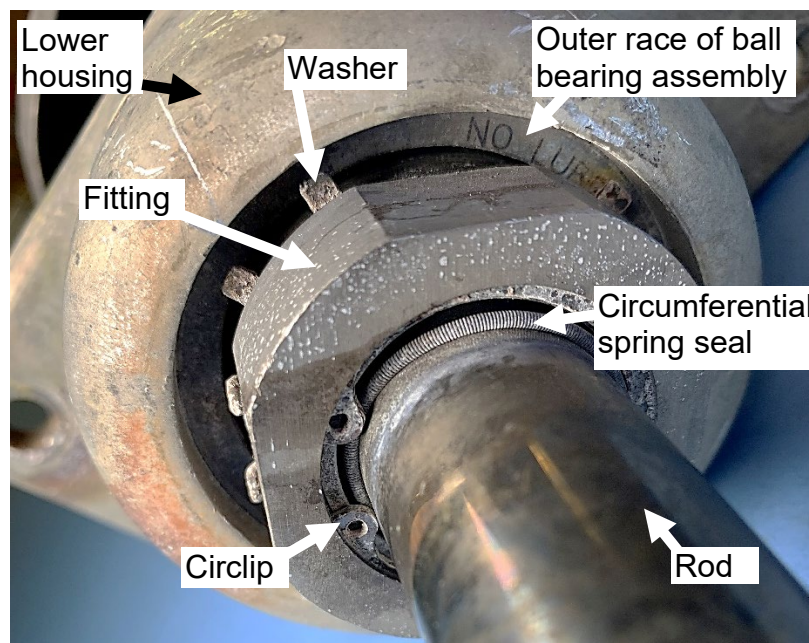
Appendix 2A. Side view of the left lateral servo showing resolidified portion of the upper housing and wrinkle marks indicated by white arrows that extended from the resolidified area.



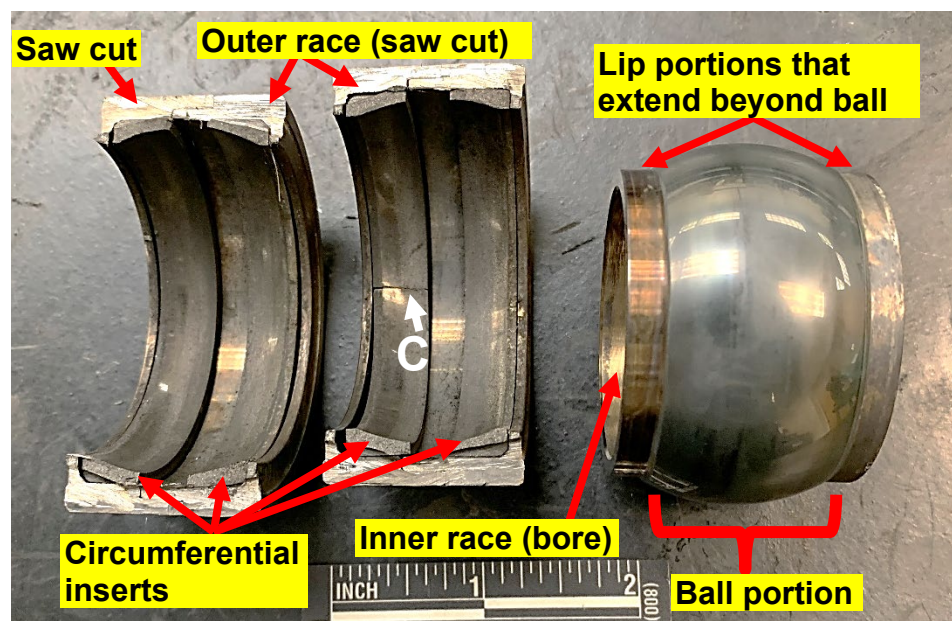
Appendix 2B. View looking down at the upper housing showing the installed circlip and circumferential spring seal.



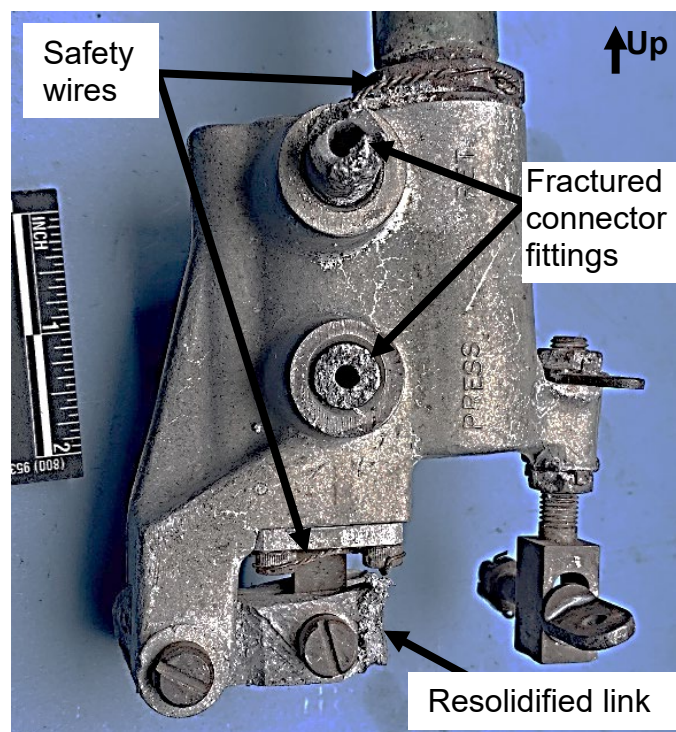
Appendix 2C. Side view of the lower housing for the left servo.



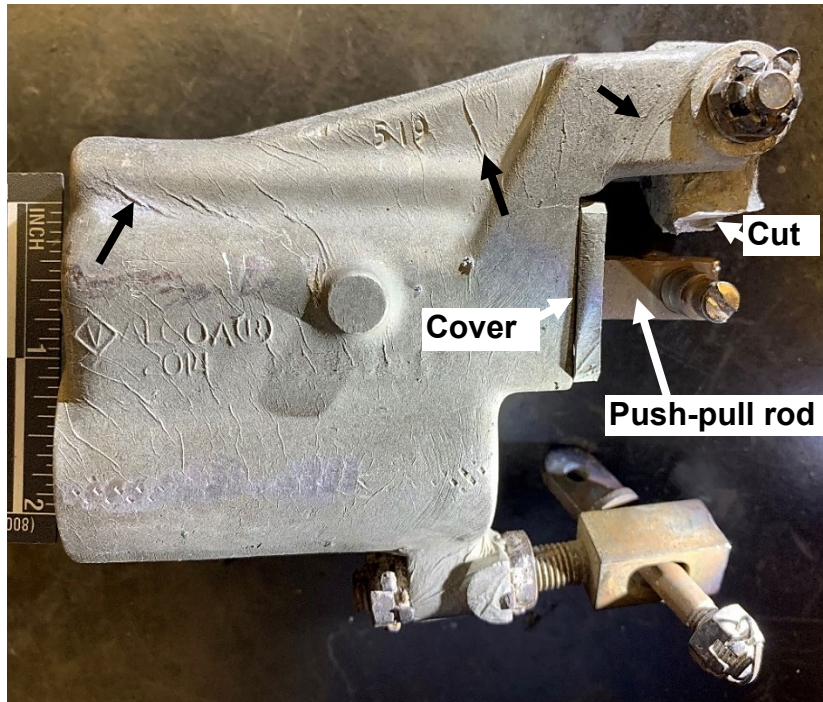
Appendix 2D. Photograph looking up at the fitting in the installed position (left side of page) and side view of the fitting and washer after disassembly (right side of page). In the assembled condition, the external threaded portion of the fitting is engaged (attached) to internal threads at the bottom end of the center housing.



Appendix 2E. View of the disassembled ball bearing and exposed inner surface of the outer race. Saw cuts were made through diametrically opposite sides of the outer race and circumferential inserts to expose the ball portion. Crack in one circumferential insert (area indicated by arrow “C”) occurred during disassembly in the laboratory.



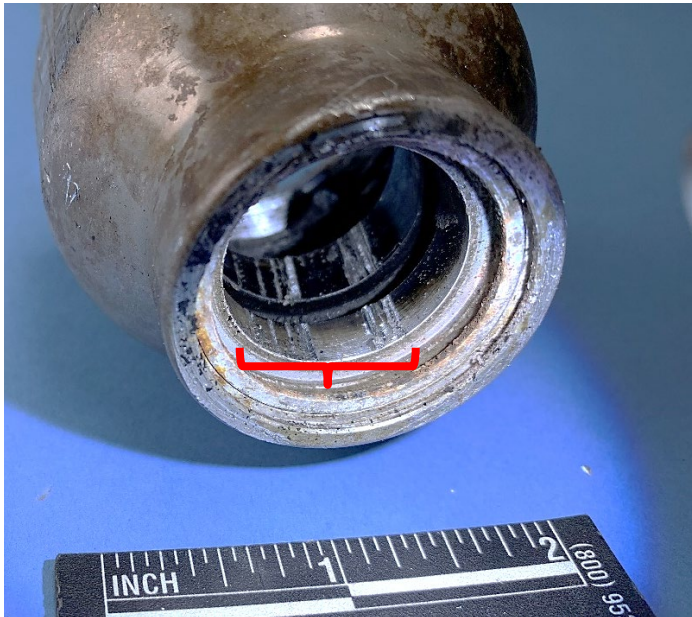
Appendix 2F. Photograph of the hydraulic servo cylinder for the left lateral servo showing a link that had separated and resolidified; fractured ends of the connector fittings, and intact safety wires.



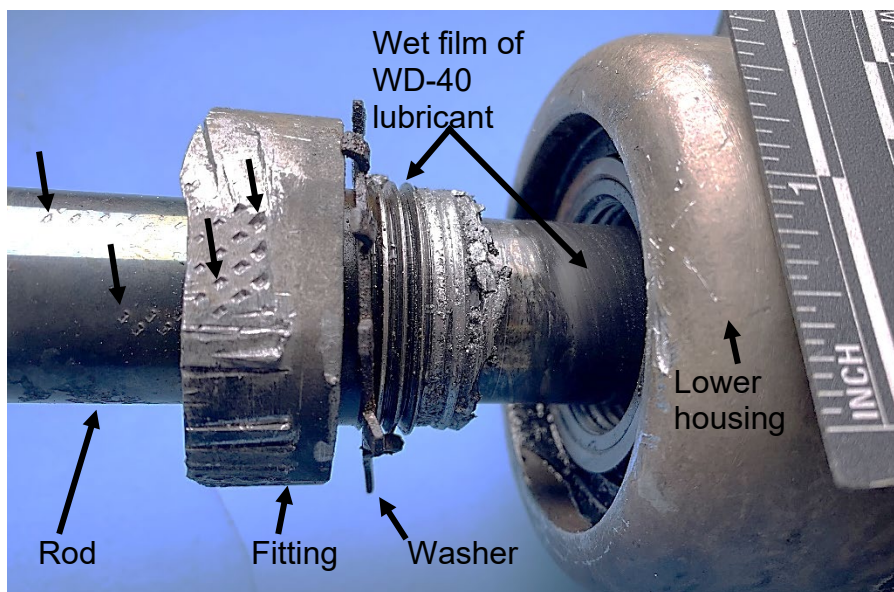
Appendix 2G Outer surface of the hydraulic servo cylinder for the left lateral servo showing wrinkle marks on the outer surface, indicated by arrows. The cover is attached by four screws to the body of the hydraulic servo cylinder. In this photograph, the external links to the push-pull rod were cut and disassembled; and the four screws (with intact safety wires) were removed from the cover, clearing the way for the internal spool and sleeve to be pulled out of the port.

APPENDIX 3

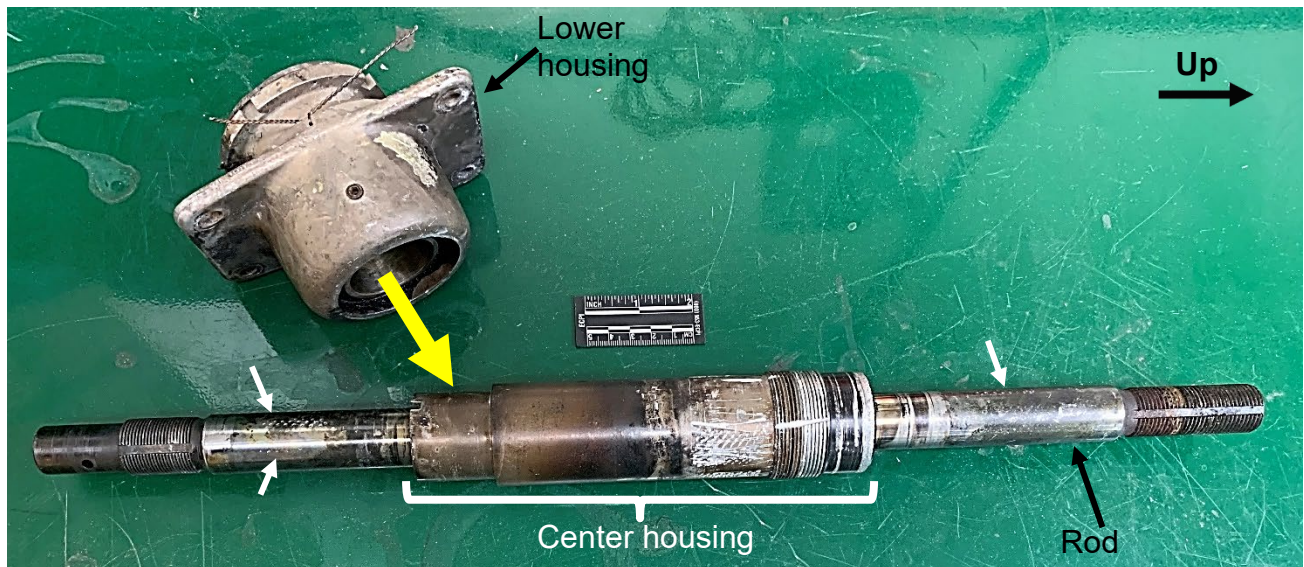
Collective Servo



Appendix 3A. View looking down at the inner reduced diameter portion of the upper housing showing nearly axial gouge marks in an isolated area indicated by a bracket. A bench vice was utilized to secure the rod portion during disassembly. The grip portion of the bench vice left teeth marks on the rod portion. The nearly axial gouge marks on the inner face of the upper housing correspond to location of teeth marks on the rod.



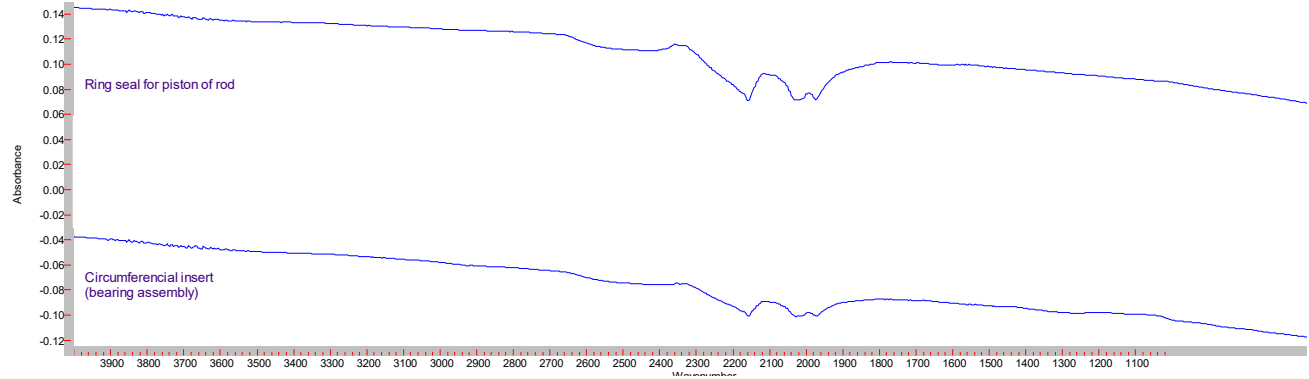
Appendix 3B. Side view of the fitting after it was removed from the lower housing while it remained attached to the rod portion. Prior to disassembly, WD-40 lubricant was sprayed into the rod and threaded area of the fitting to assist disassembly. A bench vice was used to grip the rod end during disassembly which left teeth marks on the rod. Example of teeth marks from the bench vice are indicated by arrows.



Appendix 3C. Side view of the rod with the center housing attached. The bore portion (inner race) for the ball bearing was attached to the outer reduced diameter portion of the center housing in the area indicated by an arrow. The surface of the rod showed evidence of staining. A bench vice was used to grip the rod ends during disassembly which left teeth marks on the rod. Example of teeth marks from the bench vice are indicated by arrows. With the exception of teeth marks left by the bench vice to assist disassembly, the surface of the rod was smooth and showed no evidence of gouge or corrosion damage.

APPENDIX 4

FTIR Spectra



Appendix 4. Overlapping FTIR spectra (Absorbance vs. Wavenumber [cm^{-1}]) of examined samples.