

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



CEN22FA331

COMPUTED TOMOGRAPHY

Specialist's Factual Report

June 9, 2023

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A. ACCIDENT

Location: North Fork, ID

Date: July 21, 2022

Time: 1644 MDT

2244 UTC

Helicopter: Columbia Helicopters CH-47D, N388RA, SN 88-0097

B. COMPUTED TOMOGRAPHY SPECIALIST

John Flynn

National Transportation Safety Board

Washington, D.C.

C. DETAILS OF THE INVESTIGATION

The yaw Integrated Lower Control Actuator (ILCA) from the accident helicopter was subjected to x-ray radiograph and computed tomography (CT) scanning to document its internal condition. The scanning was conducted from October 05 through November 03, 2022, in Chicago, Illinois by Varex, Inc under the direction of the NTSB using the CST 9MV 4343 HE DRZ+ CT system and Actis 225/500 microfocus CT system.

For the CT scans, the component was loaded into the imaging unit and placed on a turntable. The component was then rotated in front of the x-ray source, and the x-rays were captured by a detector after they went through the part. The x-ray source produced a cone shaped beam of x-rays, and the portion of the part imaged was adjusted slightly after each scan was completed until the entire assembly (or region of interest of the part) was scanned. The x-ray energy levels measured by the detector were recorded at several thousand different points during each rotation, and this information was converted into slice images using reconstruction algorithms.

The component was scanned using a total of 8,018 slices, and the total size of the combined data sets was approximately 32.2 GB. The complete scan protocols are given in table 1. The digital radiograph and CT axial slice images were provided by Varex to the NTSB where they were examined, processed, and analyzed to evaluate the component.

Table 1. Scan Protocol

	9MeV (Megavolt)	450 kV (Microfocus)	450 kV (Microfocus)	450 kV (Microfocus)
Area Scanned	Whole Part	System 2 portion of ILCA	System 2 extensible link and manifold assembly	System 1 portion of ILCA
Number of Slices	2000	2006	2006	2006
Voxel ¹ Size - X Direction (millimeter(mm))	0.3	0.15	0.15	0.15
Voxel Size - Y Direction (mm)	0.3	0.15	0.15	0.15
Voxel Size - Z Direction (mm)	0.3	0.15	0.15	0.15
Image Projections per Revolution	2520	2880	2880	2880
Exposure Time (milliseconds)	1000	0.5	0.5	0.5
Frames to Avg (frames per projection)	1	N/A	N/A	N/A
X-ray Source Voltage (kilovolts)	9,000	450	450	450
X-ray Source Current (mA) (microfocus system)	320 hz	1.6	1.6	1.6
Source Filter Thickness (mm)	32.5	6.8	6.8	6.8
Source Filter Material	copper	brass	brass	brass
Image Matrix Size (pixels)	3072 x 3072	2000x2000x 1500	2000x2000x 1500	2000x2000x 1500

The data sets of slice images were examined, processed, and analyzed by the NTSB using the VGStudioMax software package to convert the axial slice data into orthogonal slice images and a three-dimensional reconstructed image of the component. As part of the evaluation, some sections of the components were digitally removed or rendered transparent to allow closer observation of interior parts. In all the images, the higher density areas were shown as brighter shades of gray and lower density areas were shown as darker shades of gray. Each 2-D quadrant within the images shows a scale at the bottom of that quadrant - note that the scales in each quadrant may be different. The pointers shown in some of the images denote specific areas of interest within that image. The numbers associated with the pointer are the gray value at the pointer location and the three positional coordinates of the pointer.

The actuator structures were “virtually unrolled” using the CT image visualization software. This process required the identification of a path for the software to use when unrolling the data set, and it resulted in a cylindrical structure being “unrolled” to show a round surface as a flat planar image.

The images of the components were examined for any signs of missing or damaged parts, contamination, or any other anomalies. Specific results (including example images) are presented in subsequent sections of this report.

¹ A voxel is a three-dimensional picture element (pixel).

D. FACTUAL INFORMATION

1.0 Yaw ILCA Description

The yaw ILCA is shown in Figure 1. The yaw ILCA is a 1500 pounds per square inch (psi) actuator that provides a boost to the cockpit control inputs and Advanced Flight Control System (AFCS) inputs. (The AFCS is also referred to as the stability augmentation system (SAS).) The boost sections of the ILCA (Figures 2, 3 and 4) hydraulically assists control movement and prevents control feedback. The ILCA incorporates separate manifolds for hydraulic Systems 1 and 2 to prevent fluid transfer between systems. The housing assembly connects the two manifold assemblies. The AFCS is an electronic system that independently changes the position of the flight controls as needed to keep the helicopter steady in flight. The extensible links convert the electrical signals from the AFCS into a hydraulic input to the flight controls. (Figures 2 and 5)

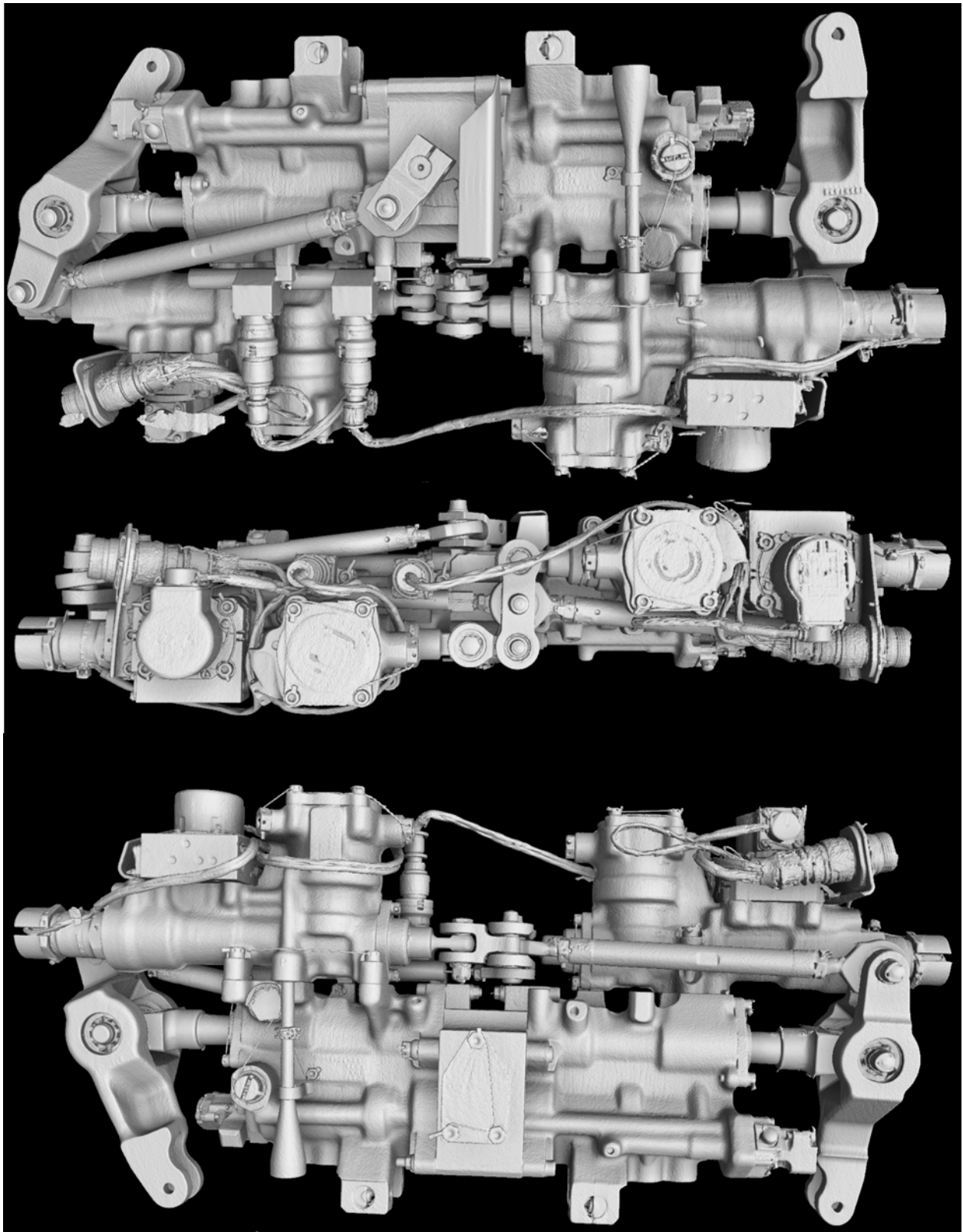


Figure 1. CT images of the front, top and back of the exterior of the yaw ILCA.

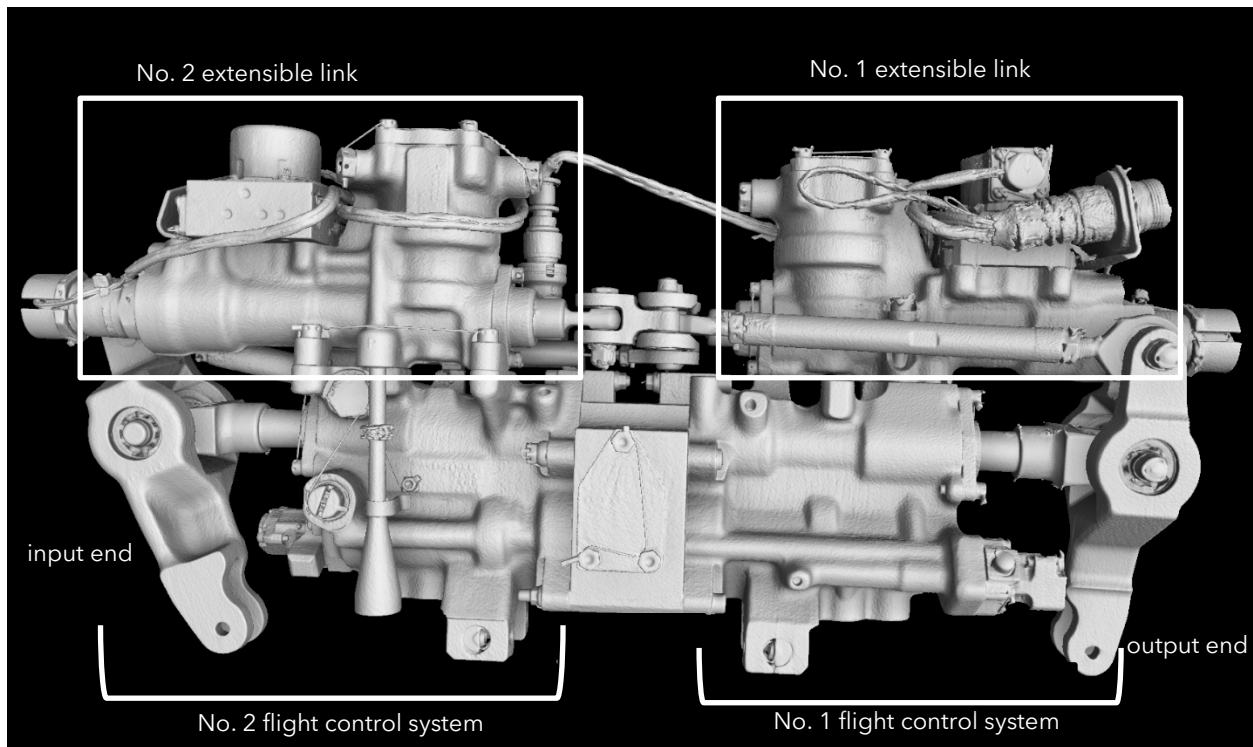


Figure 2. External image of the yaw ILCA with components labeled.

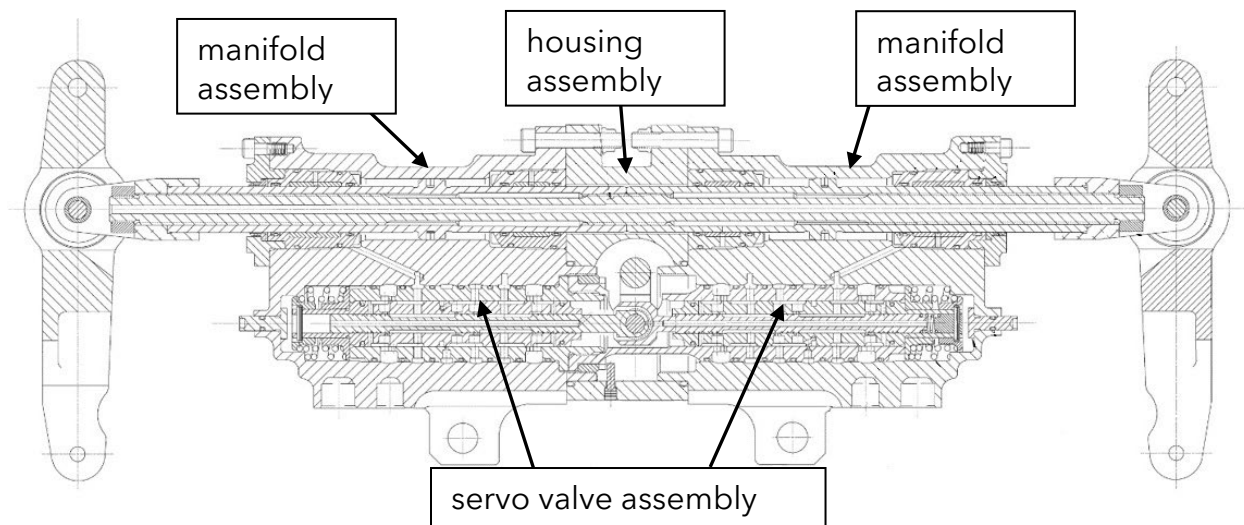


Figure 3. Diagram of the yaw ILCA boost section. (Courtesy of Columbia Helicopters)

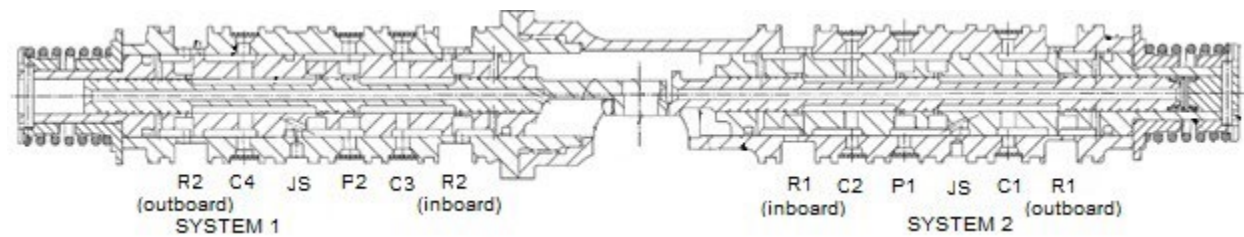


Figure 4. Expanded view of yaw ILCA boost section servo valve assembly. (Courtesy of Boeing)

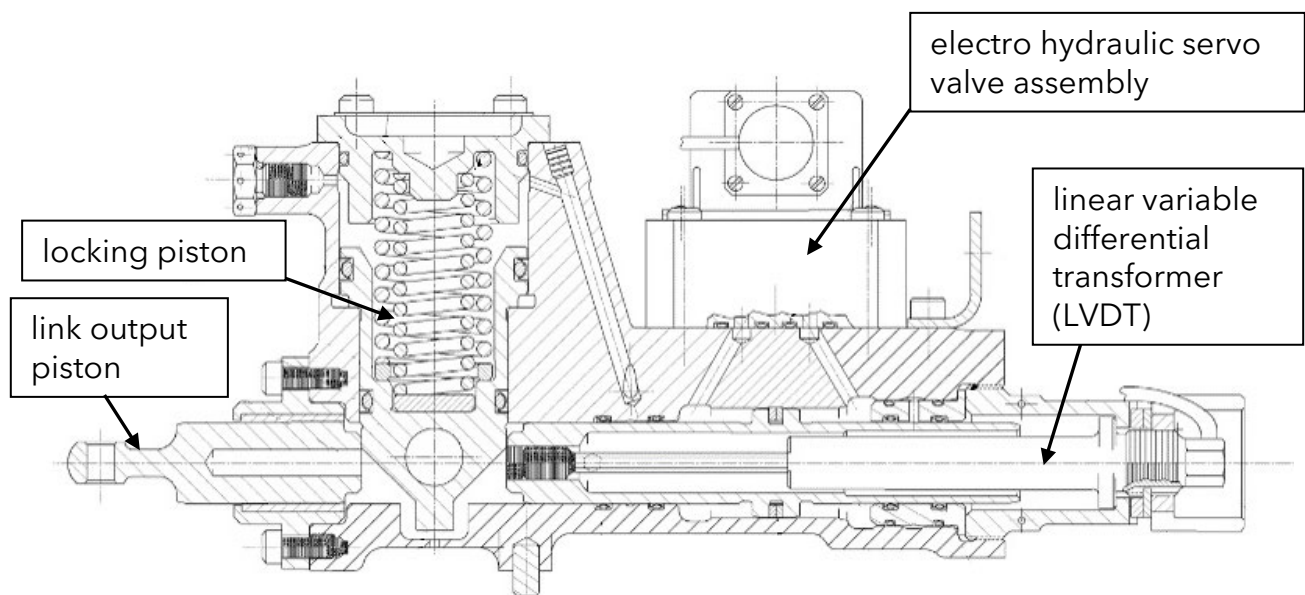


Figure 5. Diagram of the yaw ILCA extensible link. (Courtesy of Columbia Helicopters)

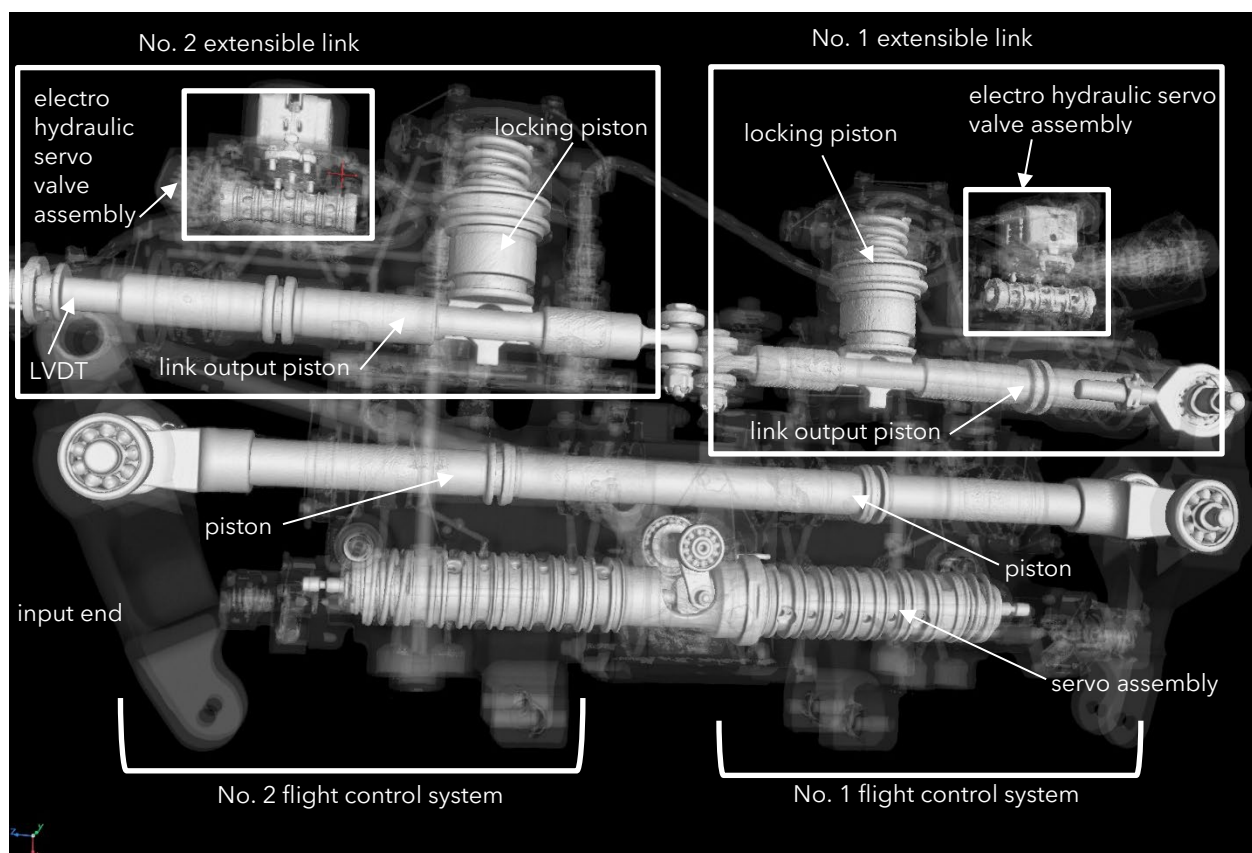


Figure 6. CT image of the yaw ILCA with internal components labeled.

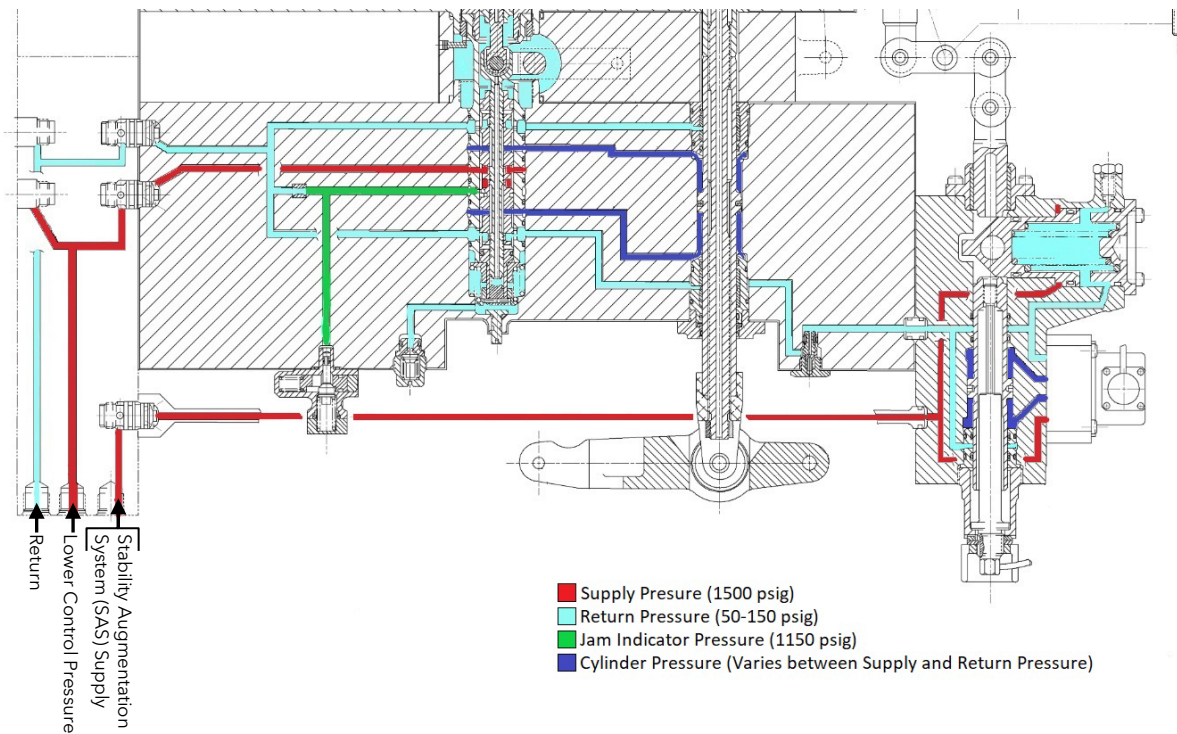


Figure 7. Schematic of the yaw ILCA internal view showing pressures. (Courtesy of Boeing)

2.0 Yaw ILCA System 1 Boost Section

The CT images of the System 1 boost section of the yaw ILCA were examined. A piece of the sleeve assembly was fractured near the input connection (Figures 8 and 9). There were indications of medium density material in the C4 passageway annular groove (Figure 10), jam pressure passageway annular groove (Figure 12), P2 passageway annular groove (Figures 13 and 14), C3 passageway annular groove (Figure 15) and inboard R2 passageway annular groove of the servo assembly (Figure 17). The filter screens appeared to be intact for the C4 passageway annular groove (Figures 10 and 11), P2 passageway annular groove (Figures 13 and 14), and C3 passageway annular groove (Figures 15 and 16). The MS16555-619 pin was correctly located in the 12 o'clock position (Figure 18). The lower boost valve nut retaining pin (part number 145H7329-1) was installed (Figure 19). There were indications of a low density area in the 145H7356-2 piston ring set (Figure 20).

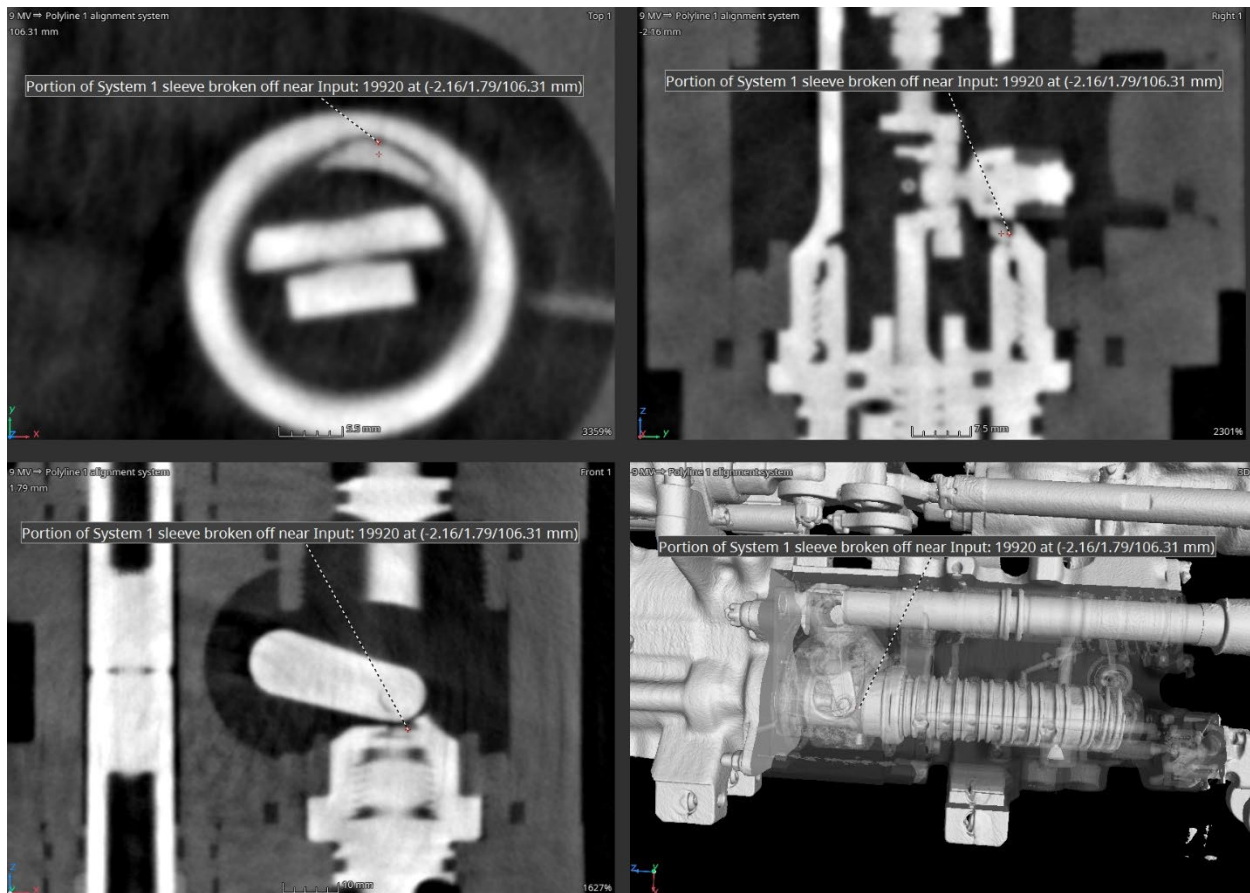


Figure 8. CT images of System 1 portion of yaw ILCA illustrating damage to sleeve near input connection.

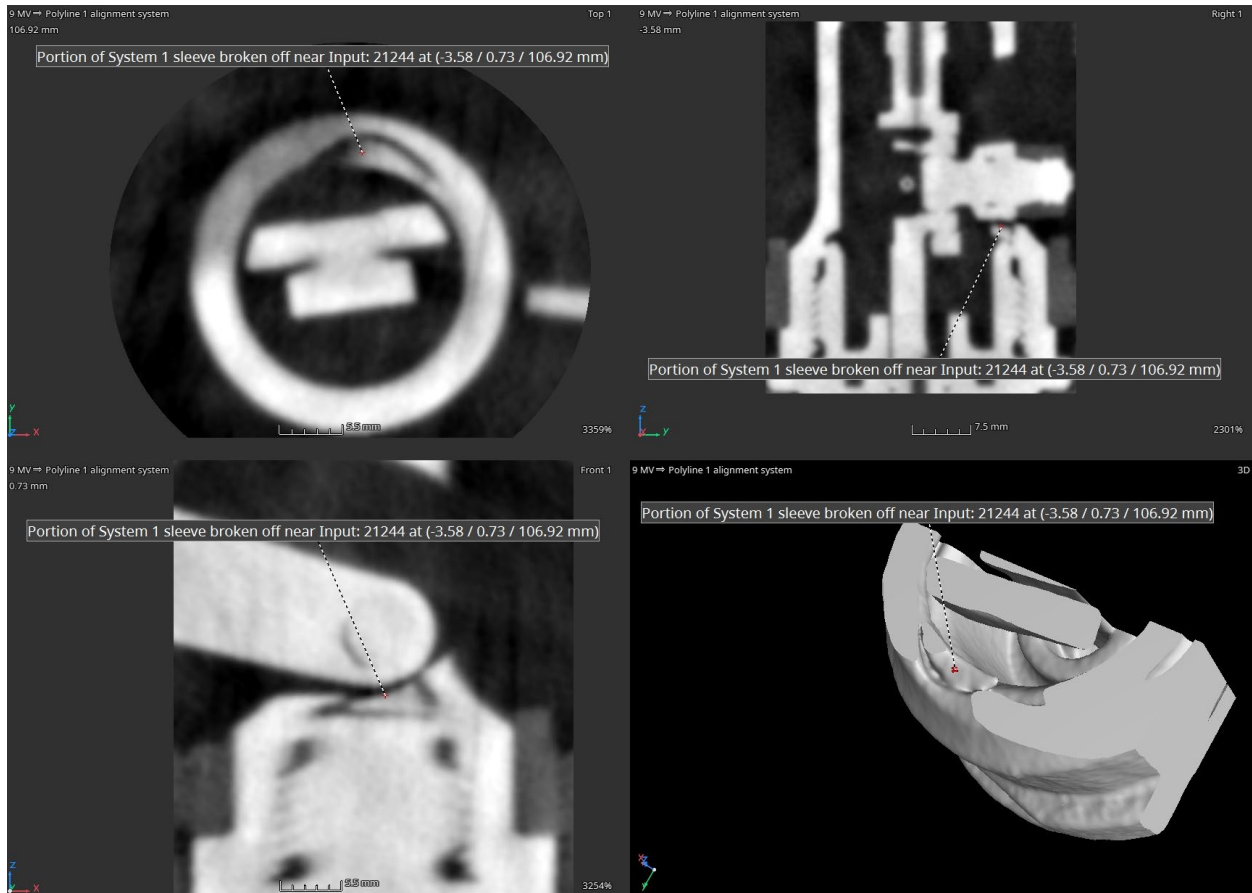


Figure 9. CT images of System 1 portion of yaw ILCA close-up of damage to sleeve near input connection.

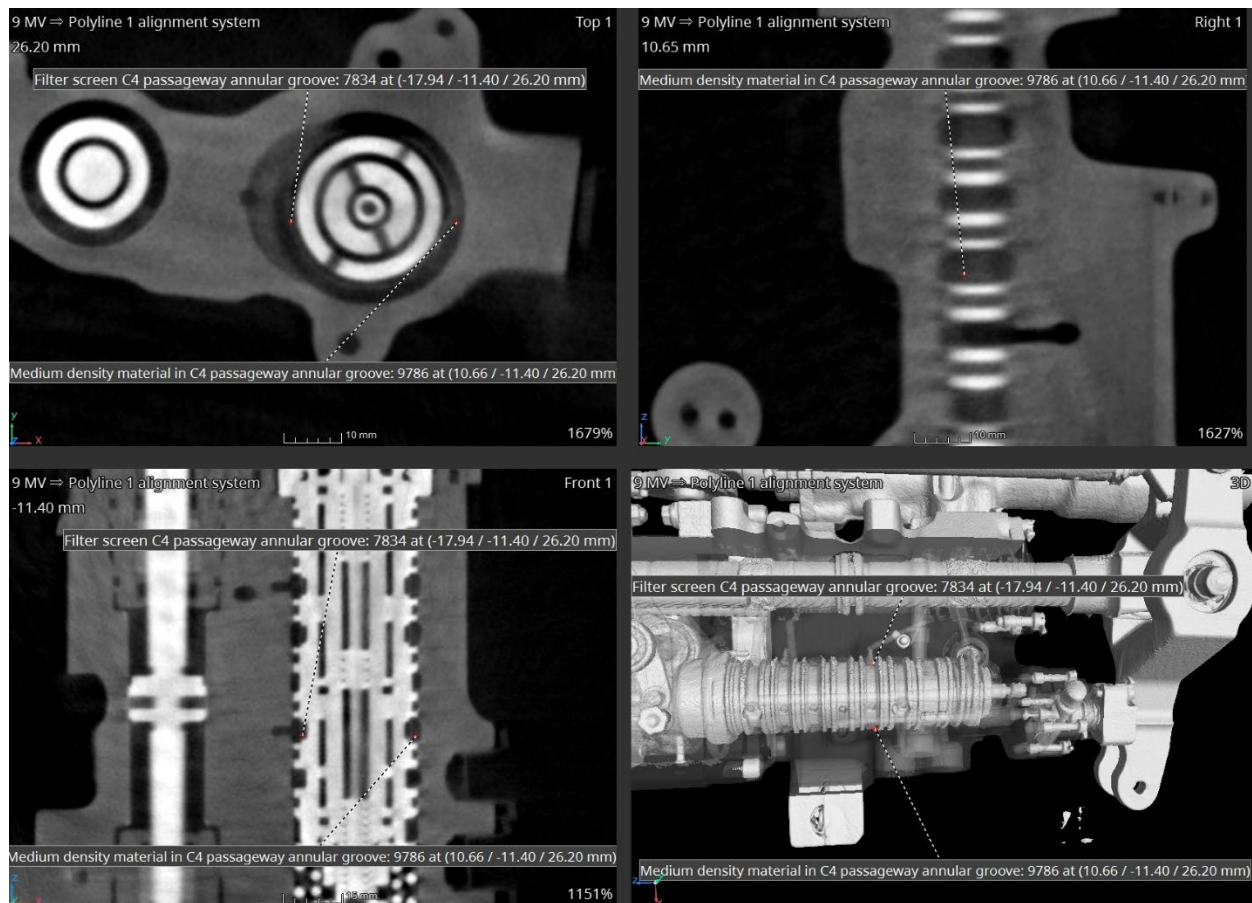


Figure 10. CT images of System 1 portion of yaw ILCA illustrating medium density material and filter screen in the C4 passageway annular groove between the sleeve and housing. (9 MV)

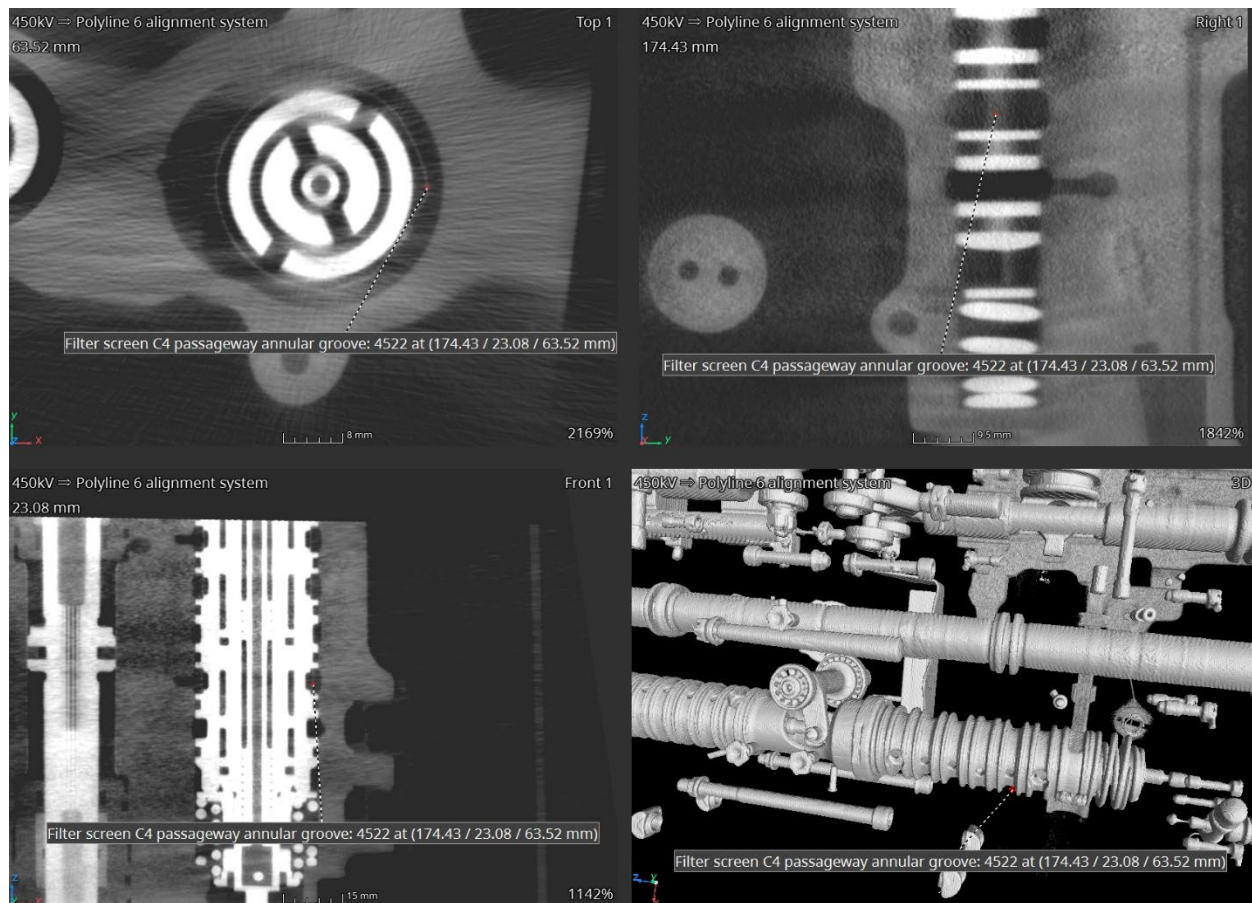


Figure 11. CT images of System 1 portion of yaw ILCA illustrating the filter screen in the C4 passageway annular groove. (450 kV)



Figure 12. CT images of System 1 portion of yaw ILCA illustrating medium density material in jam pressure passageway annular groove between the sleeve and housing. (9 MV)

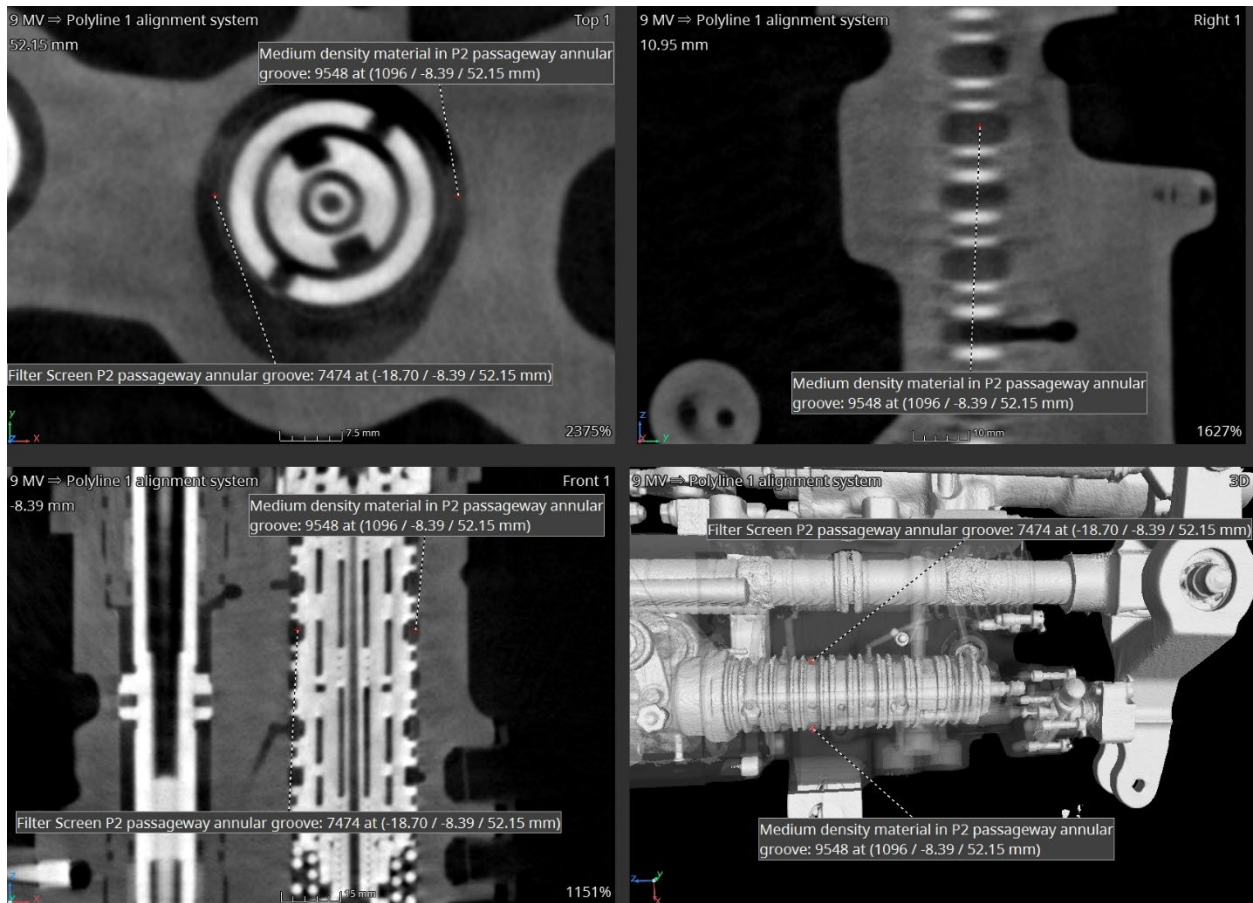


Figure 13. CT images of System 1 portion of yaw ILCA illustrating medium density material and filter screen in the P2 passageway annular groove between the sleeve and housing. (9 MV)



Figure 14. CT images of System 1 portion of the yaw ILCA illustrating medium density material and the filter screen in the P2 passageway annular groove between the sleeve and housing. (450 kV)

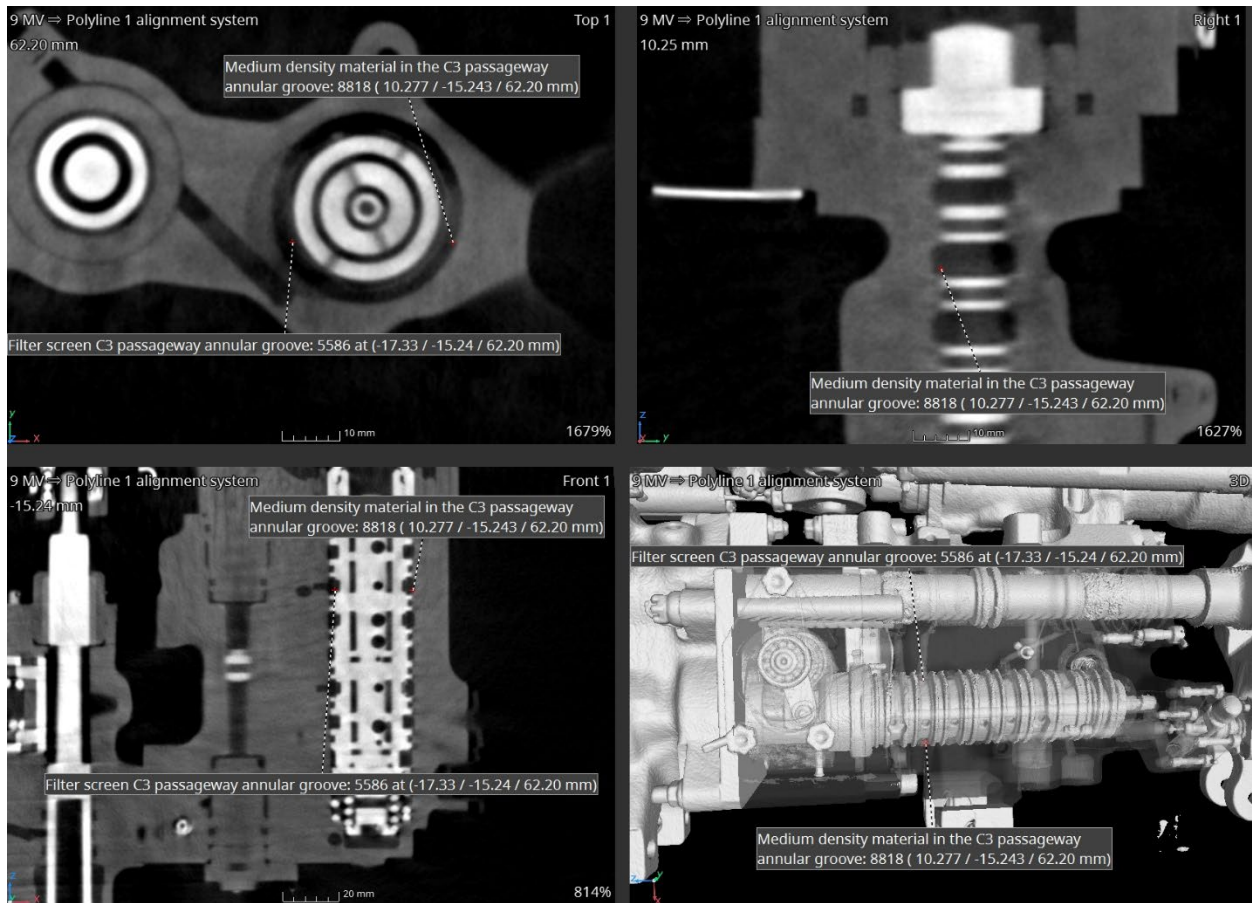


Figure 15. CT images of System 1 portion of the yaw ILCA illustrating medium density material and the filter screen in the C3 passageway annular groove between the sleeve and housing. (9 MV)

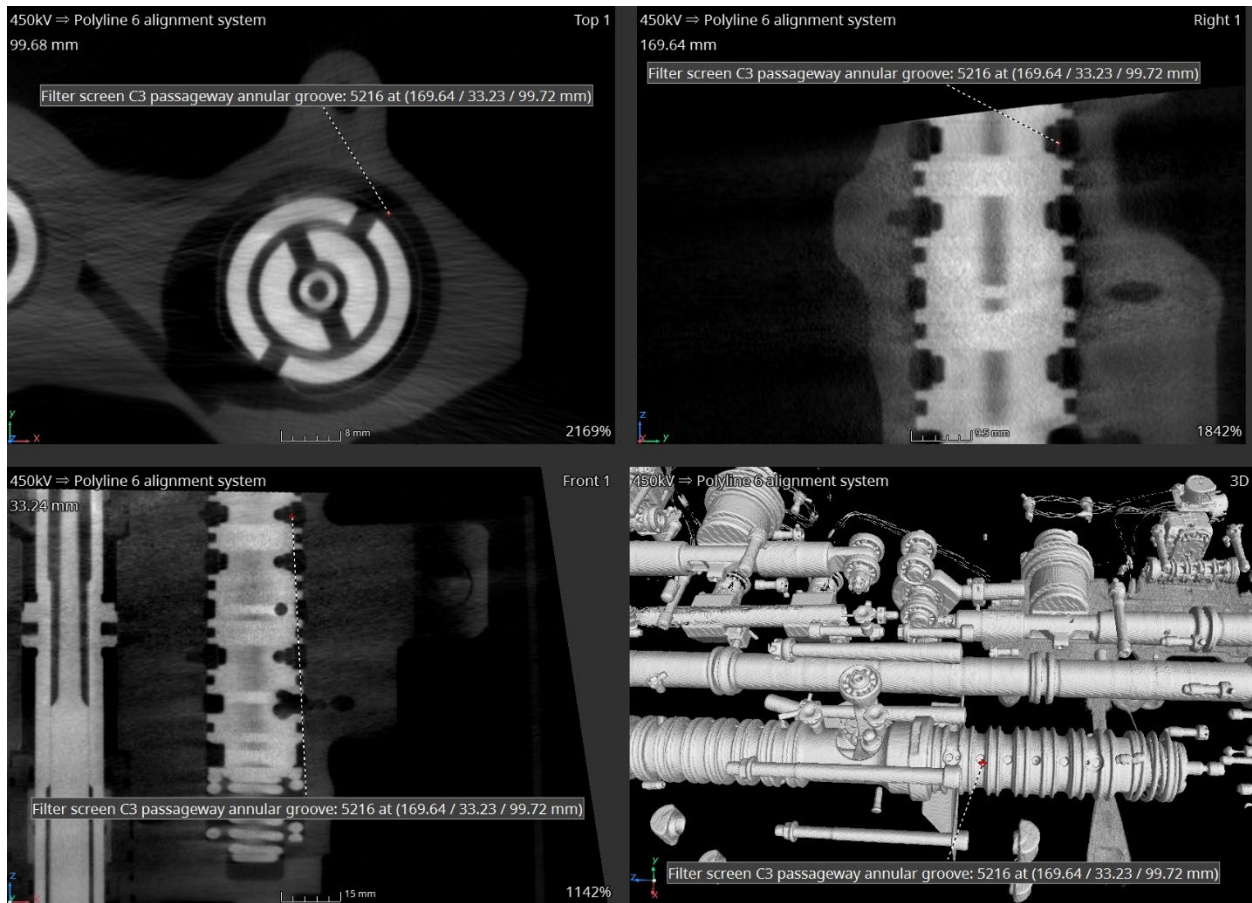


Figure 16. CT images of System 1 portion of the yaw ILCA illustrating the filter screen in the C3 passageway annular groove between the sleeve and housing. (450 kV)

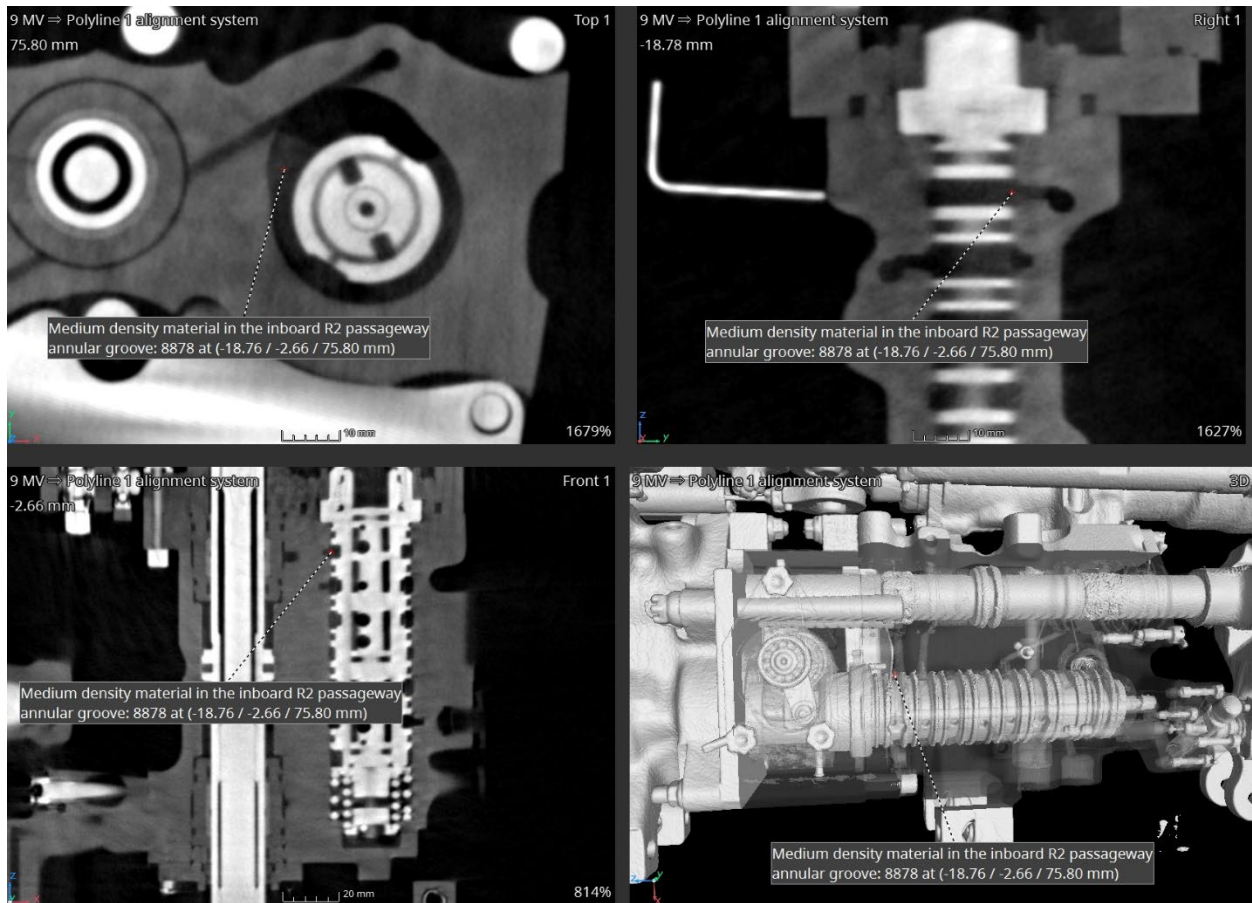


Figure 17. CT images of System 1 portion of the yaw ILCA illustrating medium density material in the inboard R2 passageway annular groove between the sleeve and housing.

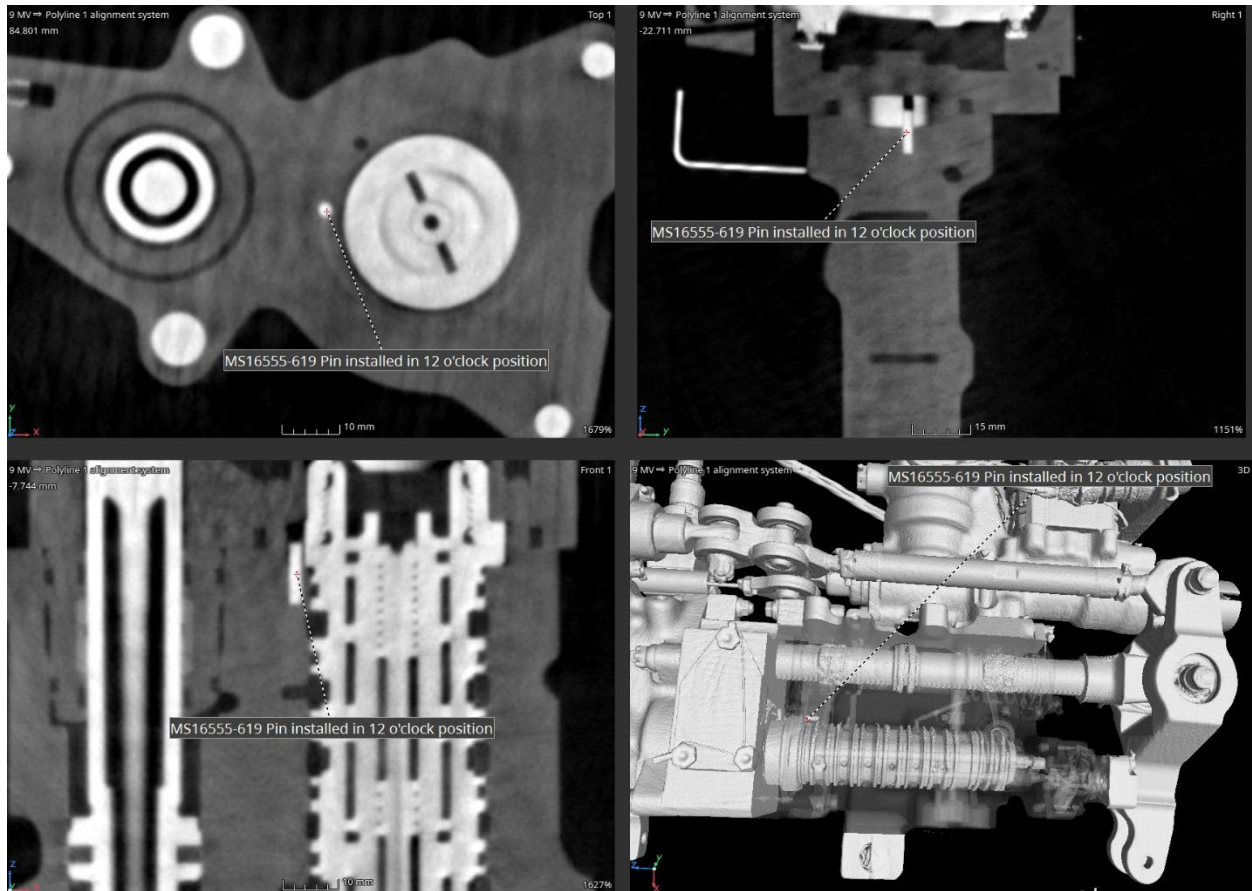


Figure 18. CT images of System 1 portion of the yaw ILCA illustrating the MS16555-619 pin installed in the 12 o'clock position.

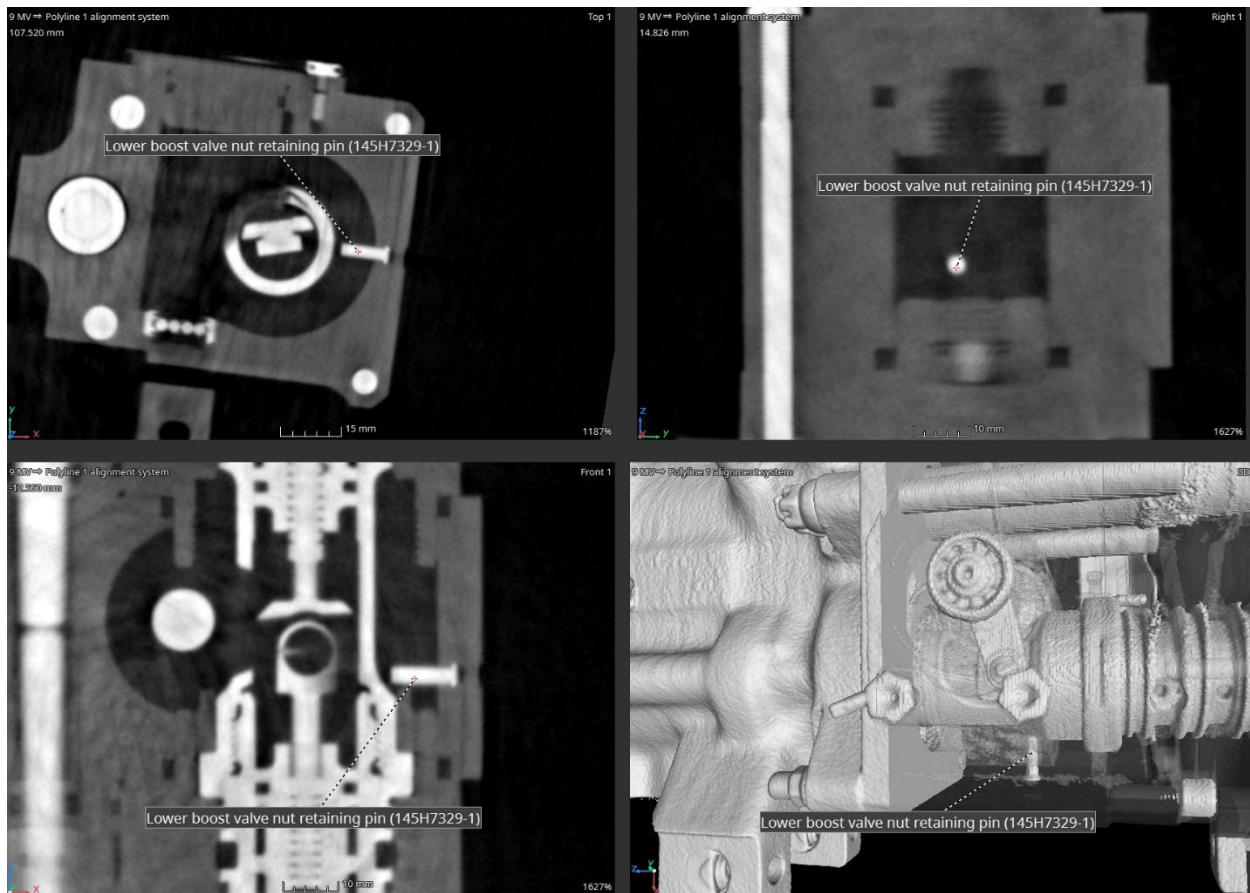


Figure 19. CT images of System 1 portion of the yaw ILCA illustrating the lower boost valve nut retaining pin (145H7329-1).

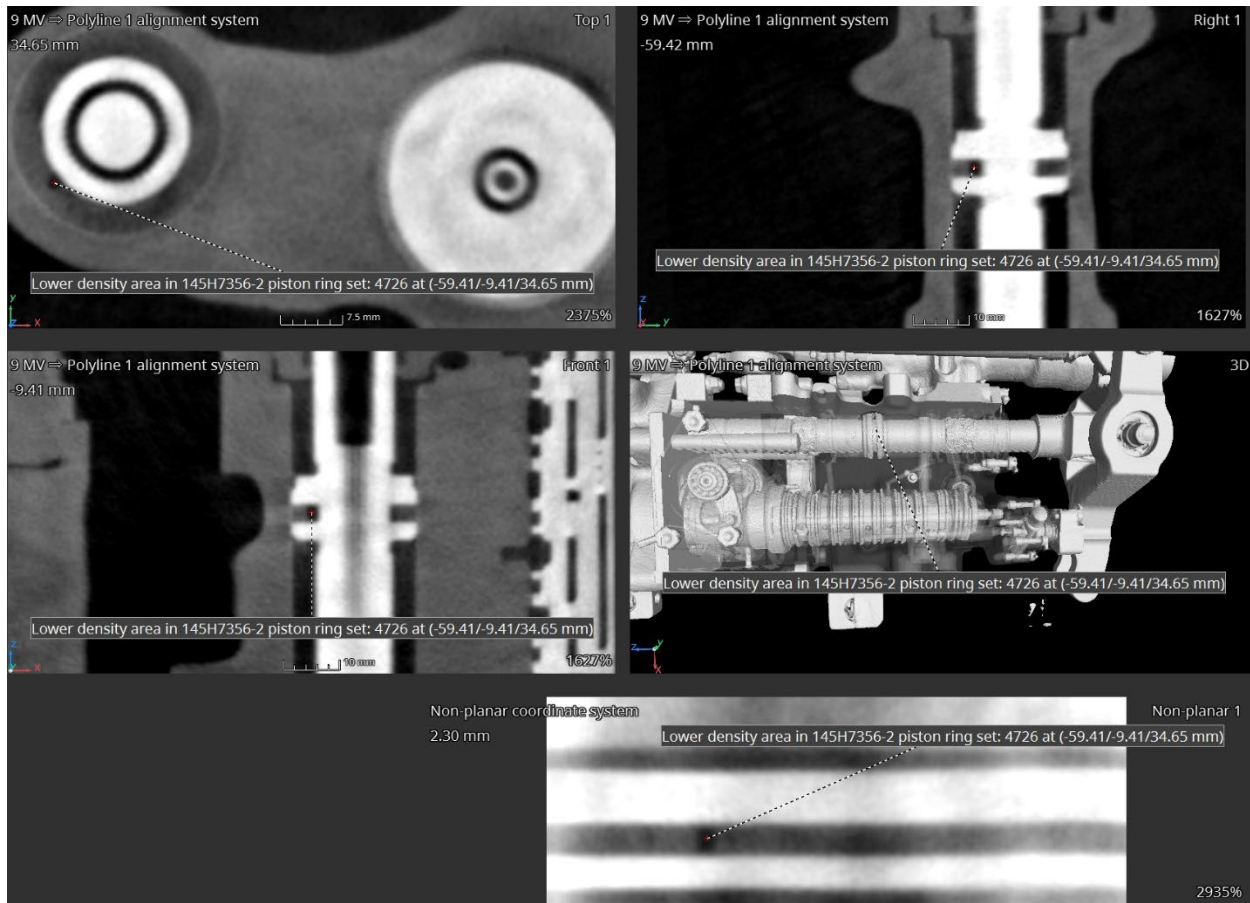


Figure 20. CT images of System 1 portion of the yaw ILCA illustrating lower density area in 145H7356-2 piston ring set.

3.0 Yaw ILCA System 1 Extensible Link Section

The CT images of the System 1 extensible link section of the yaw ILCA were examined. Figure 21 shows the System 1 extensible link. An image of the extensible link piston ring set (part number 145H7356-1) is shown in Figure 22. The 90 micron strainer in the extensible link electro hydraulic servo-valve assembly is shown in Figure 23.

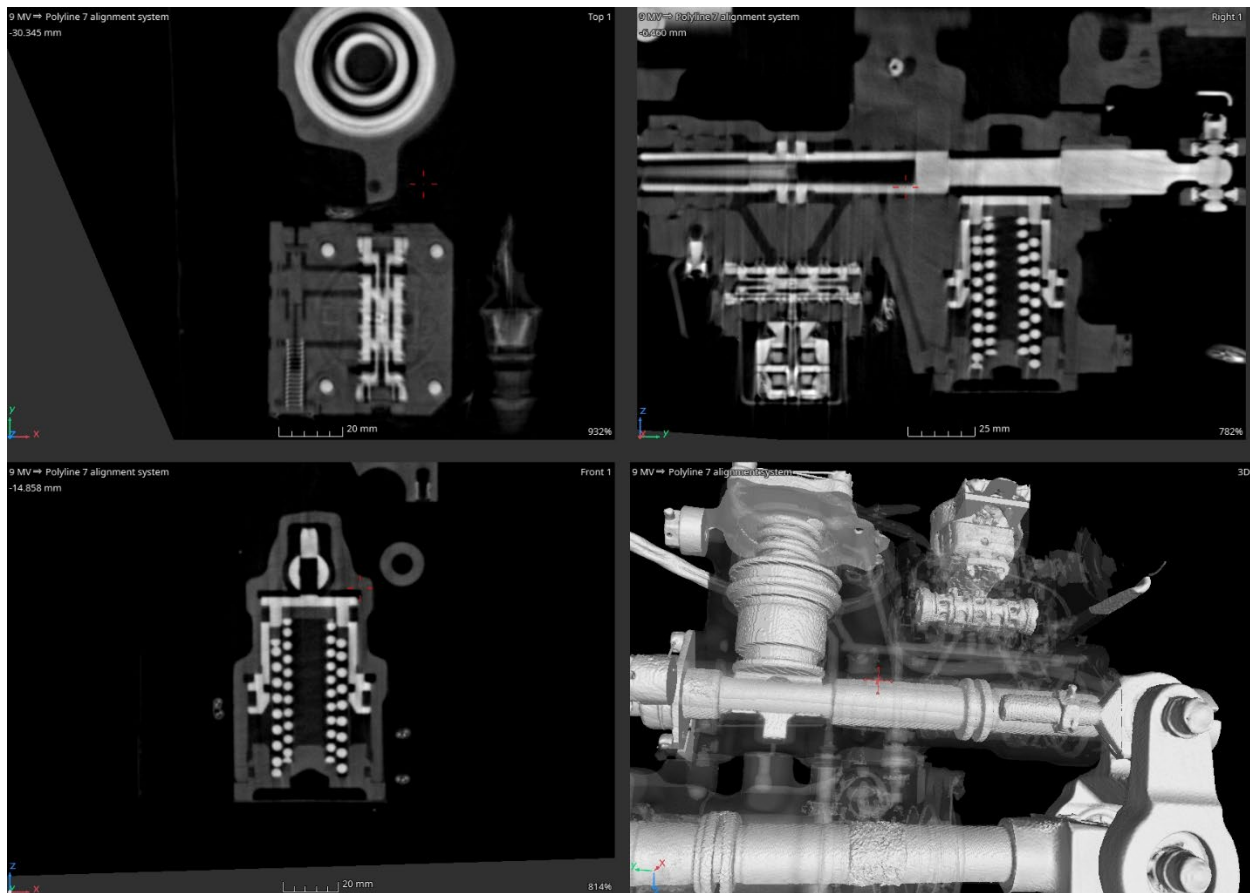


Figure 21. CT images of System 1 extensible link.

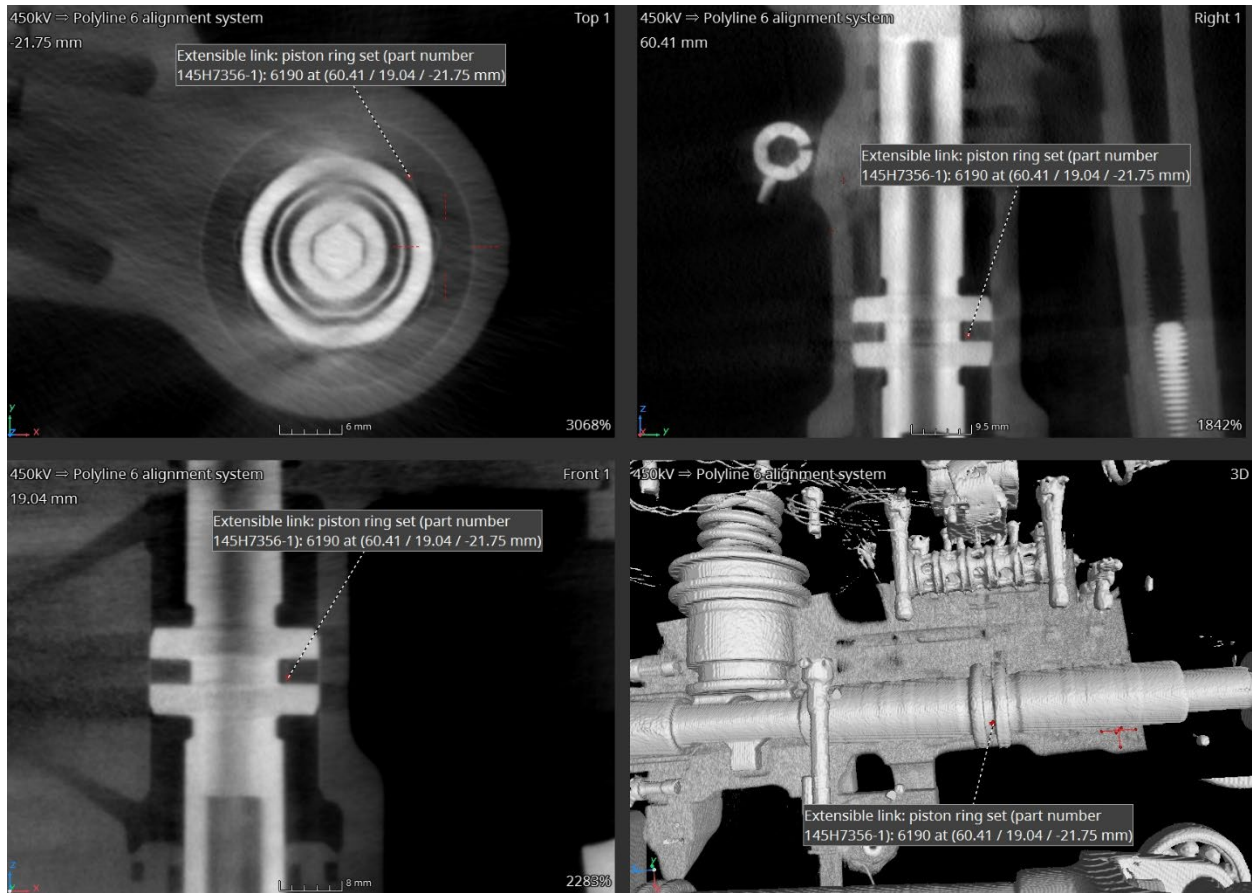


Figure 22. CT images of System 1 extensible link piston ring set part number 145H7356-1. (450 kV)

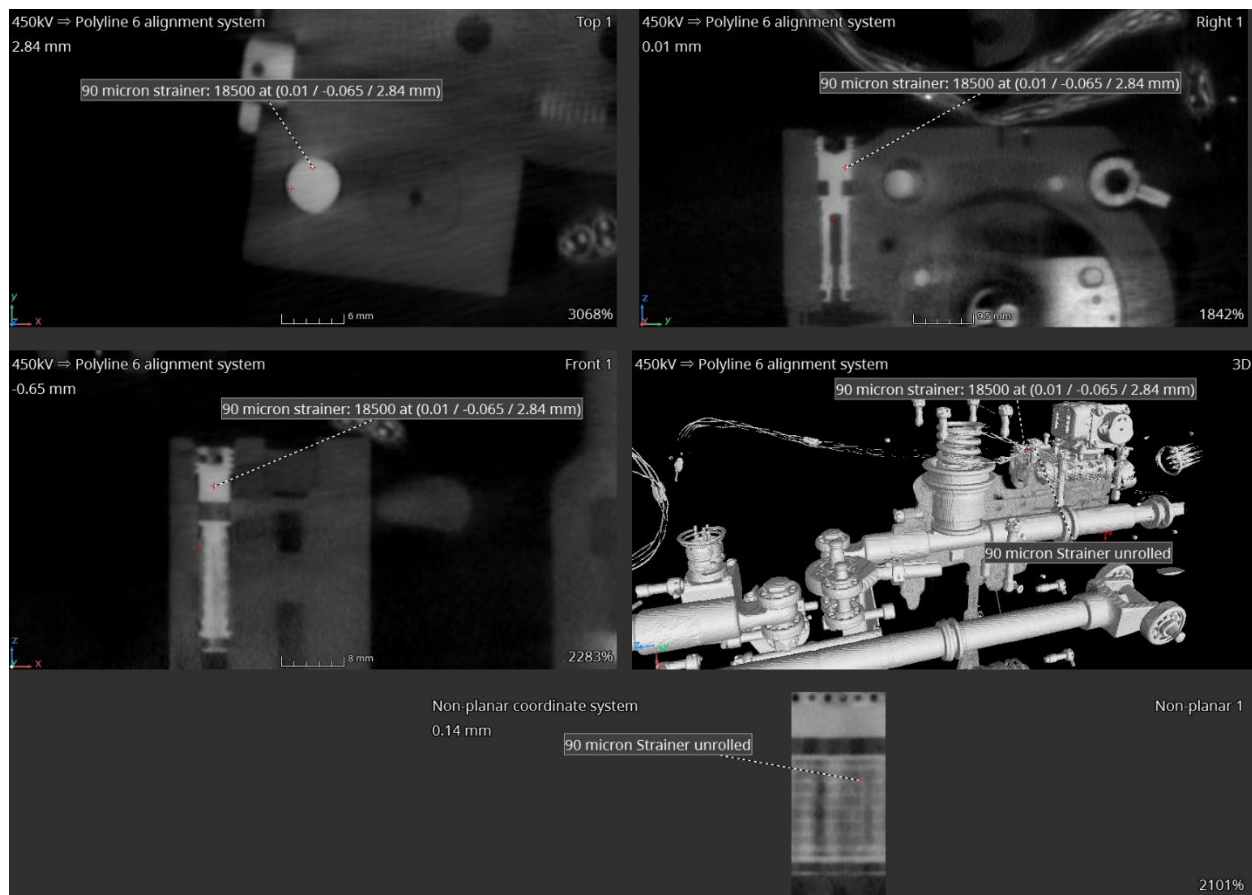


Figure 23. CT images of yaw ILCA System 1 extensible link 90 micron strainer. (450 kV)

4.0 Yaw ILCA System 2 Boost Section

The CT images of the System 2 boost section of the yaw ILCA were examined. There were indications of medium density material in the outboard R1 passageway annular groove (Figure 24), C1 passageway annular groove (Figure 25), P1 passageway annular groove (Figure 26), C2 passageway annular groove (Figure 27) and the inboard R1 passageway annular groove of the servo assembly (Figure 28). The filter screens appeared to be intact for the C1 passageway annular groove (Figure 25), P1 passageway annular groove (Figure 26), and C2 passageway annular groove (Figure 27). There were indications of a low density area in the 145H7356-2 piston ring set (Figure 29). There were indications of medium density material around the piston shaft (Figure 30).

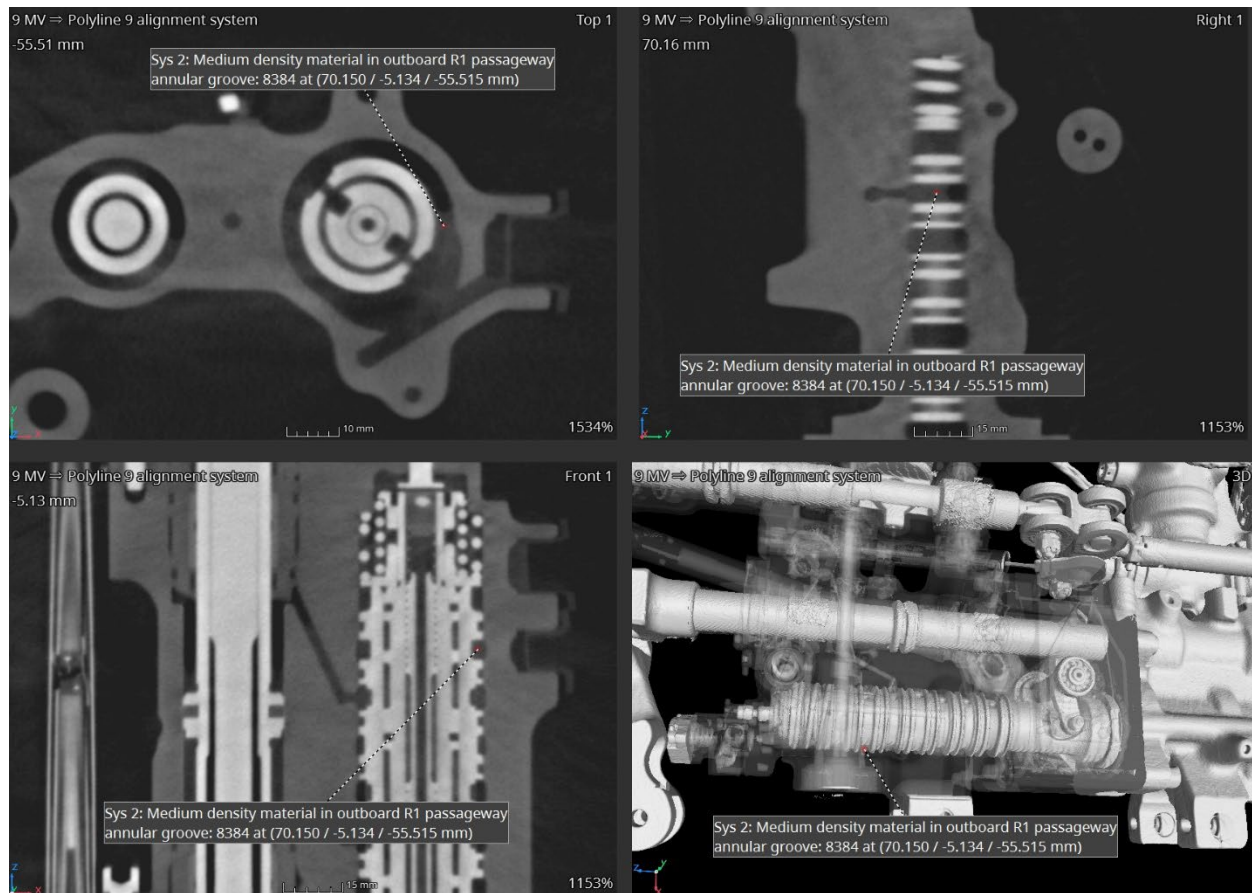


Figure 24. CT images of System 2 portion of the yaw ILCA illustrating medium density material in the outboard R1 passageway annular groove between the sleeve and housing. (9 MV)

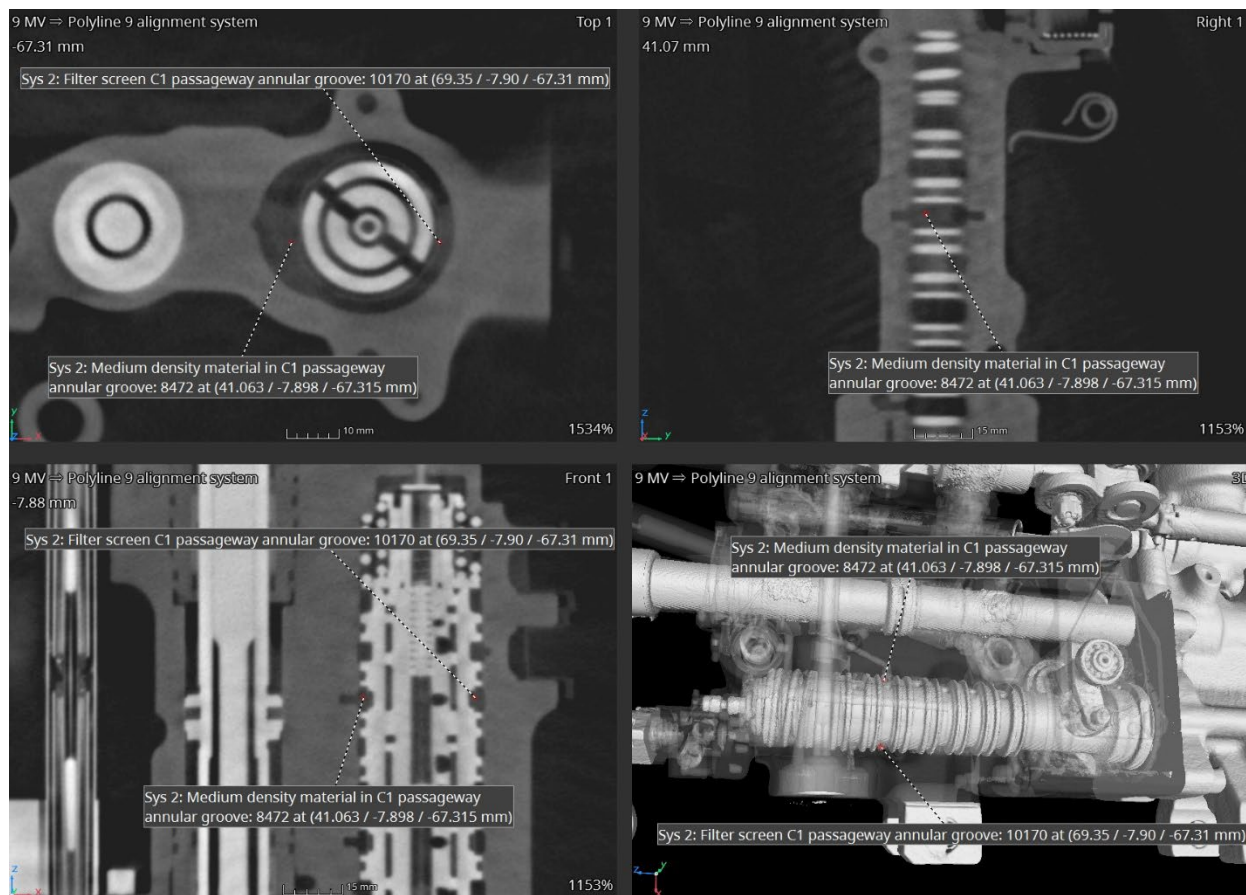


Figure 25. CT images of System 2 portion of the yaw ILCA illustrating medium density material and filter screen in the C1 passageway annular groove between the sleeve and housing. (9 MV)

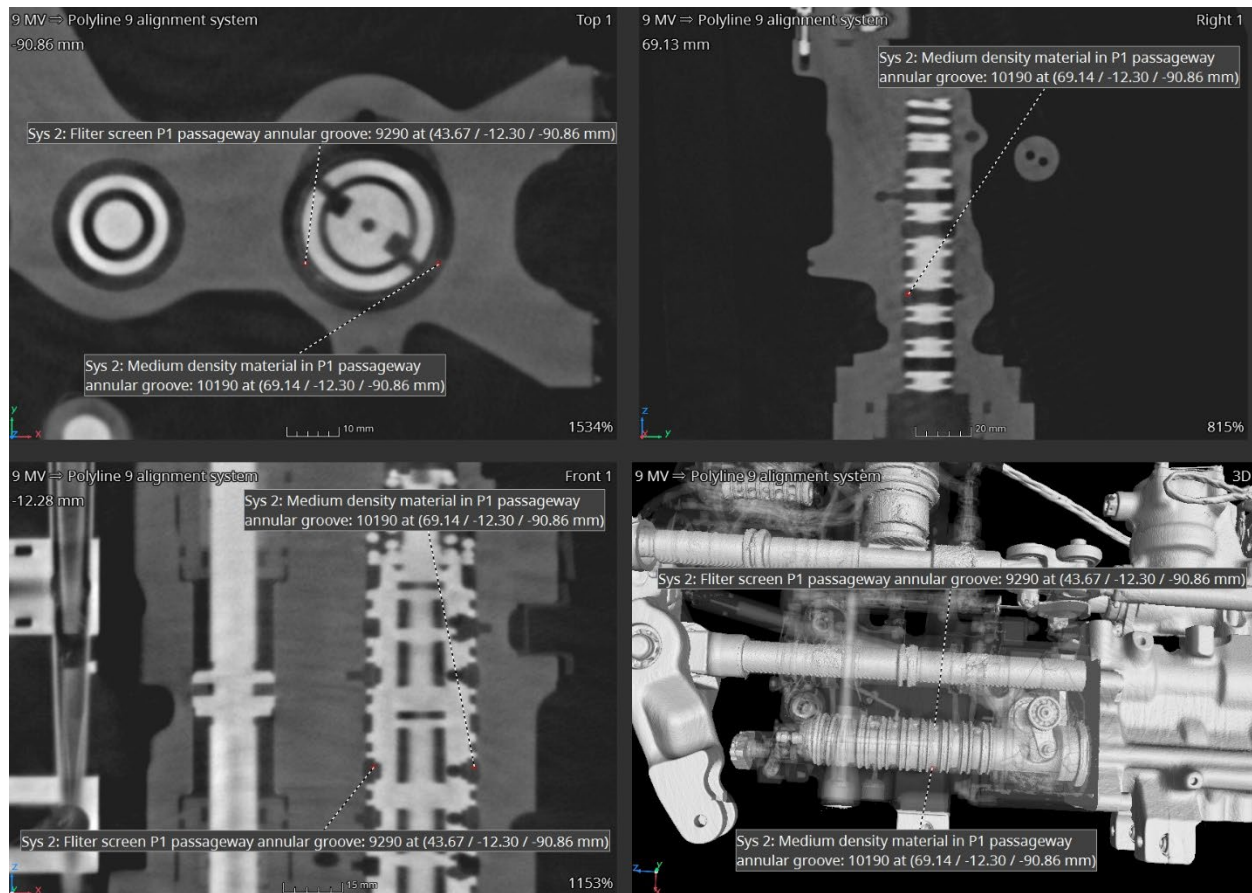


Figure 26. CT images of the System 2 portion of yaw ILCA illustrating medium density material and filter screen in the P1 passageway annular groove between the sleeve and housing. (9 MV)

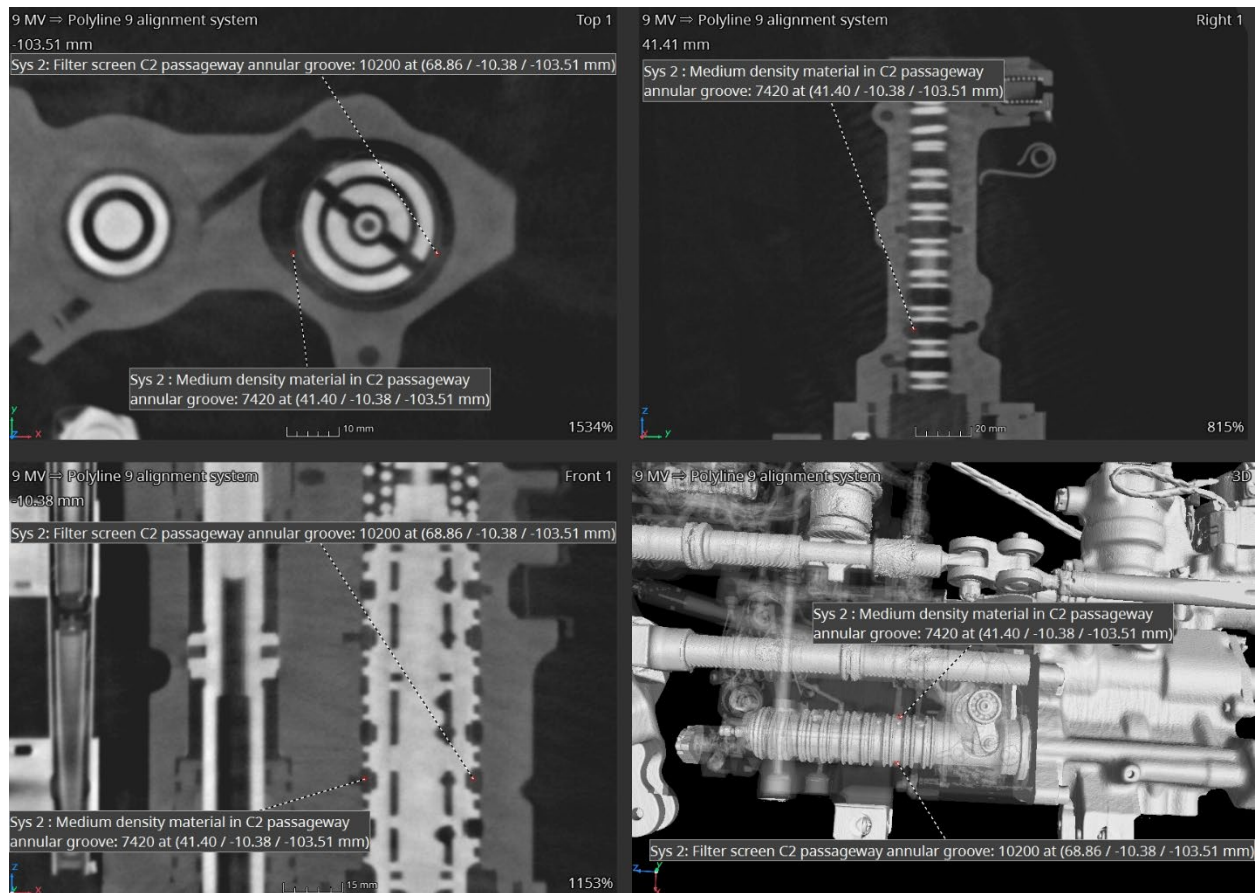


Figure 27. CT images of the System 2 portion of yaw ILCA illustrating medium density material and the filter screen in the C2 passageway annular groove between the sleeve and housing. (9 MV)



Figure 28. CT images of System 2 portion of yaw ILCA illustrating medium density material in the inboard R1 passageway annular groove between the sleeve and housing. (9MV)

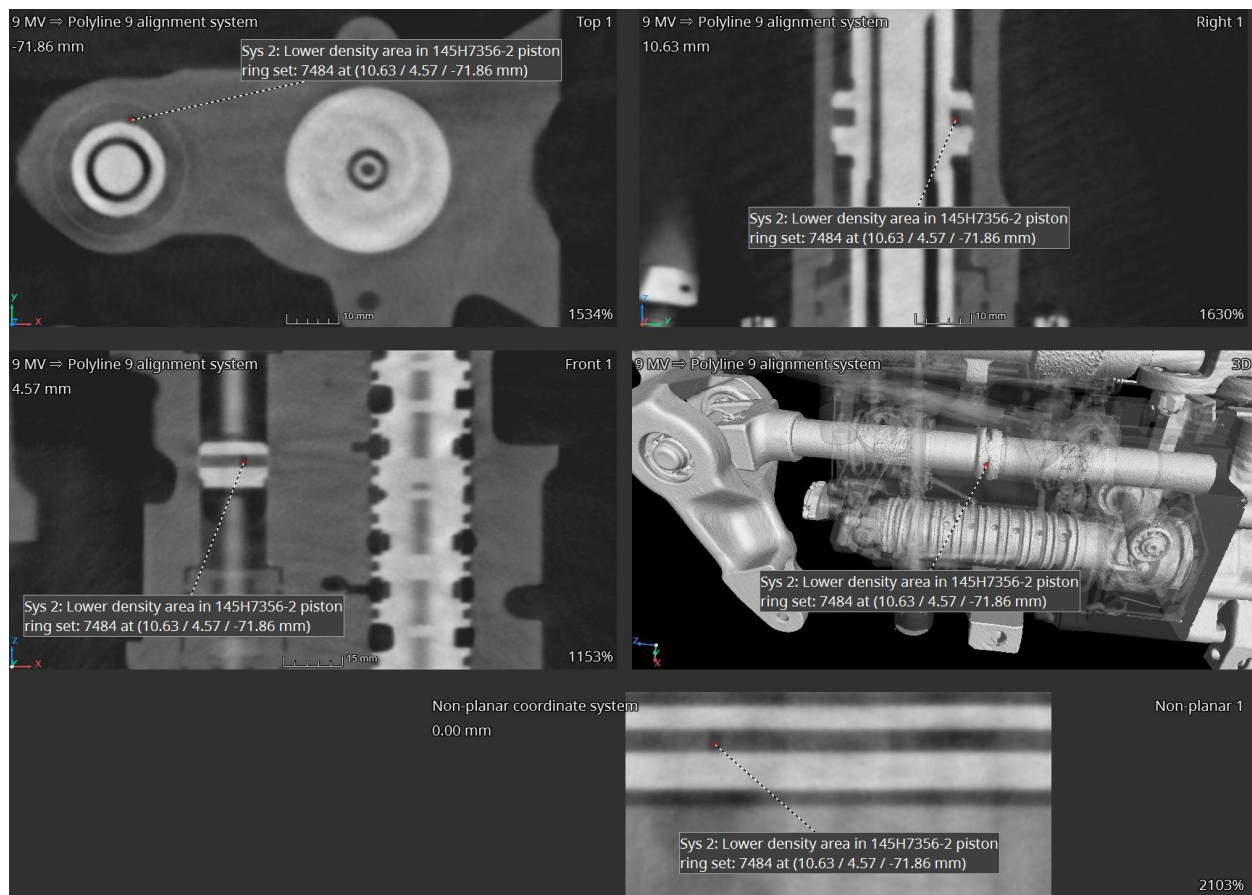


Figure 29. CT images of the System 2 portion of yaw ILCA illustrating lower density area in 145H7356-2 piston ring set.

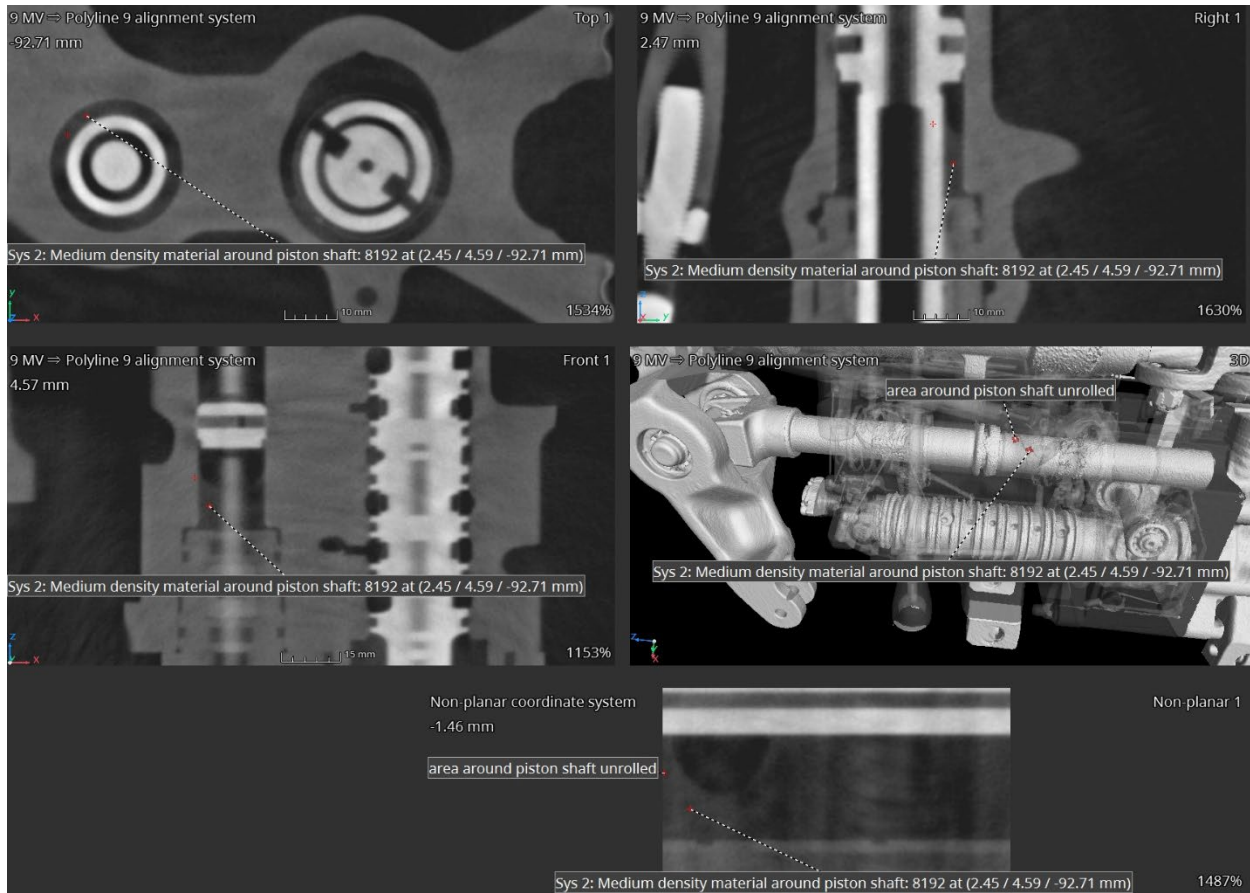


Figure 30. CT images of System 2 portion of yaw ILCA illustrating medium density material around the piston shaft.

5.0 Yaw ILCA System 2 Extensible Link Section

The CT images of the System 2 extensible link section of the yaw ILCA were examined (Figure 31). There were indications of a low density area in the locking piston MS28775-216 O-ring/MS28774-216 backup ring groove (Figure 32). The 90 micron strainer in the extensible link electro hydraulic servo-valve assembly is shown in Figure 33.

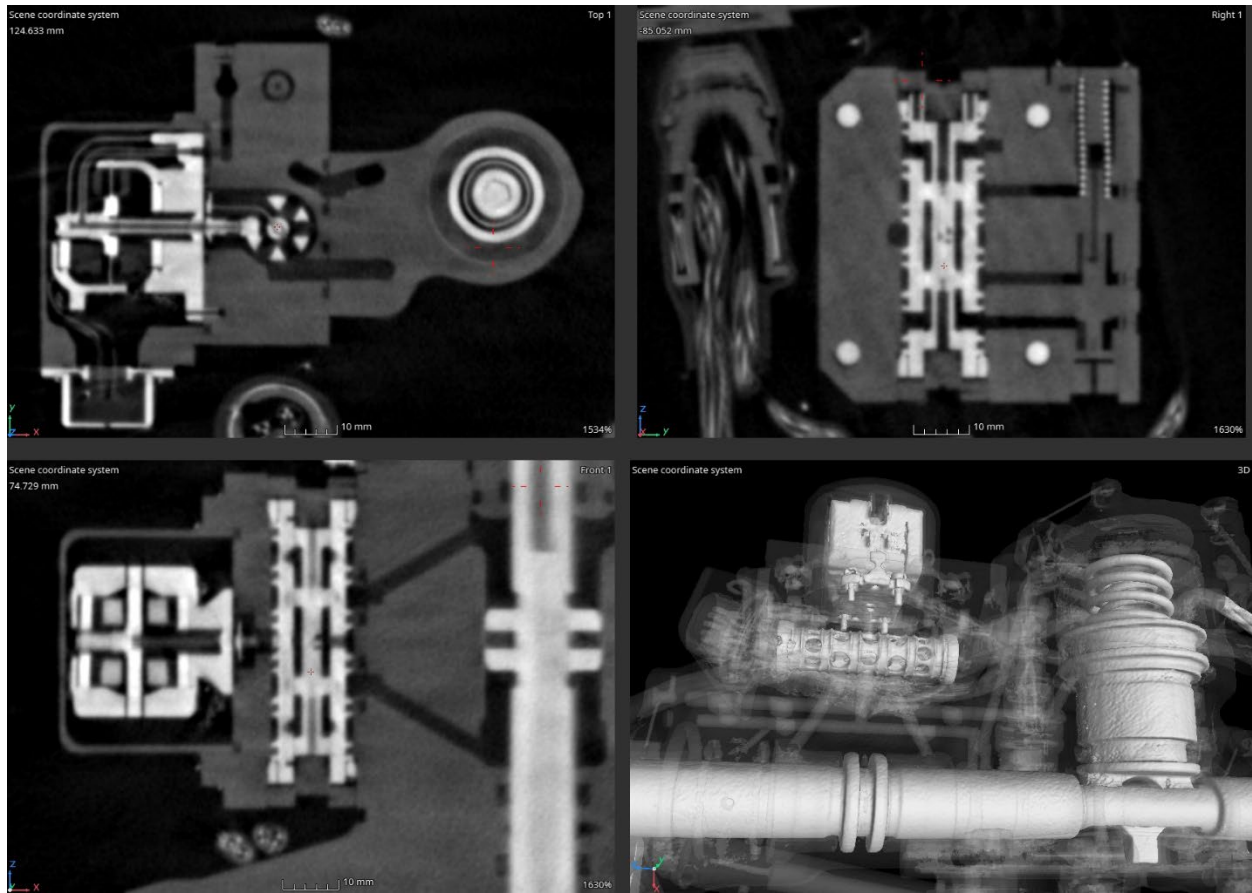


Figure 31. CT images of System 2 extensible link. (9MV)

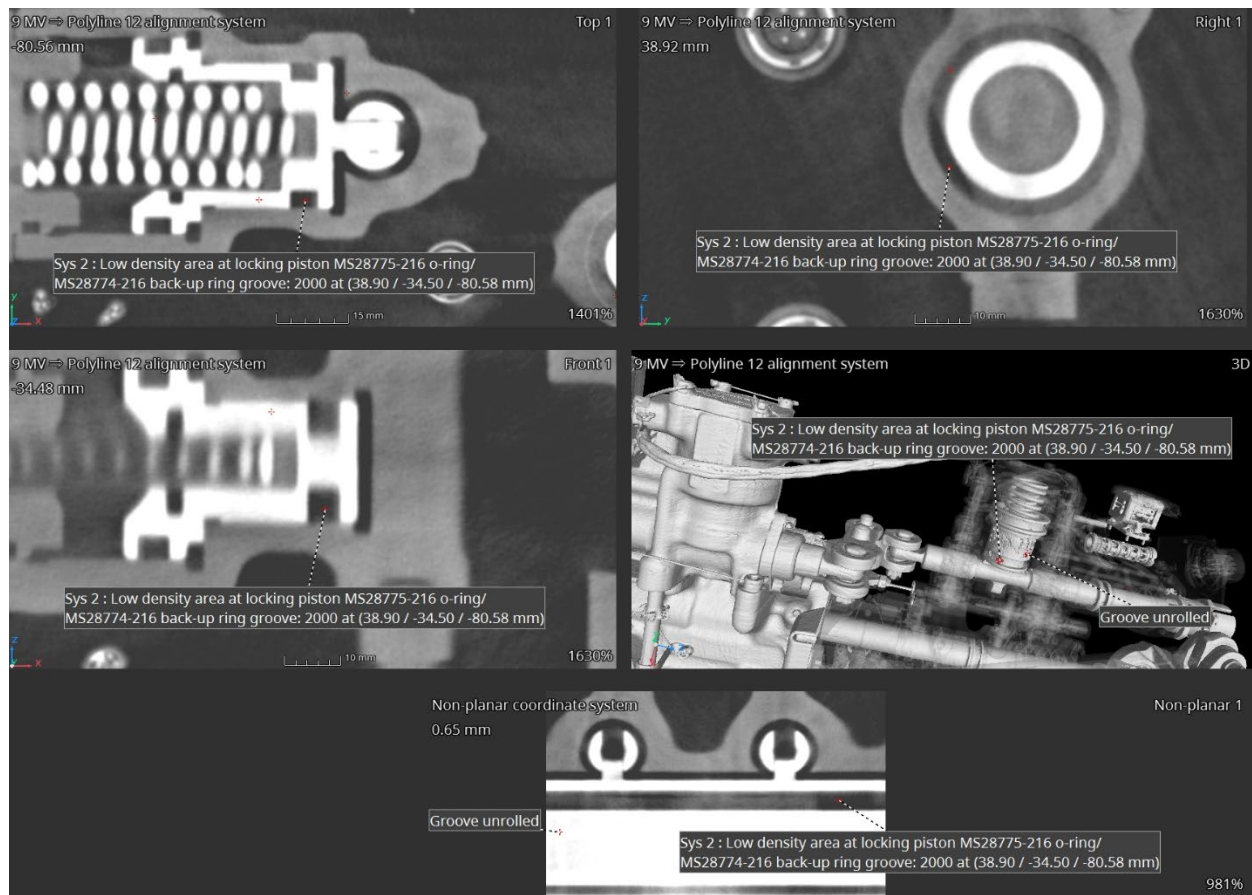


Figure 32. CT images of System 2 extensible link low density area at locking piston MS28775-216 o-ring/MS28774-216 back-up ring groove. (450 kV)

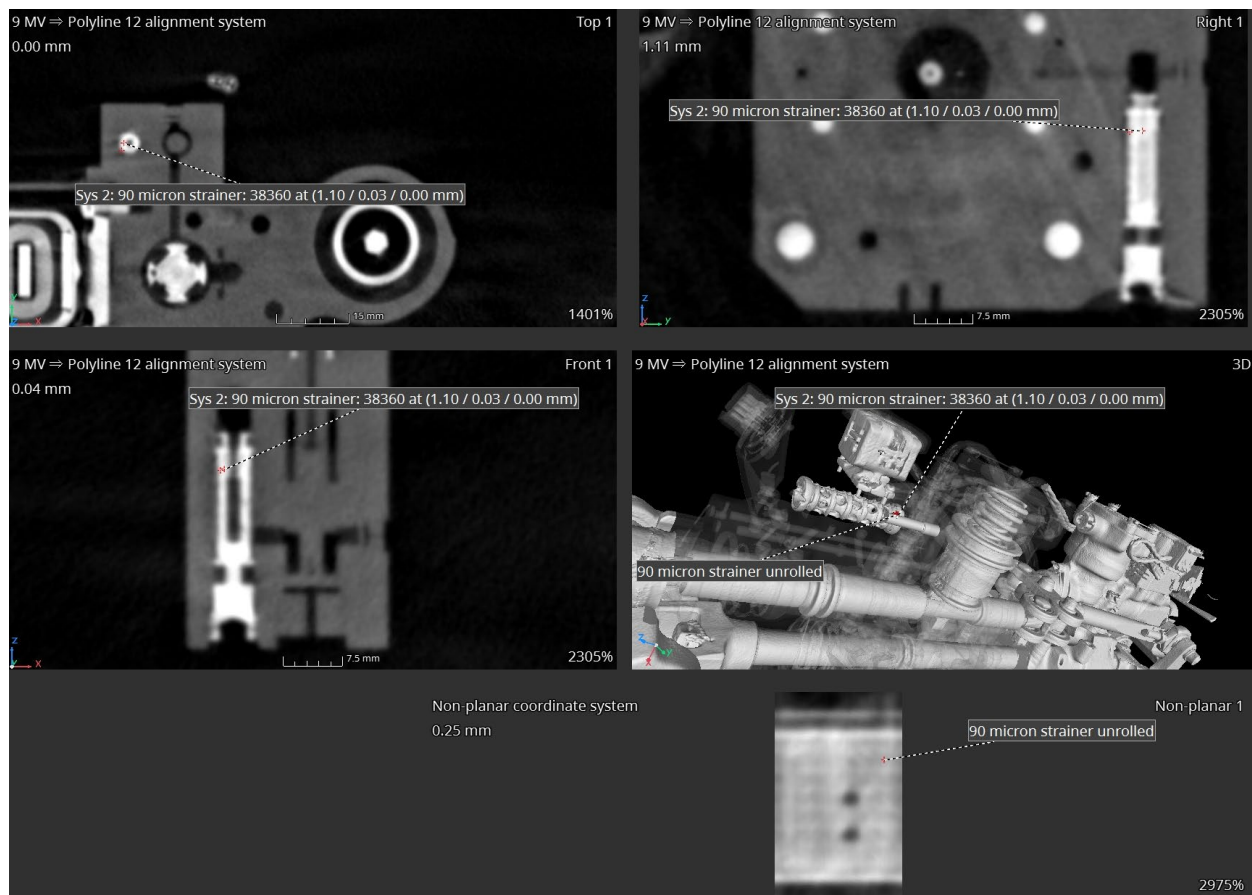


Figure 33. CT images of System 2 extensible link 90 micron strainer. (9 MV)

Submitted by:

John Flynn
Aerospace Engineer