NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

March 9, 2015

Computed Tomography Specialist's Factual Report

DCA-15-MA-019

A. ACCIDENT

Operator:	Scaled Composites, LLC
Location:	near Koehn Dry Lake, CA
Date:	October 31, 2014
Time:	1007 Pacific Daylight Time
Vehicle:	Scaled Composites SpaceShipTwo reusable suborbital rocket, N339SS

B. GROUP

Computed Tomography Specialist: Scott Warren
National Transportation Safety Board
Washington, D.C.

C. SUMMARY

On October 31, 2014, about 1007 Pacific daylight time,[1] a Scaled Composites SpaceShipTwo (SS2) reusable suborbital rocket, N339SS, experienced an in-flight anomaly during a rocket-powered flight test, resulting in loss of control of the vehicle. SS2 broke up into multiple pieces and impacted terrain over a 5-mile area near Koehn Dry Lake, California. One test pilot (the copilot) was fatally injured, and the other test pilot was seriously injured. SS2 had launched from the WhiteKnightTwo (WK2) carrier aircraft, N348MS, about 12 seconds before the loss of control. SS2 was destroyed, and WK2 made an uneventful landing. Scaled Composites was operating SS2 under an experimental permit issued by the Federal Aviation Administration's (FAA) Office of Commercial Space Transportation under the provisions of 14 *Code of Federal Regulations* (CFR) Part 437.

Radiographic studies were done from January 6-19, 2015 in Chicago, Illinois to examine and document the internal configuration of the feather lock actuation valve, right hand feather valve, left hand feather valve, left hand pressure regulator, right hand pressure regulator, left feather enable valve and right feather enable valve. These components were documented using computed tomography (CT) scans and were imaged using a total of 2,755 CT slices.

Review of the images determined that the valve orientation could be determined in all of the valves, and also indicated that there were medium density particles in both feather enable valves, packing misalignments in the left hand feather valve, and an anomaly in the area of the vent seat surface in the left hand pressure regulator.

D. DETAILS OF THE INVESTIGATION

1.0 General

The feather lock actuation valve, right hand feather valve, left hand feather valve, left hand pressure regulator, right hand pressure regulator, left feather enable valve and right feather enable valve were subjected to x-ray computed tomography (CT) scanning to document their internal conditions. The scanning was conducted from January 6-19, 2015. The scans were performed by Varian Medical Systems, Inc (formerly Bio-Imaging Research, Inc. (BIR)) under the direction of the NTSB using the Varian Actis 500/450 standard focus CT system.

For the CT scans, the components were loaded into the imaging unit and placed on a turntable. They were 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 fan beam of x-rays, and the portion of the part imaged was adjusted slightly after each scan was completed until the entire assembly was scanned. The x-ray energy levels captured by the detector were recorded at several

[1] Unless otherwise indicated, all times in this report are Pacific daylight time based on a 24-hour clock.

thousand different points during each rotation, and this information was converted into slice images using reconstruction algorithms.

The components were scanned using a total of 2,755 slices. The total size of the combined data sets was 21.54 Gb. The complete scan protocol for each component is given in table 1.

Table 1
Scan Protocol

Component	Feather Lock Actuation Valve	Right Hand Feather Valve	Left Hand Feather Valve	Left Hand Pressure Regulator	Right Hand Pressure Regulator	Left Hand Feather Enable Valve	Right Hand Feather Enable Valve
Number of slices	372	389	234	506	411	444	399
Voxel Size - X Direction (mm)	0.115	0.122	0.105	0.120	0.127	0.112	0.127
Voxel Size - Y Direction (mm)	0.115	0.122	0.105	0.120	0.127	0.112	0.127
Voxel Size - Z Direction (mm)	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Image Projections per Revolution	1440	1440	1440	1440	1440	1440	1440
Exposure time (ms)	112	112	112	112	112	112	112
Frames to Avg (frames per projection)	1	1	1	1	1	1	1
X-ray Source Voltage (kV)	450	450	450	450	450	450	450
X-ray Source Current (mA)	2	2	2	2	2	2	2
Source Filter Material	Brass	Brass	Brass	Brass	Brass	Brass	Brass
Source Filter Thickness (mm)	2	4	4	4	4	4	4
Image Matrix Size (pixels)	2048 x 2048	2048 x 2048	2048 x 2048	2048 x 2048	2048 x 2048	2048 x 2048	2048 x 2048

Each data set of slice images was evaluated using the VGStudioMax software package to create 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 to allow closer observation of interior parts. In addition, some portions of the images are colored to allow for better interpretation of the image set. In the images, the high density areas are shown as brighter shades of gray and lower density areas are shown as darker shades of gray. The pointers shown in some of the images denote specific areas of interest within that image.

The images of the components were examined for any signs of missing or damaged parts, contamination, or any other anomalies. Port identification information, when available, was provided by the Systems group chairman. Further details regarding how the ports were identified and system descriptions can be found in the Systems group chairman's factual report. Specific results (including example images) are presented in subsequent sections of this report.

2.0 Computed Tomography Results

2.1 Feather Lock Actuation Valve

The computed tomography (CT) results for the feather lock actuation valve are shown in figures 1 through 4. This valve was one of two feather lock actuation valves on the vehicle. According to the Systems group, the position of this valve in the vehicle (left hand or right hand) could not be determined. Physical examination of the valve showed that the ports were numbered from 1 to 4. No CT image evidence was found to relate those port identification numbers with their function on the vehicle. However, according to the Systems group, the valve port functions were as follows:

- Port 1 – Could not be determined (Lock or Unlock)
- Port 2 – Vent
- Port 3 – Could not be determined (Lock or Unlock)
- Port 4 – Supply

Review of the images indicated:

1. The valve ball was found to be in a position where none of the openings were completely aligned with the valve ports;

2. Port 1 was found to be open to port 2;

3. Port 3 was found to be open to port 4;

4. The valve lock tube was found to be installed in port 4.

(b) (4)

Valve lock tube

(b) (4)

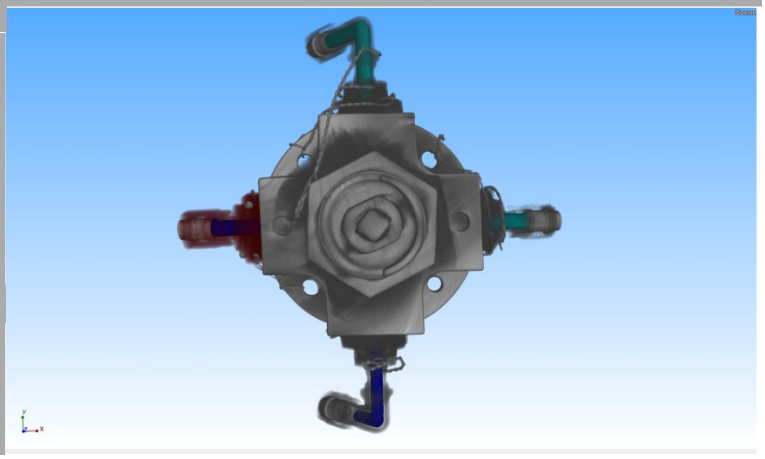

Figure 1
Feather lock actuation valve – Overall cross section

(b) (4)

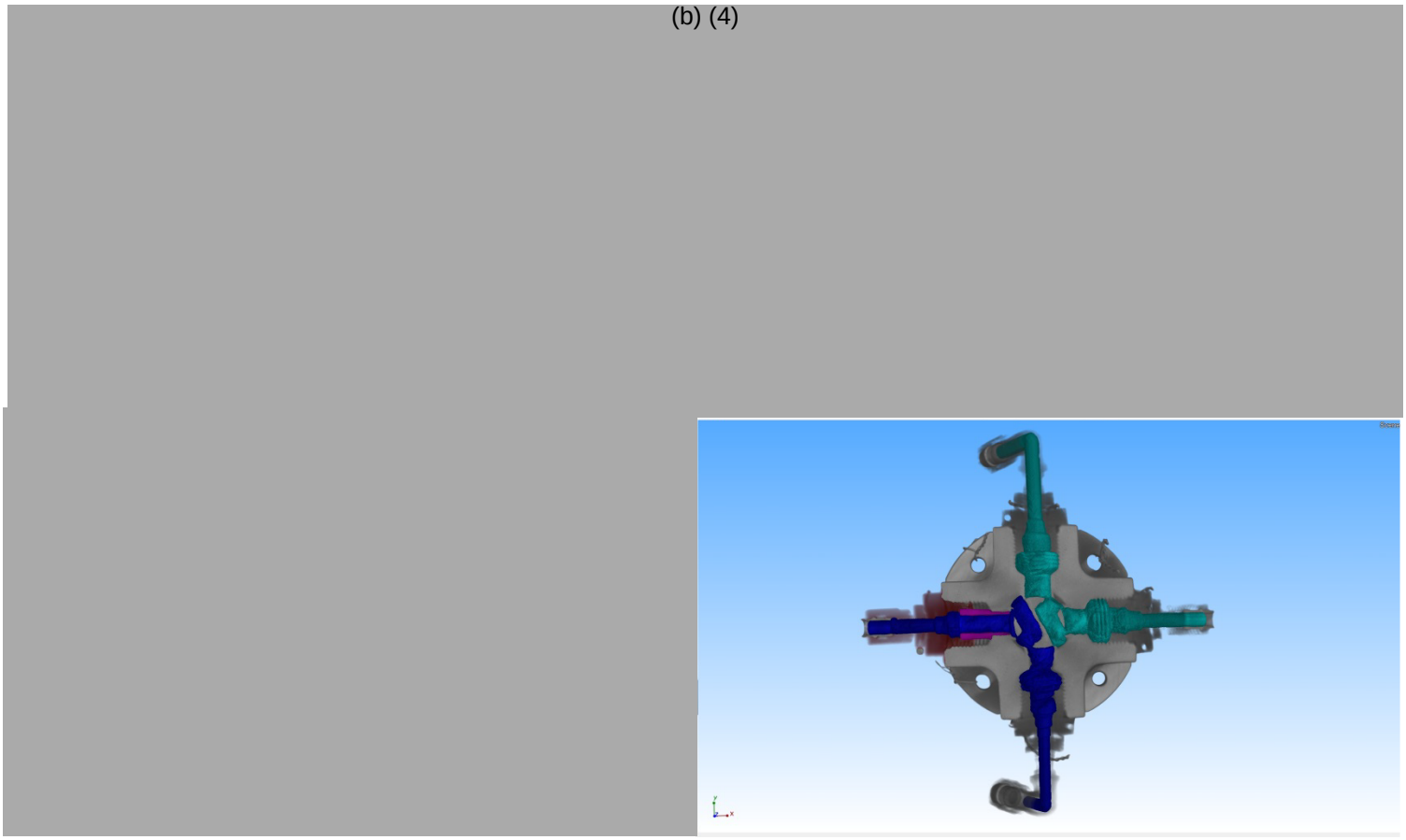

Figure 2
Feather lock actuation valve – Overall cross section through valve ball

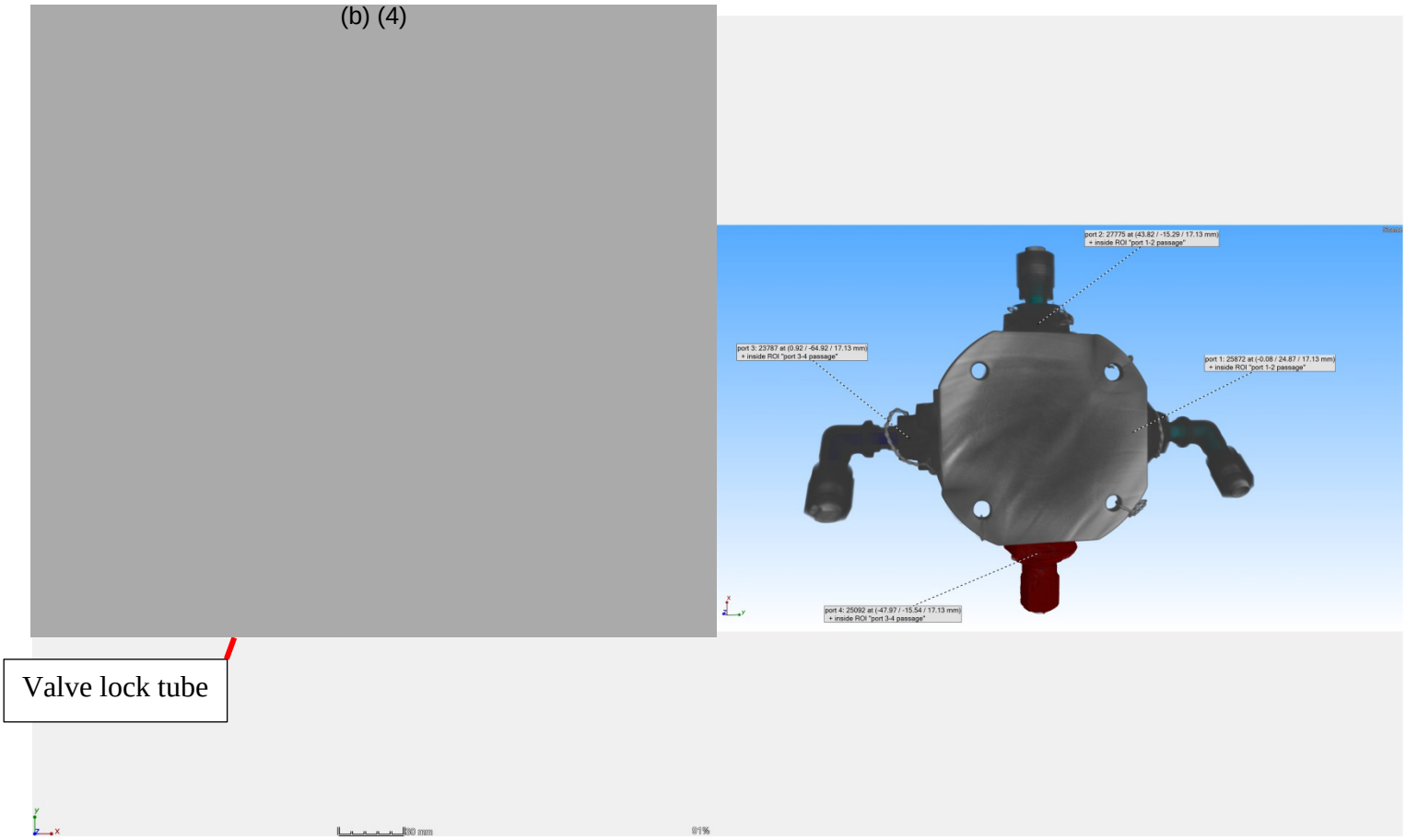

Figure 3
Feather lock actuation valve – View from mounting plate side showing port identification

(b) (4)

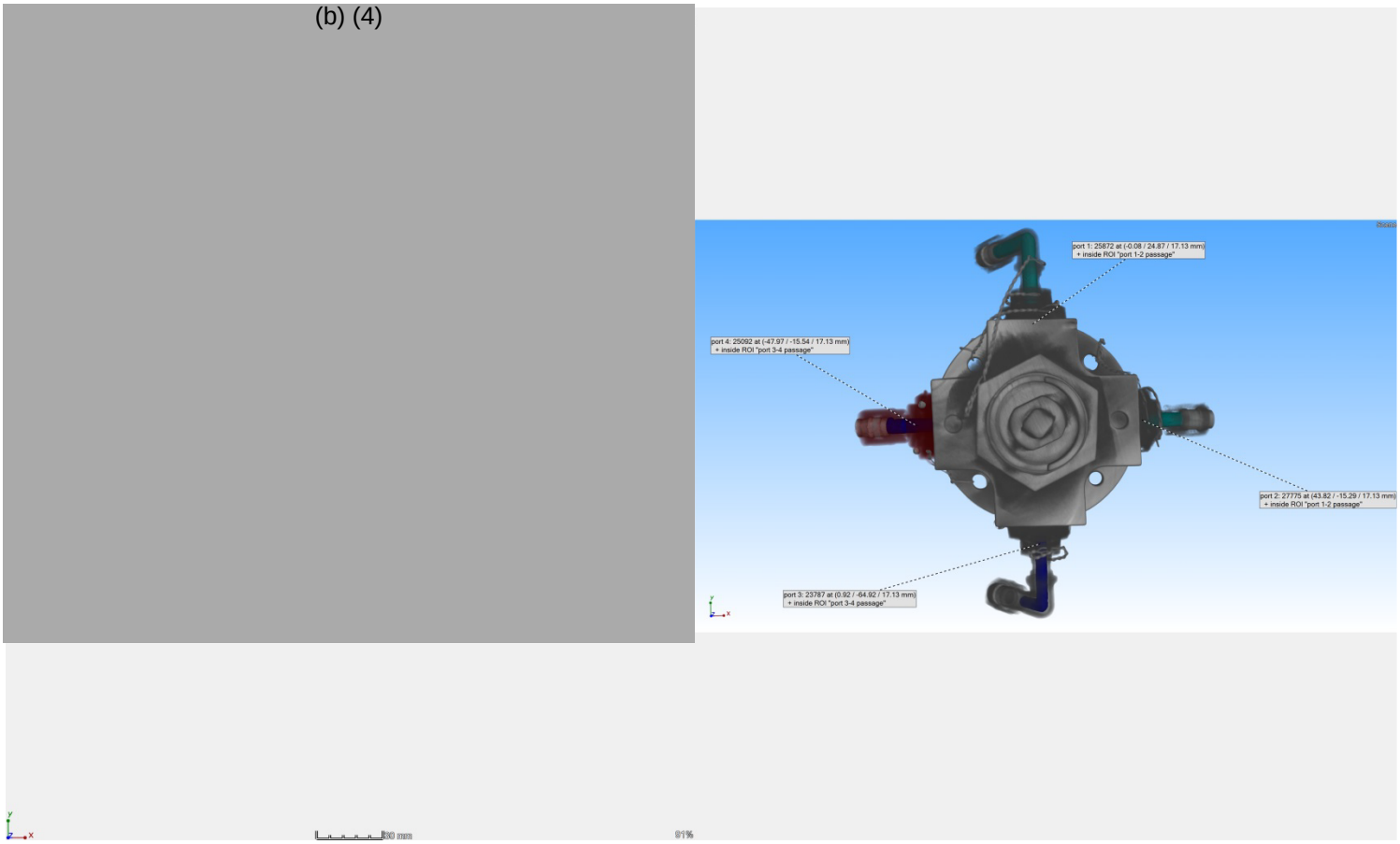

Figure 4
Feather lock actuation valve – View from shaft side showing port identifications

2.2 Right Hand Feather Valve

The computed tomography (CT) results for the right hand feather valve[2] are shown in figures 5 through 7. Physical examination of the valve showed that the ports were numbered from 1 to 4. No CT image evidence was found to relate those port identification numbers with their function on the vehicle. However, according to the Systems group, the valve port functions were as follows:

- Port 1 – Vent
- Port 2 – Up
- Port 3 – Supply
- Port 4 – Down

[2] When recovered, this valve was originally identified as "Feather Valve #1". Information provided by the Systems group chairman indicated that this valve was the right hand feather valve. The images in this section of the report were made prior to that determination, so the header information in the upper left corner of each image contains the label of "Feather Valve #1".

Review of the images indicated:

1. The valve ball was found to be in a position where the openings were almost fully aligned with the valve ports;

2. Port 1 was found to be open to port 4;

3. Port 2 was found to be open to port 3;

4. The valve lock tube was found to be installed in port 3.

(b) (4)

(b) (4)

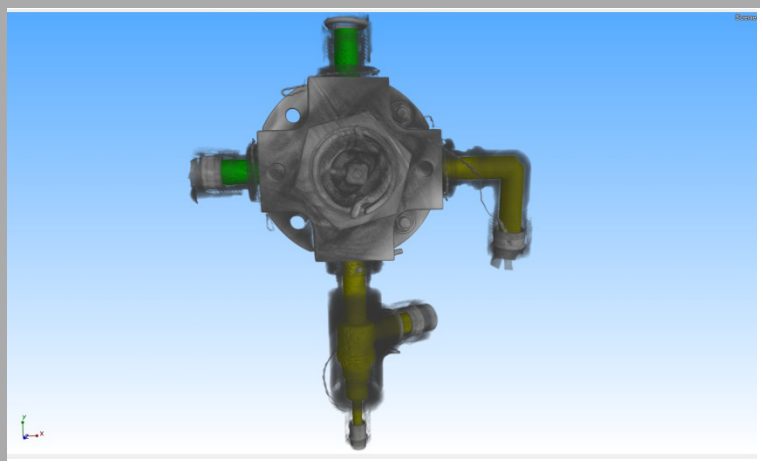

Figure 5
Right hand feather valve – Overall cross section

(b) (4)

(b) (4)

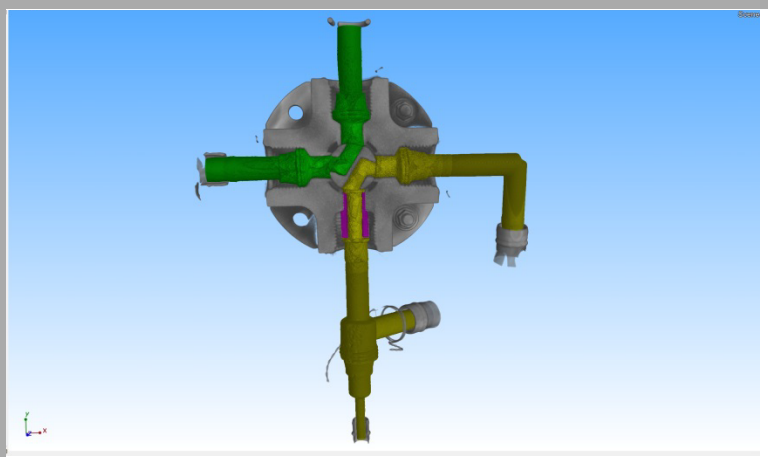

Figure 6
Right hand feather valve – Overall cross section through valve ball

(b) (4)

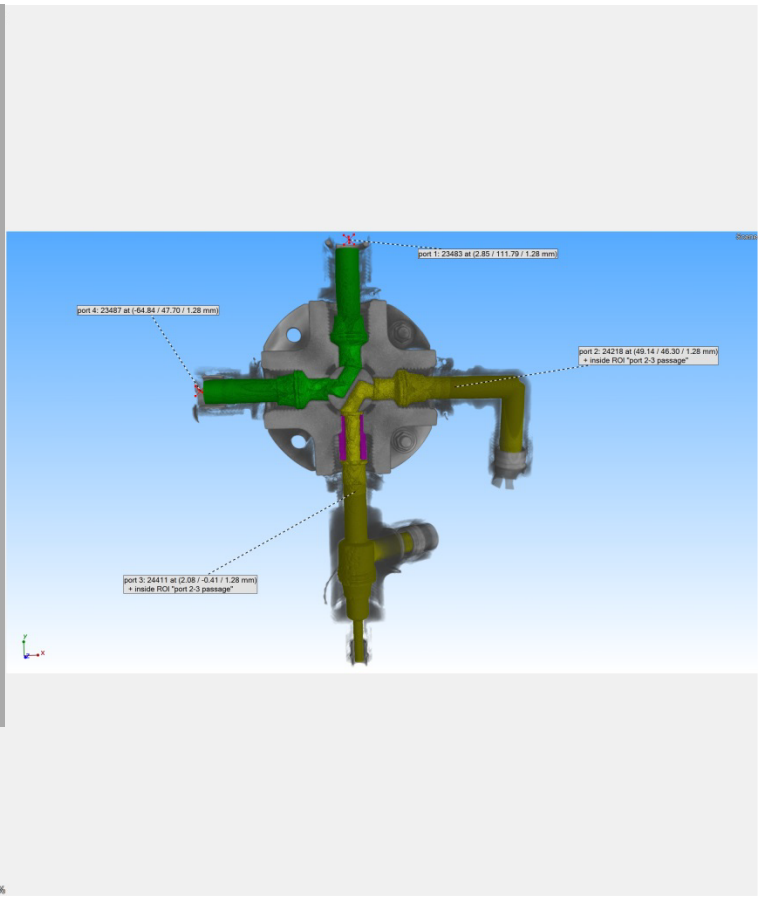

Figure 7
Right hand feather valve – View from shaft side showing port identifications

2.3 Left Hand Feather Valve

The computed tomography (CT) results for the left hand feather valve[3] are shown in figures 8 through 13. Physical examination of the valve showed that the ports were numbered from 1 to 4. No CT image evidence was found to relate those port identification numbers with their function on the vehicle. However, according to the Systems group, the valve port functions were as follows:

- Port 1 – Supply
- Port 2 – Up
- Port 3 – Vent
- Port 4 – Down

[3] When recovered, this valve was originally identified as "Feather Valve #2". Information provided by the Systems group chairman indicated that this valve was the left hand feather valve. The images in this section of the report were made prior to that determination, so the header information in the upper left corner of each image contains the label of "Feather Valve #2".

Review of the images indicated:

1. The valve ball was found to be in a position where the openings were aligned with the valve ports;

2. The valve shaft was bent in a direction towards port 4;

3. Port 1 was found to be open to port 4;

4. Port 2 was found to be open to port 3;

5. The valve body contained stamped impressions with the symbols “X” (located in two different locations on the valve body), “U”, “D”, and “S”;

6. The valve lock tube was not present within the valve as recovered;

7. The ball valve packing materials were misaligned in some locations around the valve.

(b) (4)

(b) (4)

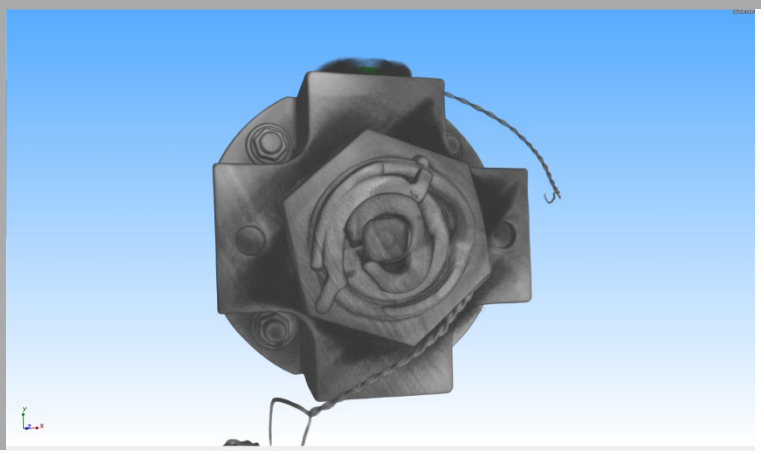

Figure 8
Left hand feather valve – Overall cross section

(b) (4)

(b) (4)

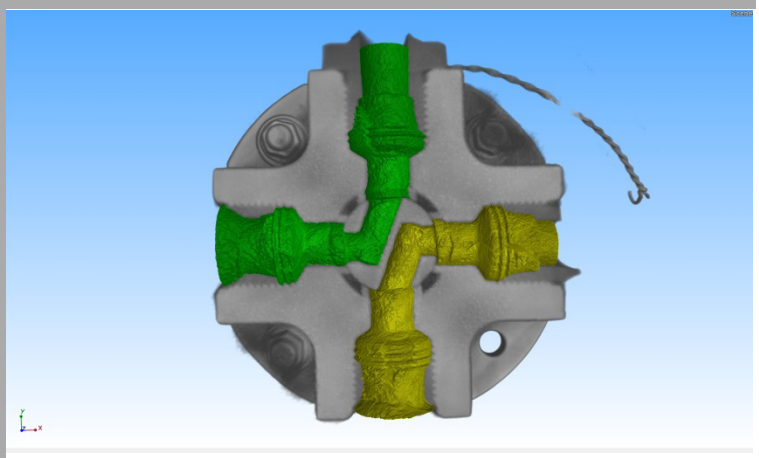

Figure 9
Left hand feather valve – Overall cross section through valve ball

Figure 10
Left hand feather valve – Cross section through valve ball showing markings on valve body

(b) (4)

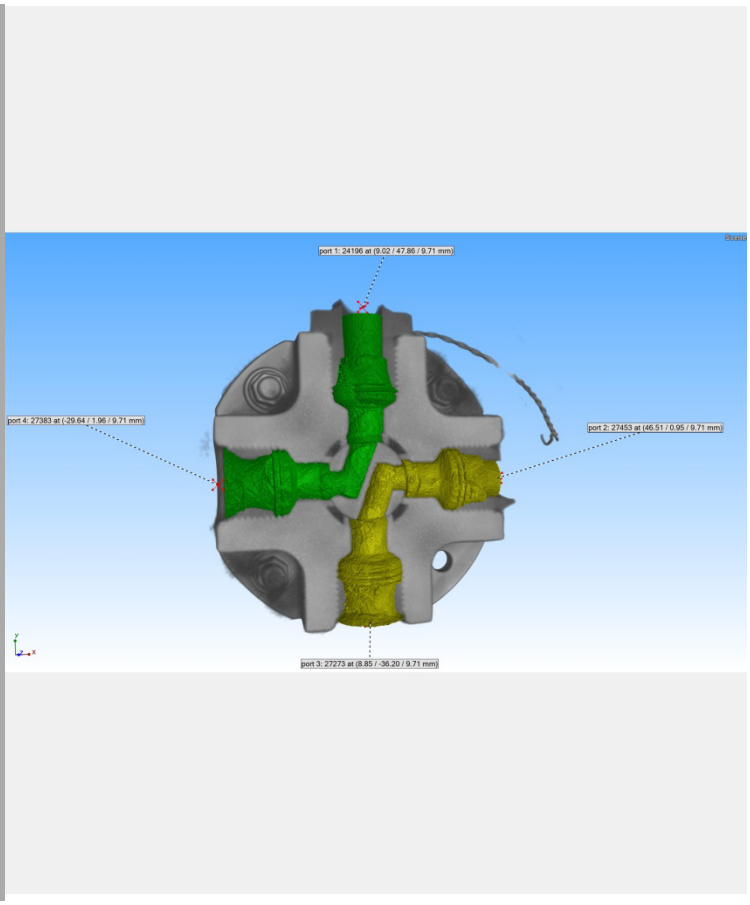

Figure 11
Left hand feather valve – View from shaft side showing port identifications

(b) (4)

(b) (4)

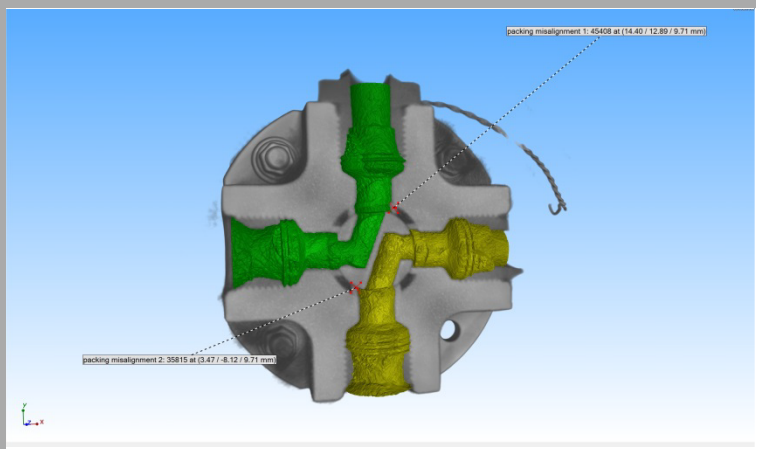

Figure 12
Left hand feather valve – View from shaft side showing packing misalignment

(b) (4)

(b) (4)

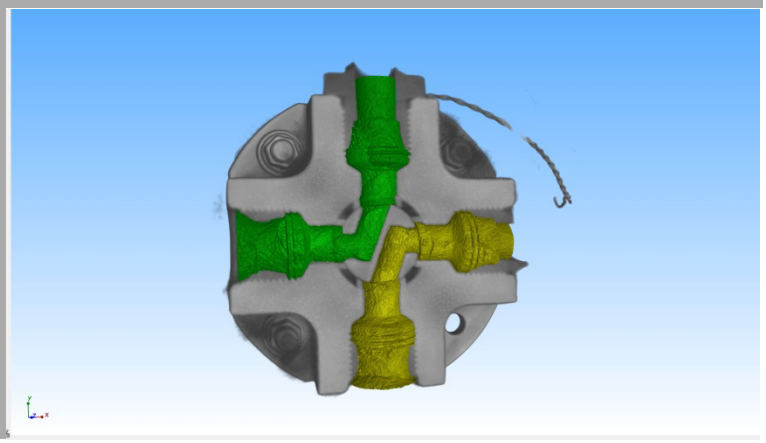

Figure 13
Left hand feather valve – View from shaft side showing packing misalignments without indicators

2.4 Left Hand Pressure Regulator

The computed tomography (CT) results for the left hand pressure regulator are shown in figures 14 through 20. Review of the images indicated:

1. No obstructions were noted within the regulator flow path;

2. The burst disc at the cap end of the regulator was present and intact;

3. There was an indication of an anomaly present in the area of the vent seat. The nature of the anomaly (i.e. damage or debris/particles) could not be determined;

4. The check valve on the outlet port of the regulator was present.

(b) (4)

(b) (4)

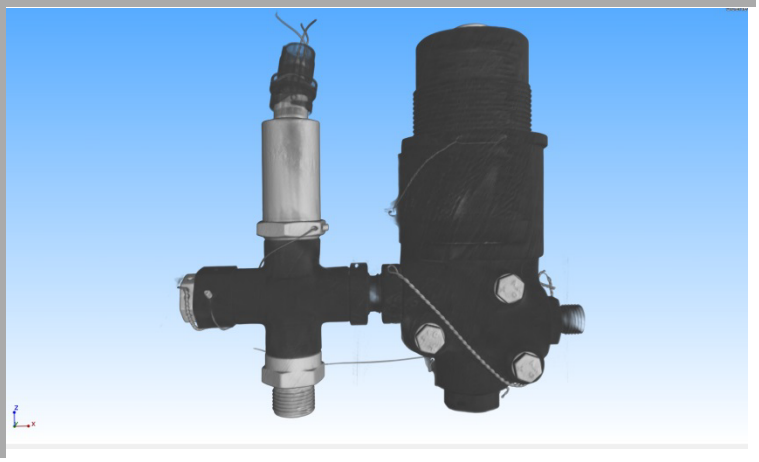

Figure 14
Left hand pressure regulator – Overall cross section through regulator section

(b) (4) (b) (4)

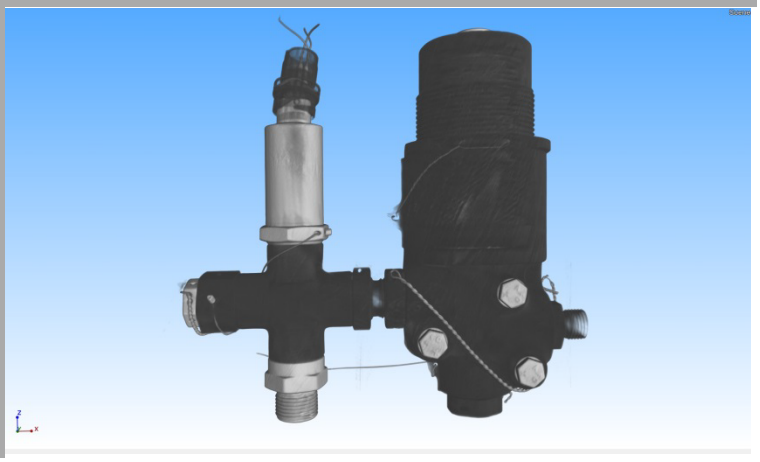

Figure 15
Left hand pressure regulator – Overall cross section through pressure transducer

Figure 16
Left hand pressure regulator – Overall cross section showing 2D flow path

Figure 17
Left hand pressure regulator – Overall cross section showing 3D flow path

(b) (4)

(b) (4)

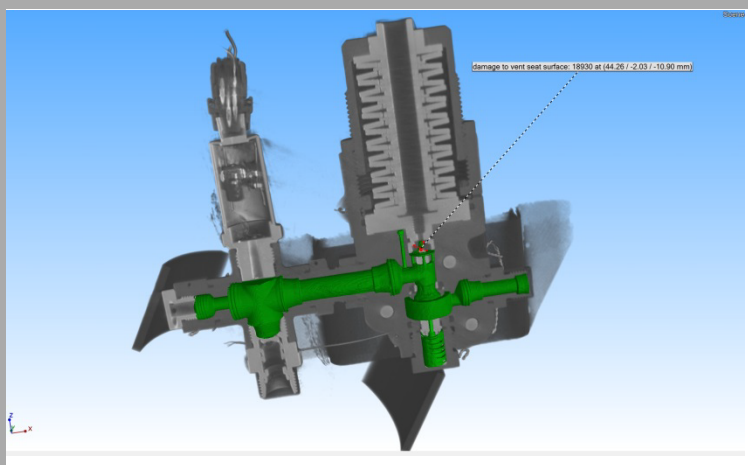

Figure 18
Left hand pressure regulator – Overall cross section showing an anomaly in the vent seat area

Figure 19
Left hand pressure regulator – Overall cross section showing an anomaly in the vent seat area – close up

Figure 20
Left hand pressure regulator – Overall cross section showing an anomaly in the vent seat area – close up with enhanced contrast

2.5 Right Hand Pressure Regulator

The computed tomography (CT) results for the right hand pressure regulator are shown in figures 21 through 24. Review of the images indicated:

1. No obstructions were noted within the regulator flow path;
2. The burst disc at the cap end of the regulator was present and intact;
3. The vent seat area appeared to be clear with no anomalies noted.

(b) (4)

(b) (4)

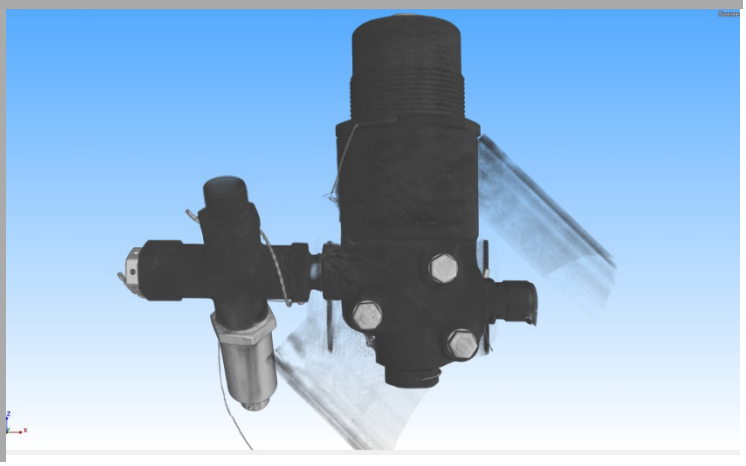

Figure 21
Right hand pressure regulator – Overall cross section through regulator section

(b) (4)

(b) (4)

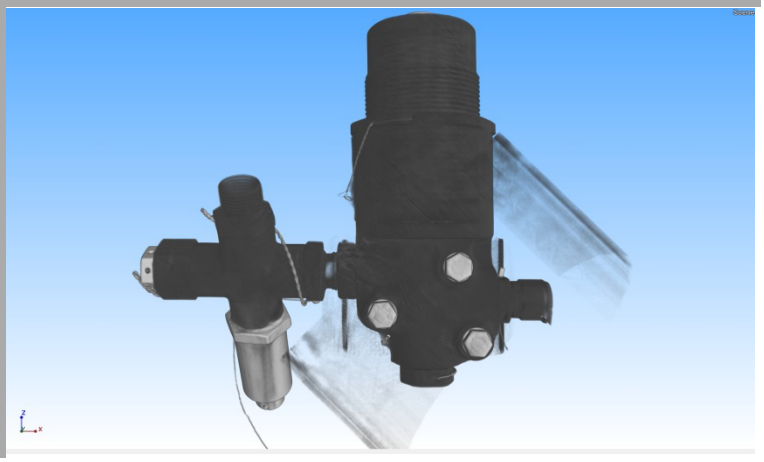

Figure 22
Right hand pressure regulator – Overall cross section through pressure transducer

Figure 23
Right hand pressure regulator – Overall cross section showing 2D flow path

(b) (4)

Figure 24
Right hand pressure regulator – Overall cross section showing 3D flow path

2.6 Left Hand Feather Enable Valve

The computed tomography (CT) results for the left hand feather enable valve are shown in figures 25 through 32. Review of the images indicated:

1. No obstructions were noted within the valve flow path;

2. The ball valve opening was aligned with one of the valve ports;

3. There was a stamped impression of the symbols “LH” on the valve body;

4. There were medium density particles noted in three areas of the valve.

(b) (4)

(b) (4)

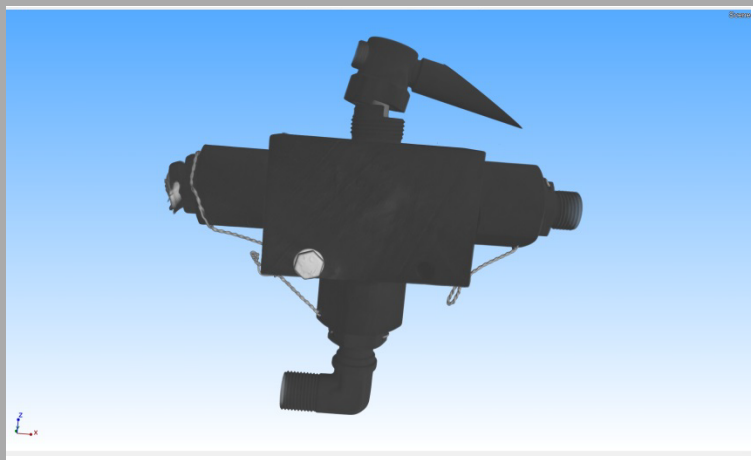

Figure 25
Left hand feather enable valve – Overall cross section

(b) (4)

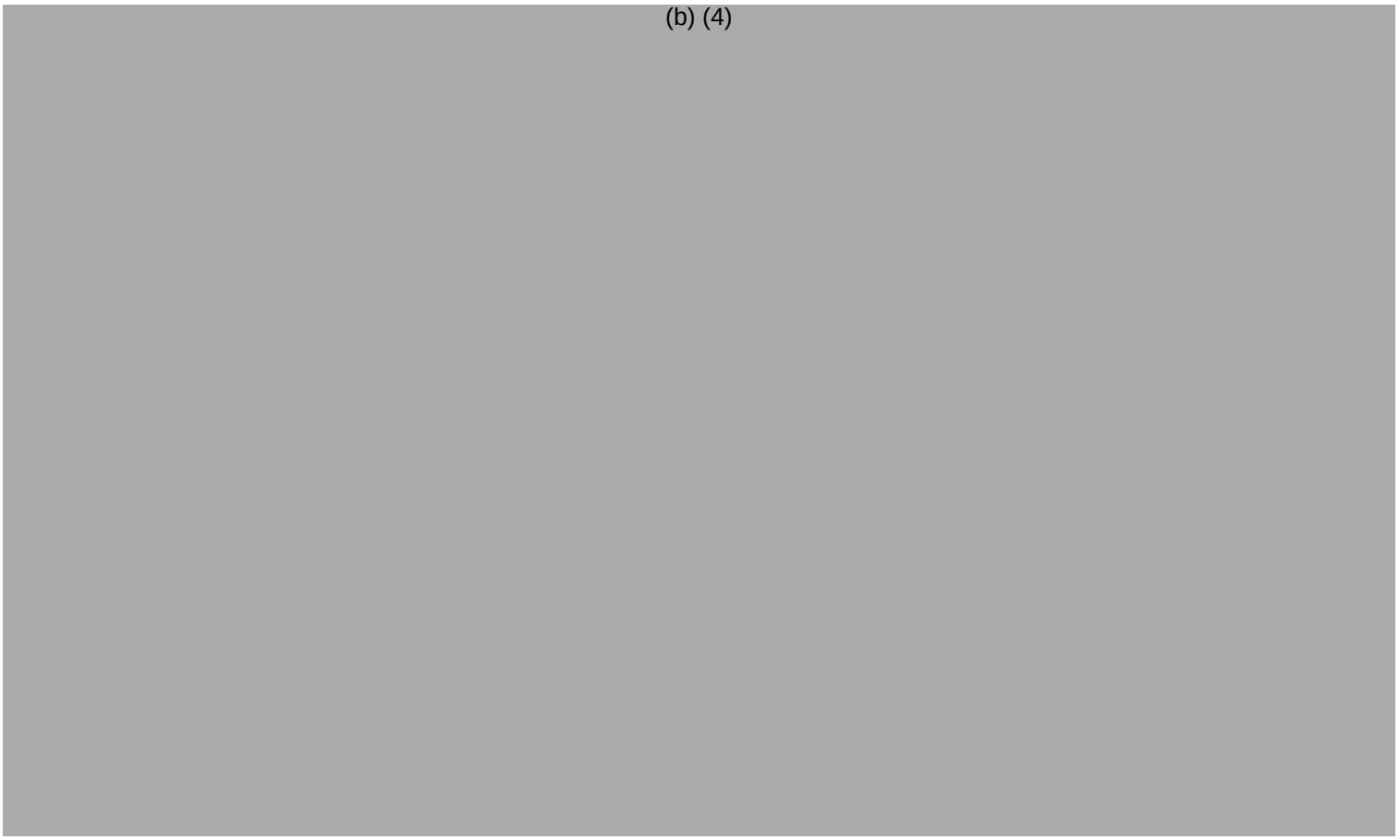

Figure 26
Left hand feather enable valve – Overall cross section with close up of ball valve area

Figure 27
Left hand feather enable valve – Overall cross section showing flow path

Figure 28
Left hand feather enable valve – Overall cross section showing flow paths

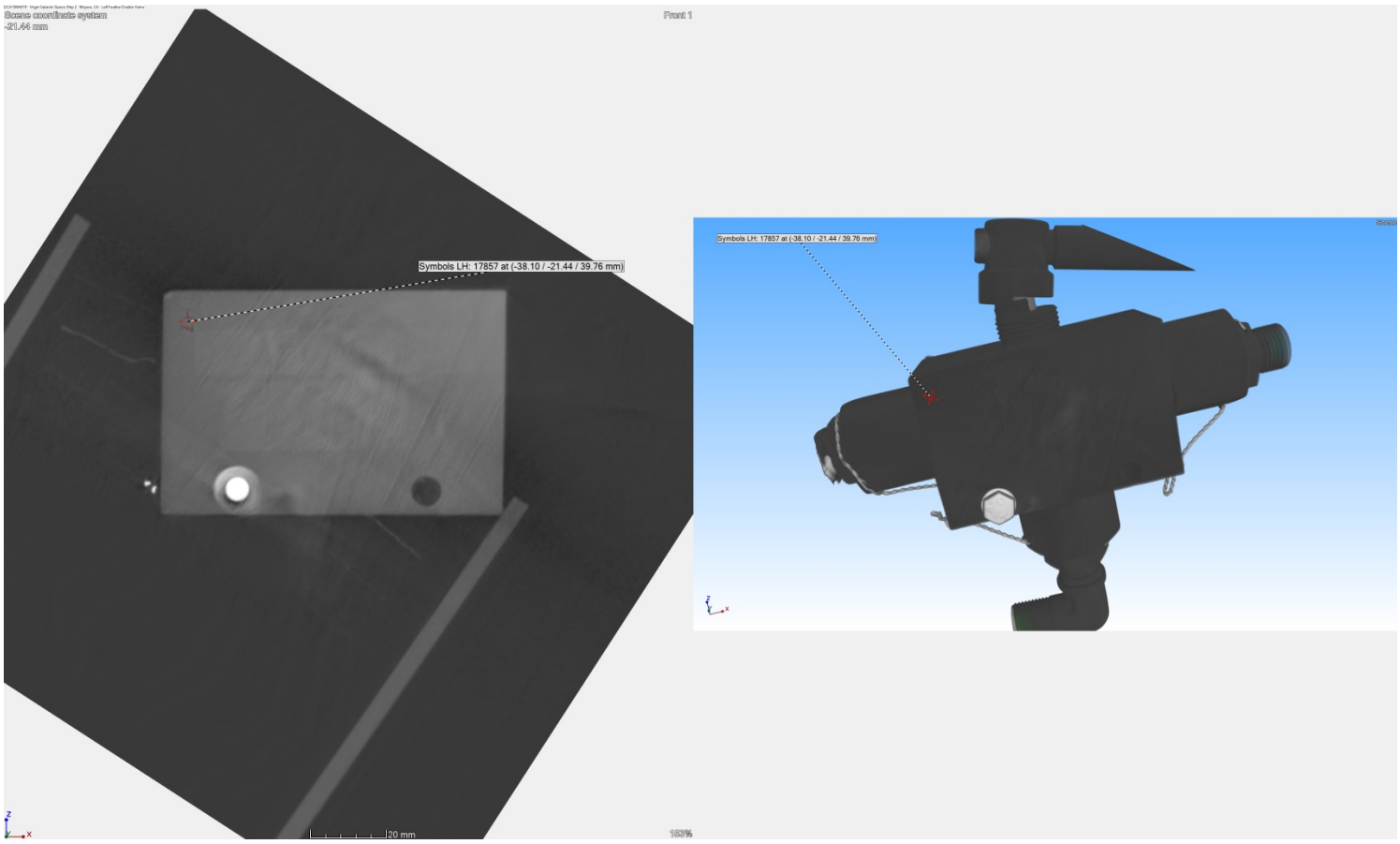

Figure 29
Left hand feather enable valve – Location of symbols “LH”

Figure 30
Left hand feather enable valve – Medium density debris 1

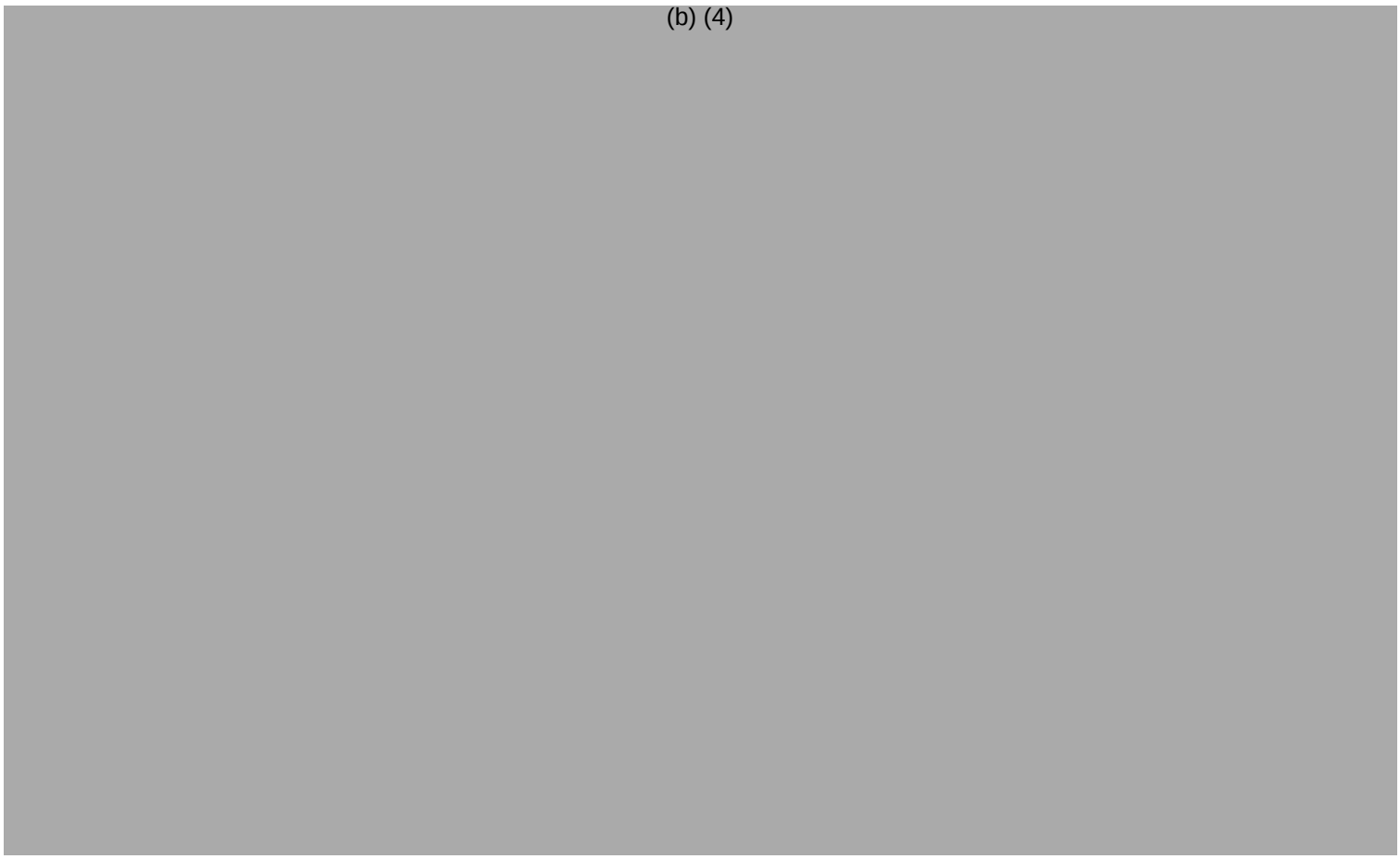

Figure 31
Left hand feather enable valve – Medium density debris 2

Figure 32
Left hand feather enable valve – Medium density debris 3

2.7 Right Hand Feather Enable Valve

The computed tomography (CT) results for the right hand feather enable valve are shown in figures 33 through 42. Review of the images indicated:

1. No obstructions were noted within the valve flow path;

2. The ball valve opening was noted to have a slight mis-alignment with one of the valve ports;

3. There was a deformation and crack noted in the valve body;

4. There was a stamped impression of the symbols “RH” on the valve body;

5. There was a gap noted between the valve handle set screw and the valve shaft;

6. There were medium density particles noted in one area of the valve.

(b) (4)

(b) (4)

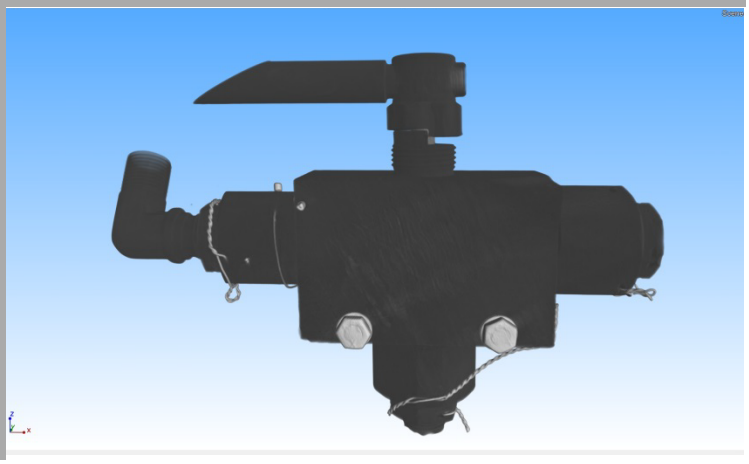

Figure 33
Right hand feather enable valve – Overall cross section

(b) (4)

Figure 34
Right hand feather enable valve – Overall cross section showing ball valve

Figure 35
Right hand feather enable valve – Overall cross section showing ball valve – close up

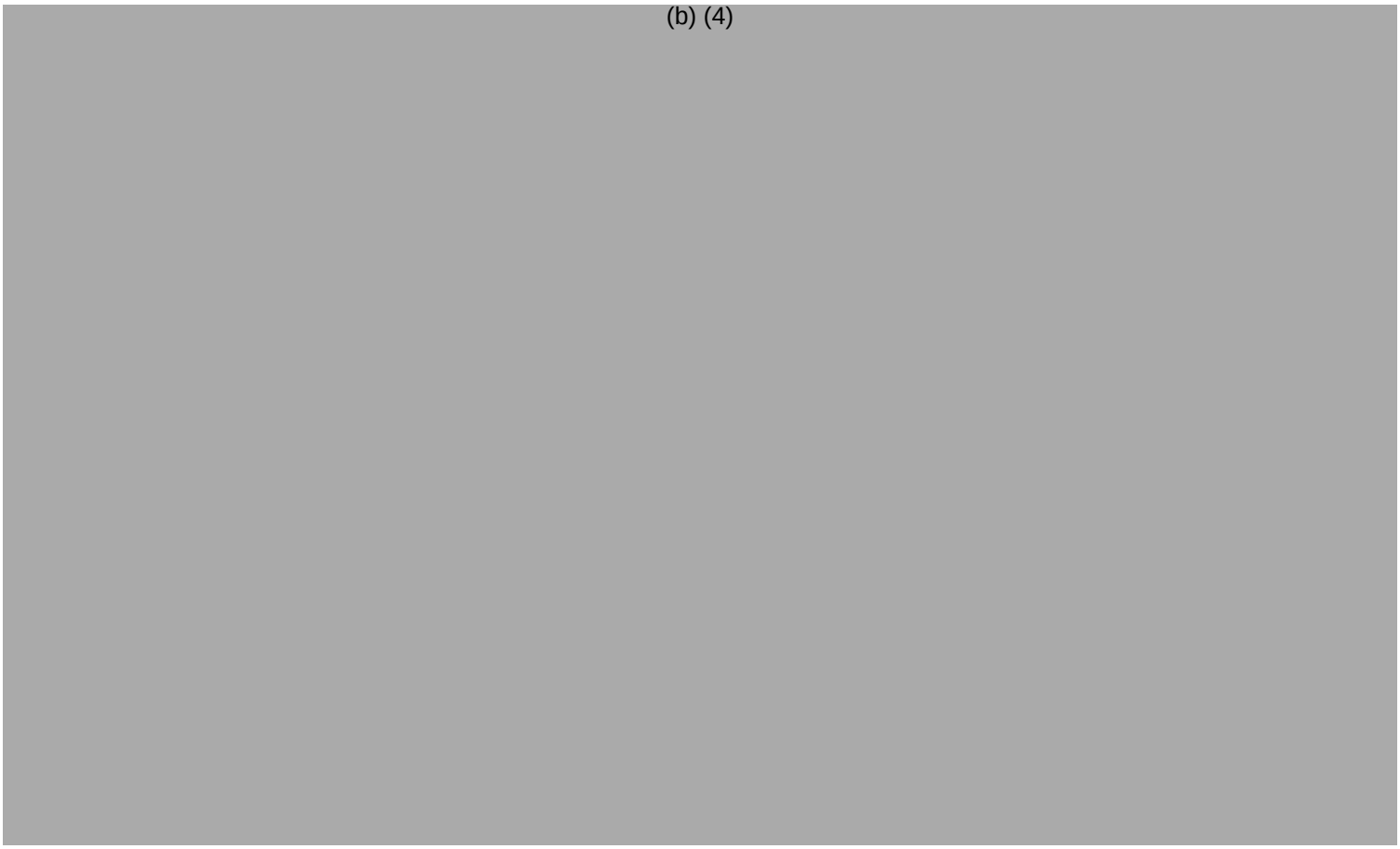

Figure 36
Right hand feather enable valve – Overall cross section showing flow paths

Figure 37
Right hand feather enable valve – Overall cross section – 3D

(b) (4)

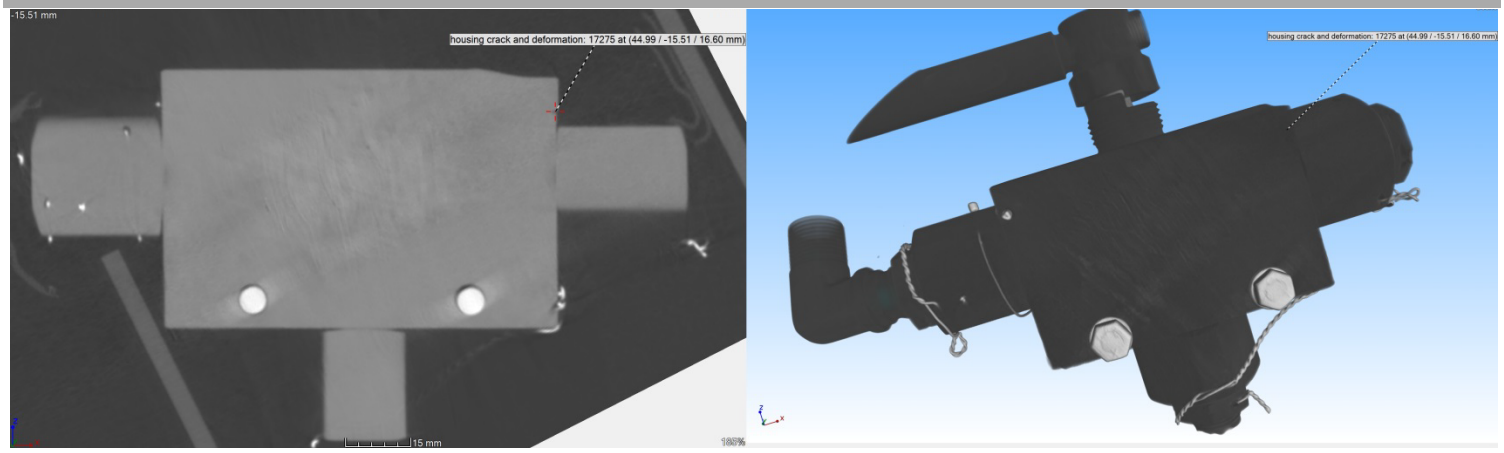

Figure 38
Right hand feather enable valve – Location of housing crack and deformation

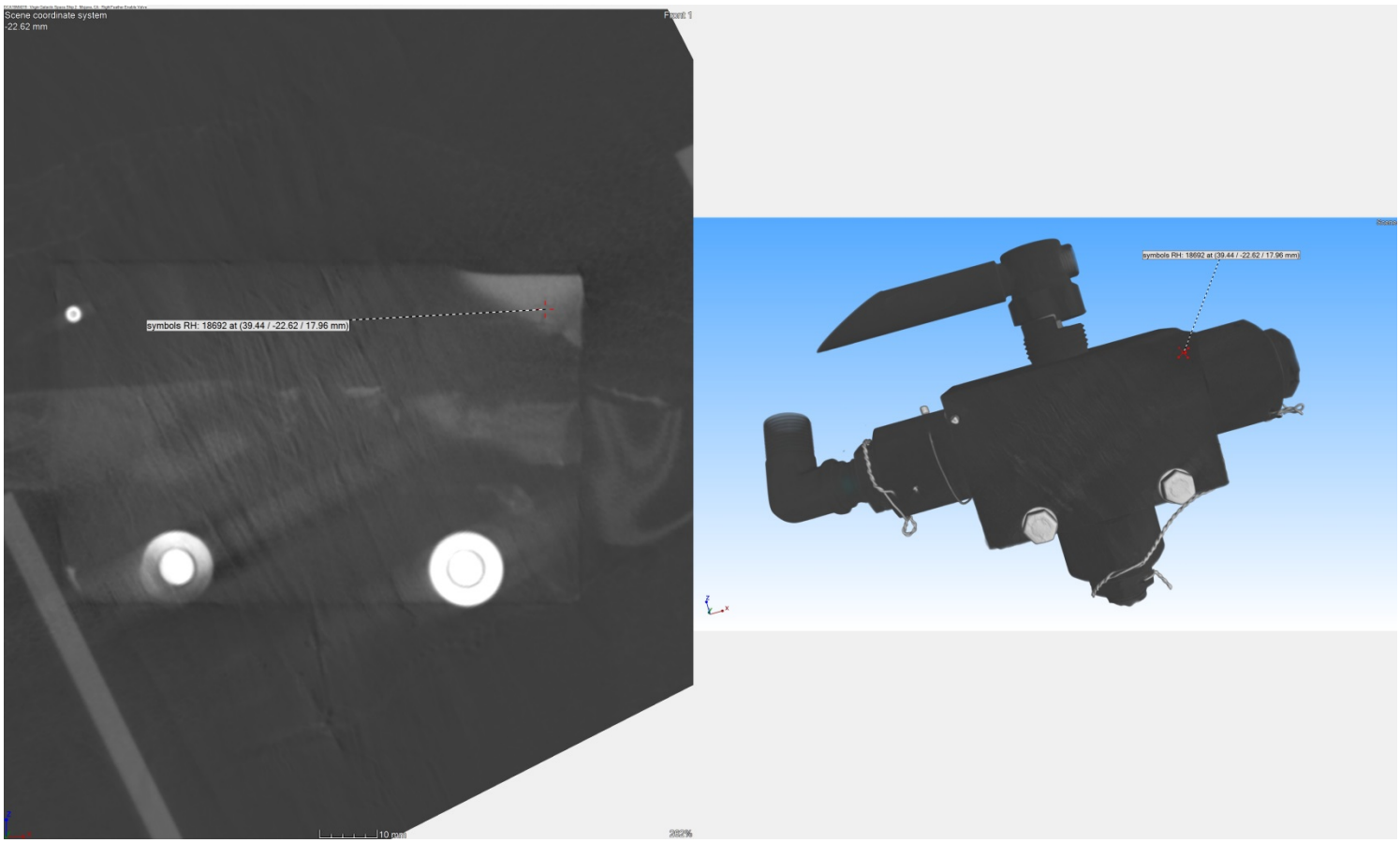

Figure 39
Right hand feather enable valve – Location of symbols “RH”

Figure 40
Right hand feather enable valve – Gap between set screw and shaft

(b) (4)

(b) (4)

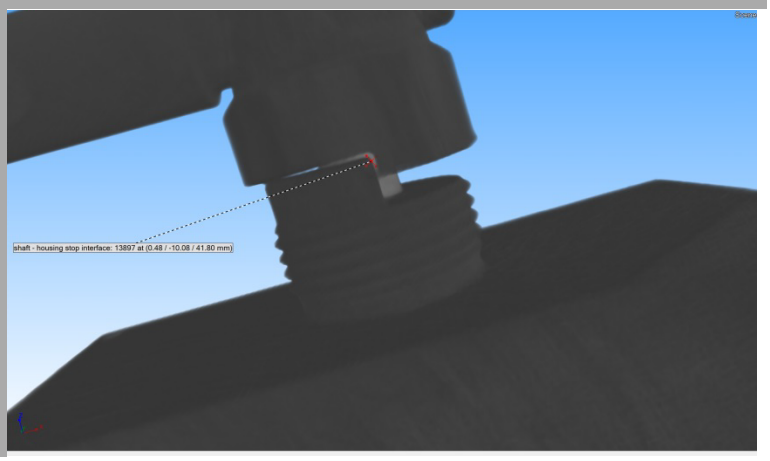

Figure 41
Right hand feather enable valve – Shaft/housing interface

Figure 42
Right hand feather enable valve – Location of medium density particles

Scott Warren
Lead Aerospace Engineer - Aircraft Systems
(Computed Tomography Specialist)