ET Hydrogen Vent QD/GUCP Alignment Investigation Team

Team Contributors

- Chris Broadway; NASA KSC ET
- Chip Doherty; Boeing KSC SE&I
- Fred Lockhart, Moin Masoodi, Mark Pokrywka; Lockheed Martin ET
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- Mark Minich, Charlie Stevenson, Dr. John Lane, Jeff Carlson, Kevin Murtland; ESC- Team QNA
- Roystan King, Pete Richiuso; NASA Metrology Lab
- Ross McCoy, Bryan Salisbury; KSC USA SE
- John Trautwein; NASA Prototype Lab
- Jorge Rivera; NASA
- USA Ground Ops Technicians:

Eddy Carillion	Tony Marketon
Bryan Hall	Scott Peabody
James Hart	

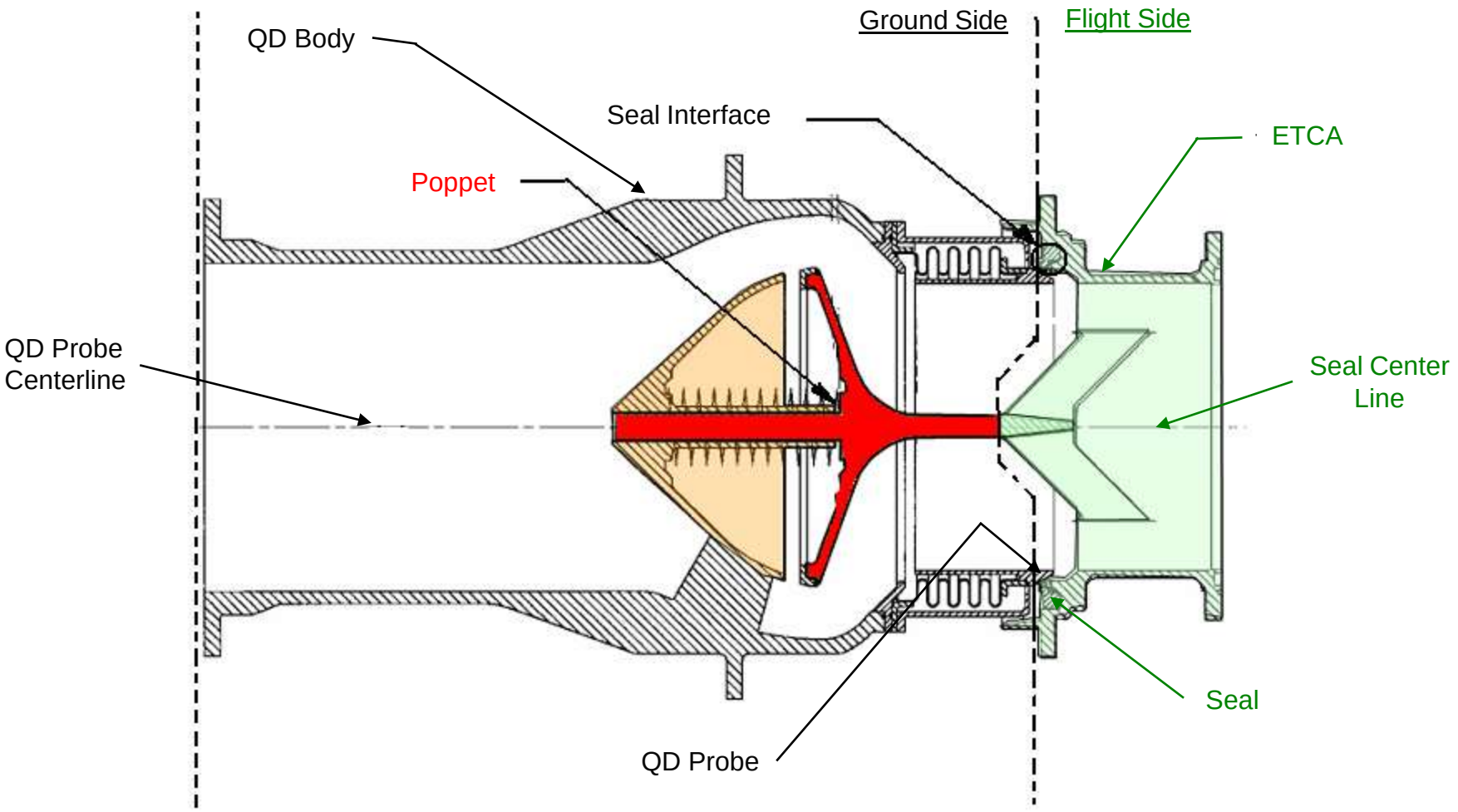
Objective

- **As the result of the STS-127 and STS-133 Hydrogen Vent Arm Leak, a team was developed with a specific purpose to assess the physical kinematic and dynamic interactions between: the Quick Disconnect (QD) "sealing surface" probe of the QD Body, the Ground Umbilical Carrier Plate (GUCP) and the External Tank seal during the installation process (OMI T-1147).**

Scope of effort:

- ***How does the build-up of centerline misalignments (concentricity) of the QD probe and Carrier Plate relative to the ETCA effect the sealing interface?***
- ***Does the sealing surface engage uniformly?***
- ***What is the contact sealing surface area?***
- ***What pressure is exerted between the QD probe and ETCA sealing surface?***
- ***Does the interface self-align?***
- ***How much concentricity offset will the system tolerate?***
- ***What is the QD Probe, QD Body and Carrier Plate displacements and travel paths during a typical installation?***
- ***What are the effect of the QD Guide Pins during the installation process?***
- ***Does the Bellows probe act as a self aligning 'spring' or more like a 'solid pipe'? If so, is there a transition point?***

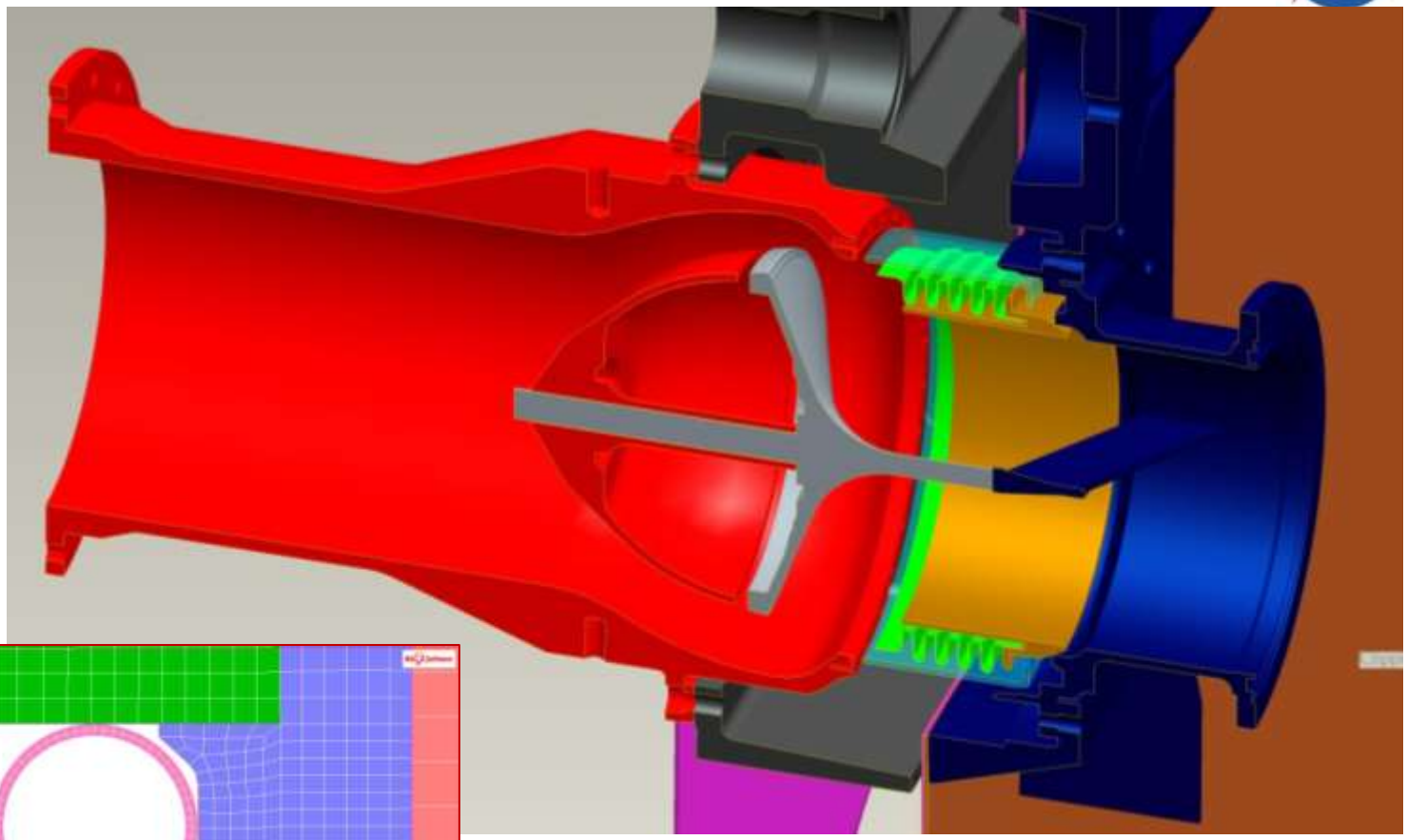
GH2 Vent Interface

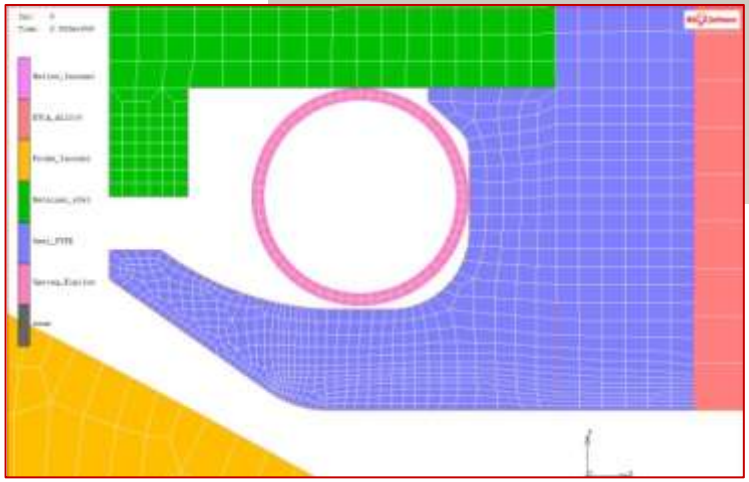


Section View

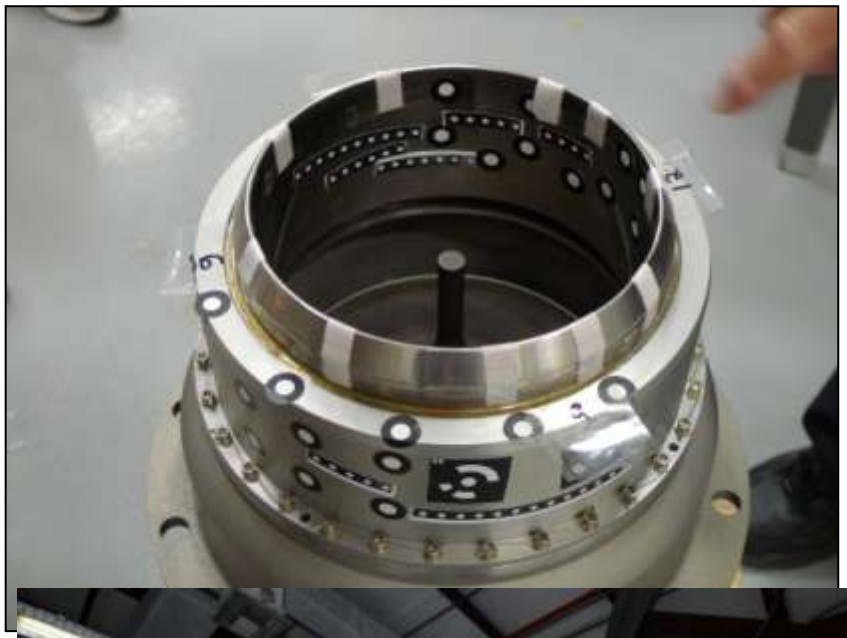
GH2 Vent Interface

KSC-TA-11539





Approach: Photogrammetry



Approach: Photogrammetry

During the installation process:

- **Advanced photogrammetry was identified as a way to track the motion of the QD and Carrier Plate relative to the ET seal**
- **The Carrier Plate was installed in different positions (quantified with concentricity tool) and with different washer restraint of the carrier plate feet**
- **The QD probe centerline offset was quantified by the USA Optics Lab utilizing a Coordinate Measurement Machine (CMM)**
- **The ET test fixture position was determined using the CMM and Photogrammetry to establish the overall coordinate system**
- **Existing CAD models were positioned using the photogrammetry displacement data, CMM and concentricity tool to map the positions and displacements of this process**
- **Each component was developed into a CAD model, marked with visual targets, and given its own datum (x, y, z). The components were then placed in an overall coordinate system and tracked during the installation process**

Approach: Photogrammetry

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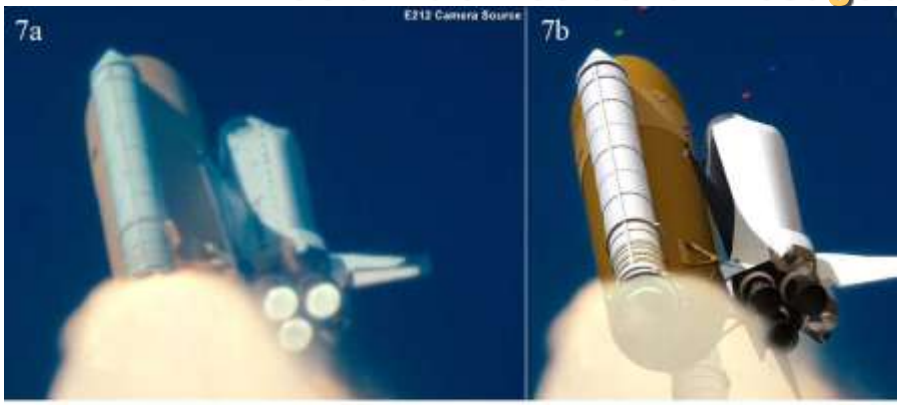
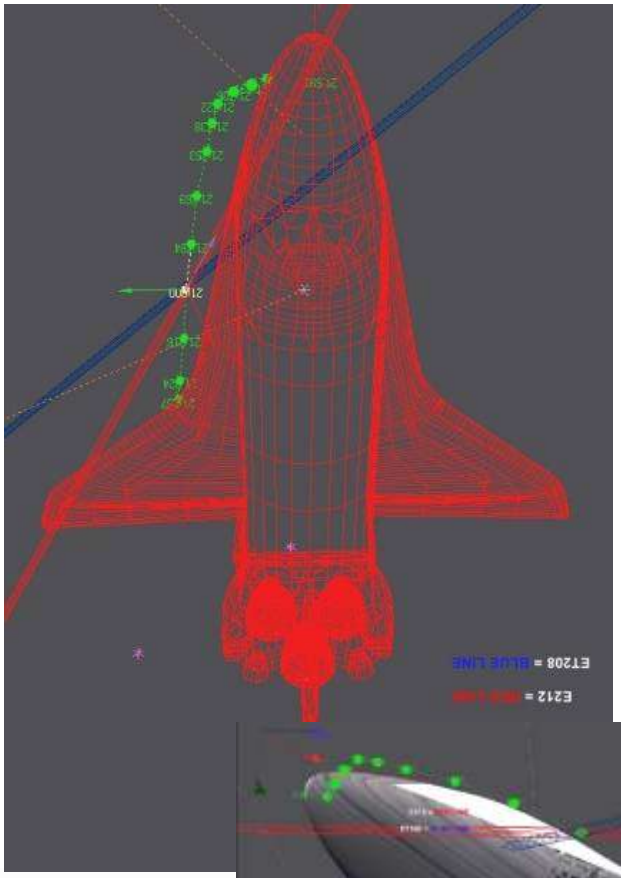
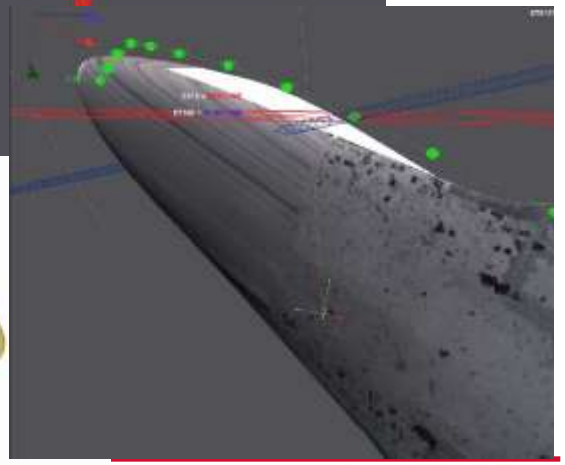
Columbia Accident Investigation







Approach: Photogrammetry

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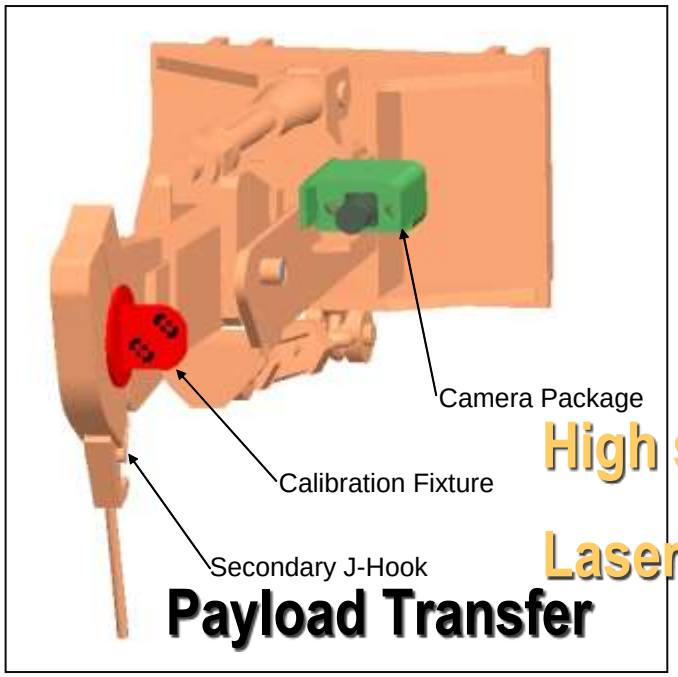
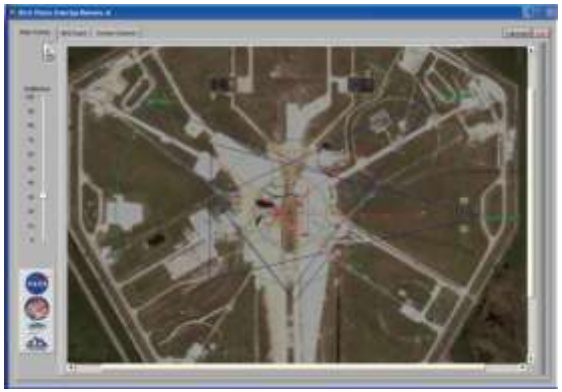
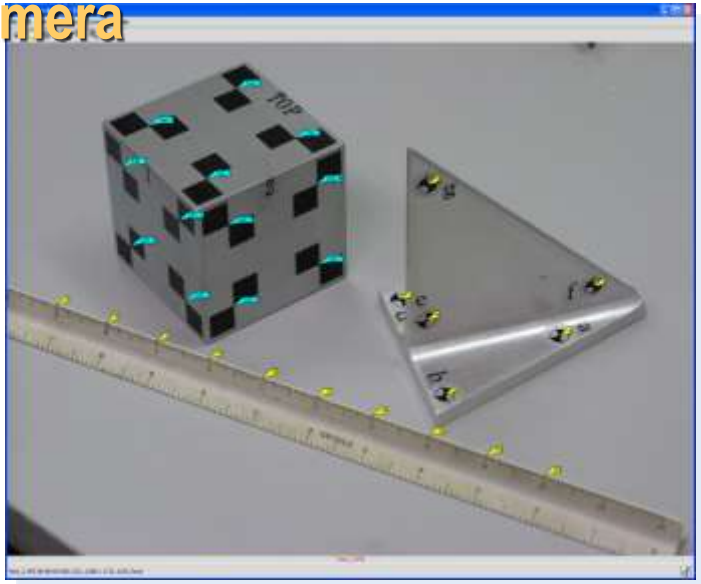


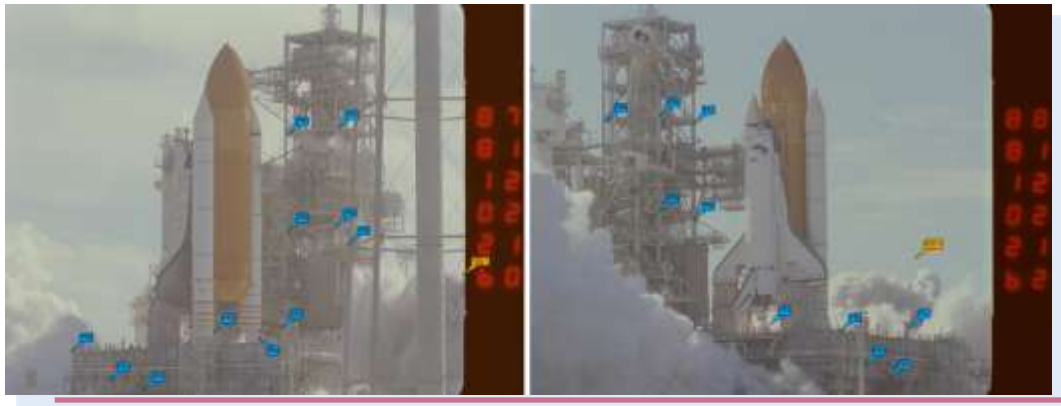


High speed video camera

Laser measurement



Flame Trench - High Flyer



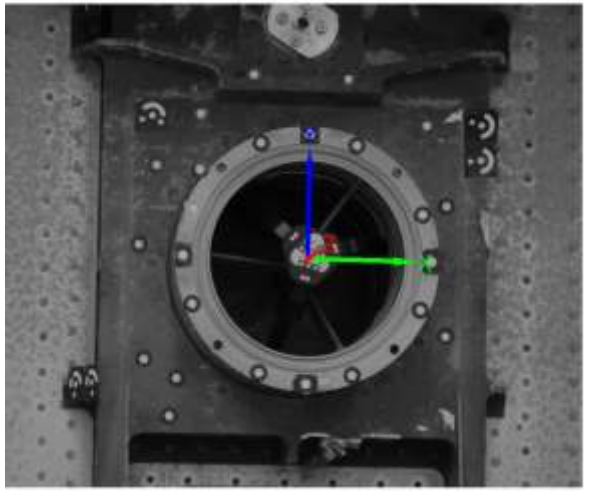
3-D Crime Scene Analysis

Approach: Photogrammetry

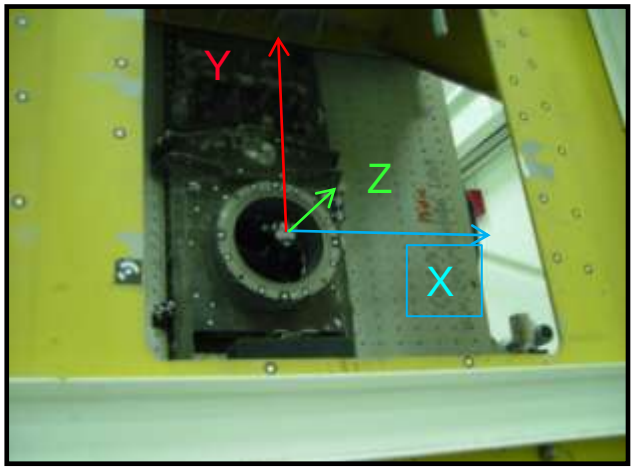
- The hidden ETCA seal and QD probe were imaged utilizing a custom fabricated device called the “spider”

Probe

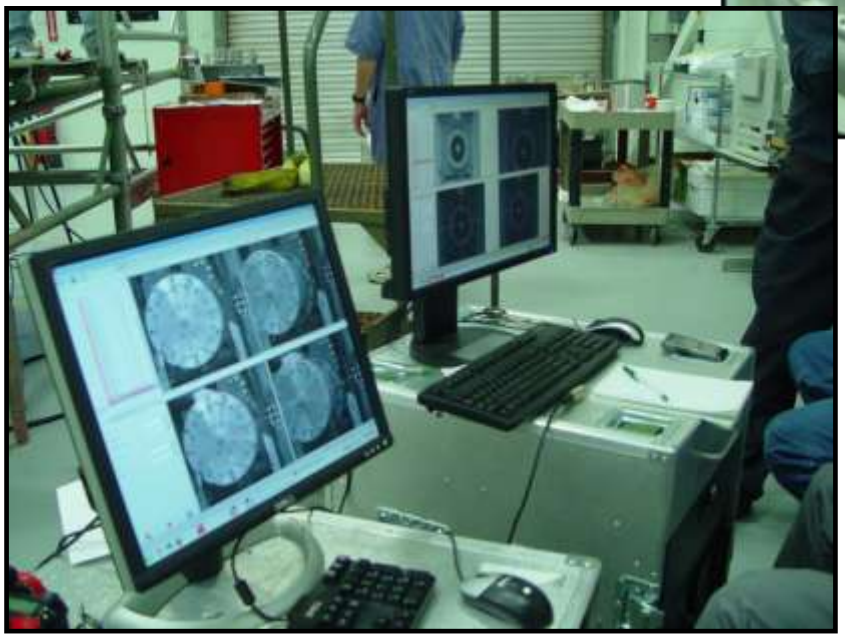
Seal



Approach: Photogrammetry



- Advanced photogrammetry tracked the 'Dots' and 'Calibrated Targets' on the fixed ETCA tank test stand, the Carrier Plate and the QD body to determine their change in displacement and rotation during the installation process



Approach: Optics Measurement of Offsets

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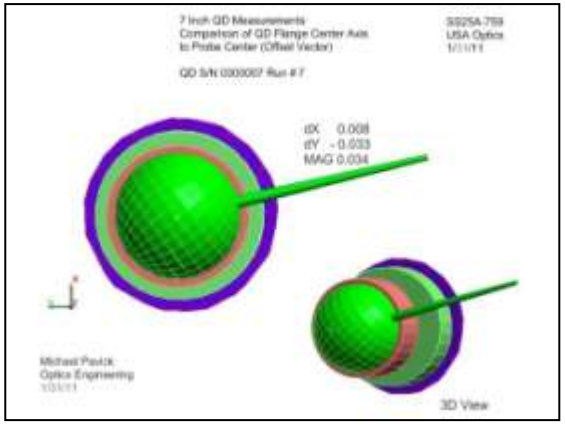
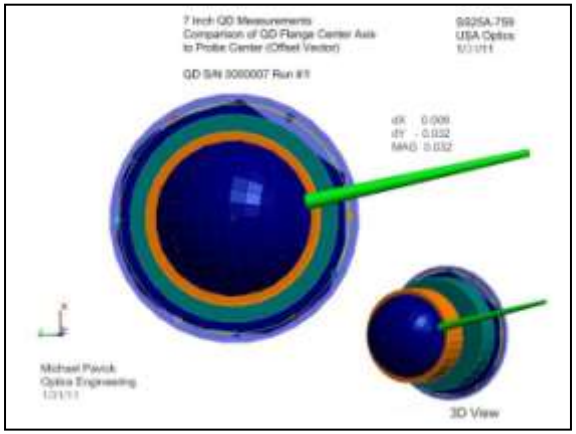
Test 14 GUCP offset, best fit, QD 180^0 clocking, feet restrained with washers



Before



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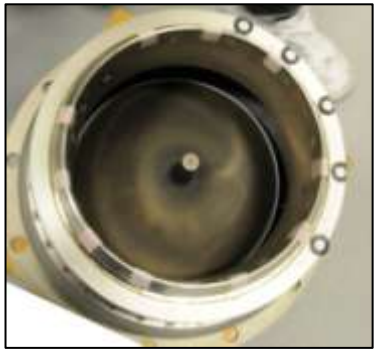
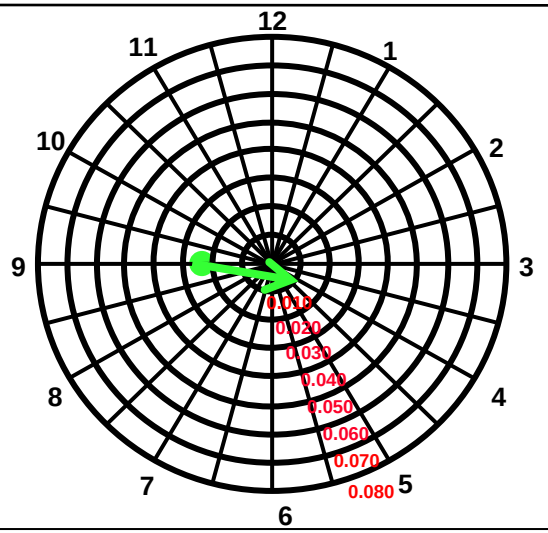


QD =0.034 @ 9:07 (13.94^0)

GUCP = .024 @ 9:00 (0^0)

Max Offset	
12 to 6	0.002
11 to 5	0.014
10 to 4	0.023
9 to 3	**0.024**
8 to 2	0.018
7 to 1	0.010



Resultant GUCP and QD combined = 0.010

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Approach: Test Configurations

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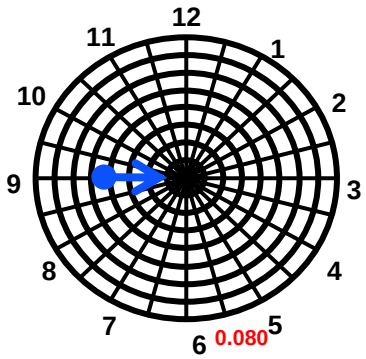
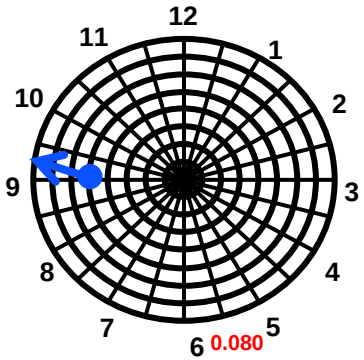
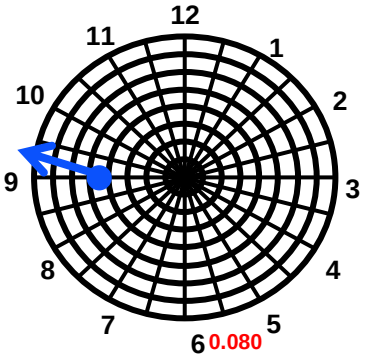
Test 9 - "Best Fit"
Offset 0.012 @ 9:00
GUCP Unrestrained



Test 11 - "Worst Fit"
Offset 0.083" @ 9:00
GUCP Restrained

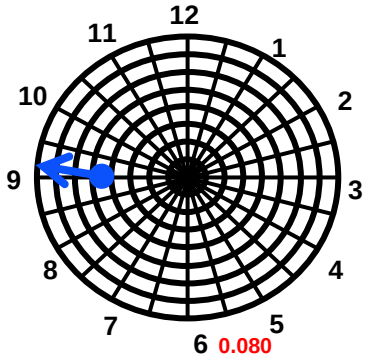


Test 13 - "Worst Fit"
Offset 0.087" @ 9:00
GUCP Restrained

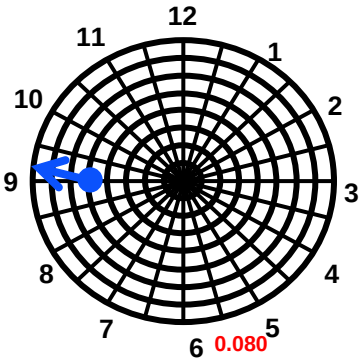


Guide Pins Removed @ 0.45"

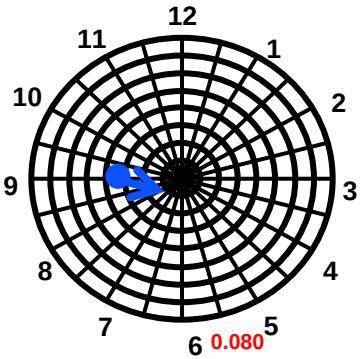
Test 10 - "Worst Fit"
Offset 0.078" @ 9:00
GUCP Unrestrained



Test 12 - "Worst Fit"
Offset 0.080" @ 9:00
GUCP Restrained



Test 14 - "Best Fit"
Offset 0.010" @ 8:00
GUCP Restrained

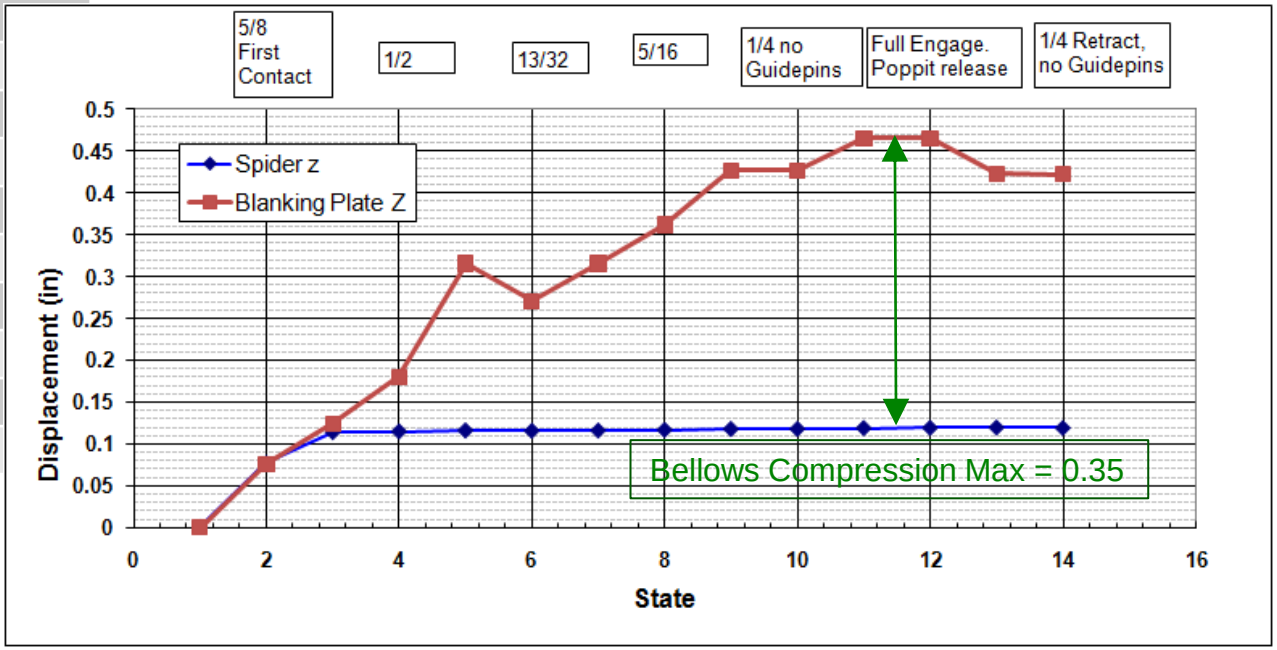


Approach: Photogrammetry Data

KSC-TA-11539

Test 14 GUCP offset, best fit, QD 180^0 clocking, feet restrained with washers

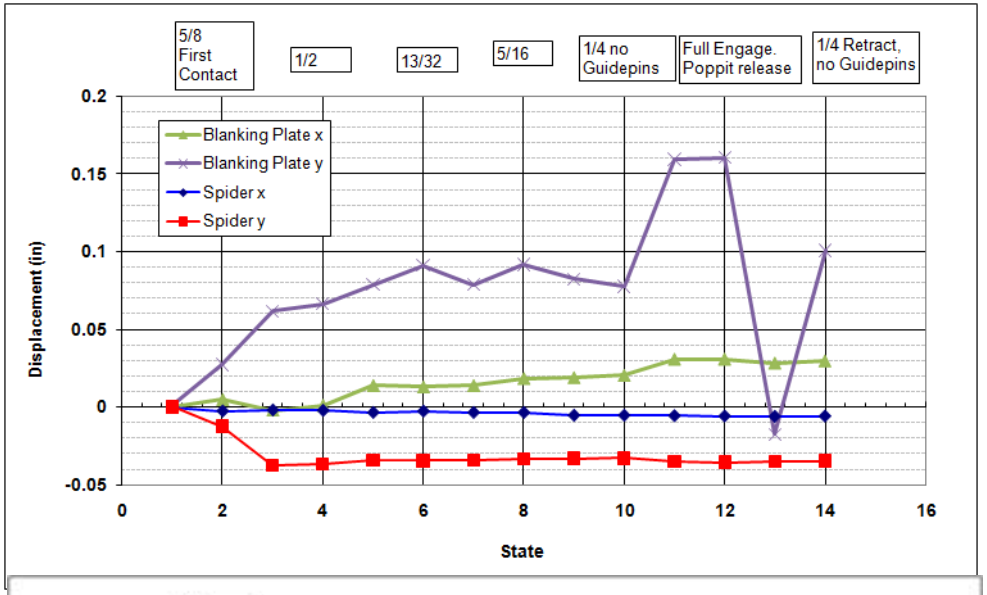
State	Description
1	11/16“- Before Contact
2	5/8” – Initial Contact
3	9/16”
4	1/2”
5	15/32”
6	13/32”
7	3/8”
8	5/16”
9	¼” with Guide Pins
10	¼” without Guide Pins
11	Full Engage, Poppet retracted
12	Full Engage, Poppet released
13	¼” Retract, without Guide Pins
14	¼” Retract, with Guide Pins

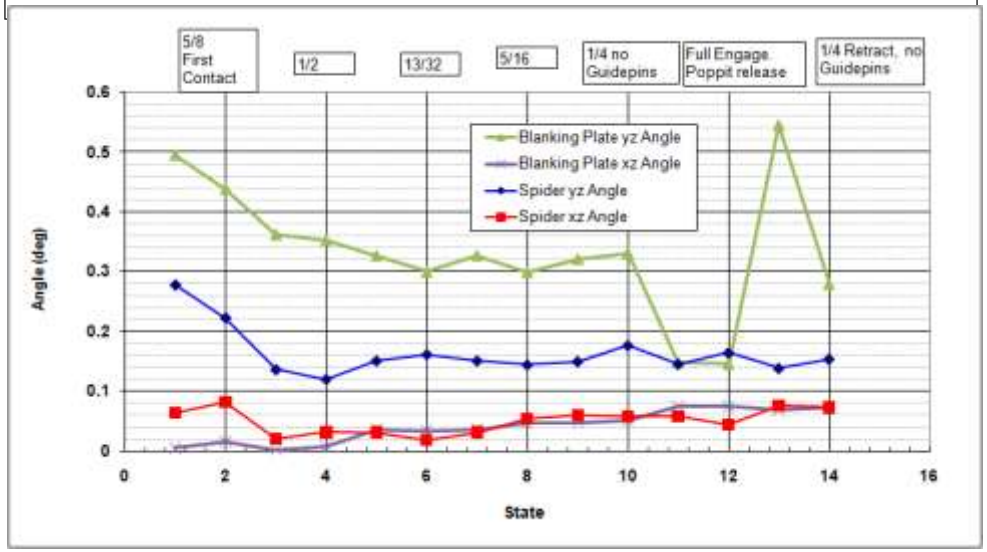


Approach: Photogrammetry Data

Test 14 GUCP offset, best fit, QD 180^0 clocking, feet restrained with washers

State	Description
1	11/16“- Before Contact
2	5/8” – Initial Contact
3	9/16”
4	1/2”
5	15/32”
6	13/32”
7	3/8”
8	5/16”
9	¼” with Guide Pins
10	¼” without Guide Pins
11	Full Engage, Poppet retracted
12	Full Engage, Poppet released
13	¼” Retract, without Guide Pins
14	¼” Retract, with Guide Pins



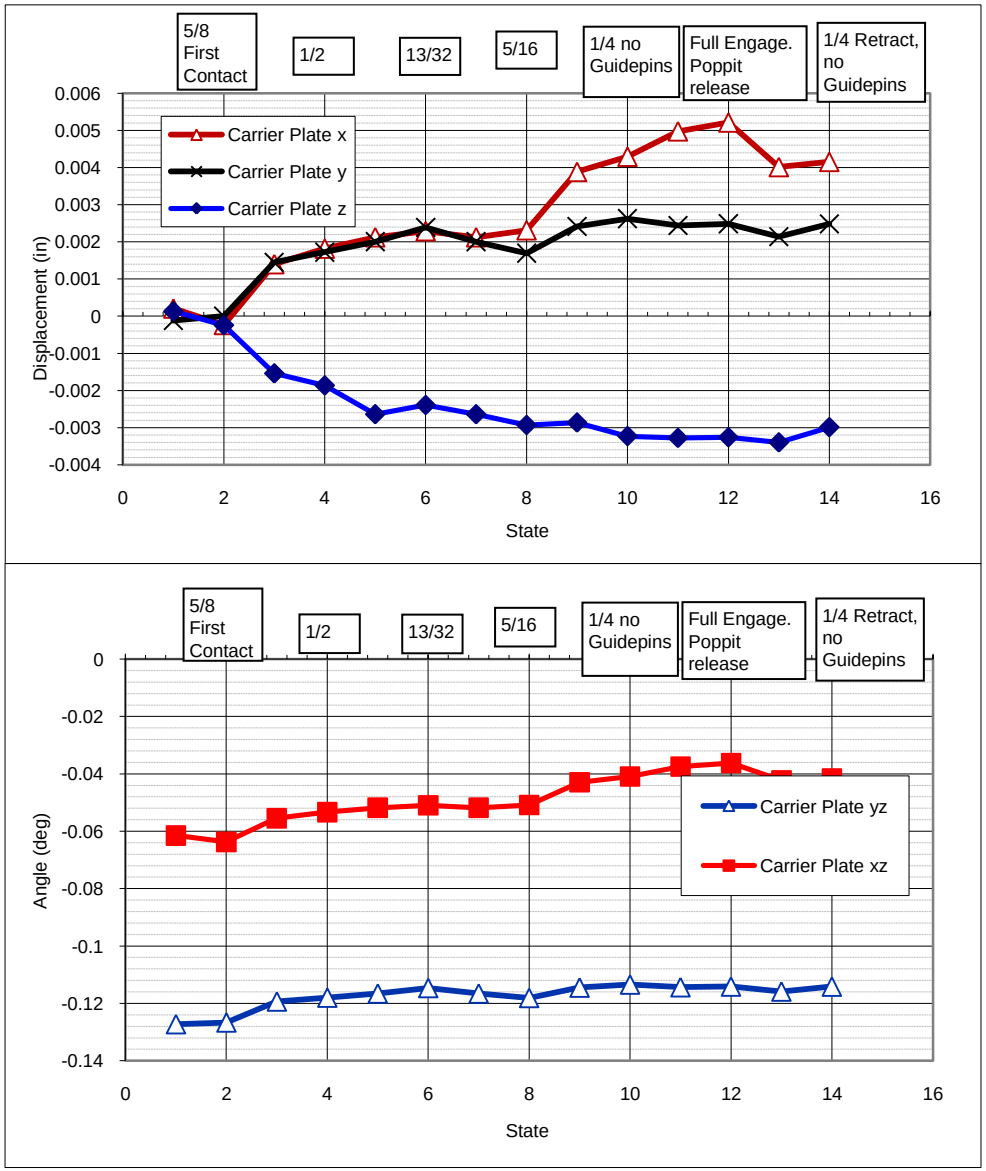


Approach: Photogrammetry Data

Test 14 GUCP offset, best fit, QD 180^0 clocking, feet restrained with washers

State	Description
1	11/16“- Before Contact
2	5/8” – Initial Contact
3	9/16”
4	1/2”
5	15/32”
6	13/32”
7	3/8”
8	5/16”
9	¼” with Guide Pins
10	¼” without Guide Pins
11	Full Engage, Poppet retracted
12	Full Engage, Poppet released
13	¼” Retract, without Guide Pins
14	¼” Retract, with Guide Pins

Carrier Plate Motion



Approach: Photogrammetry Test - Spider

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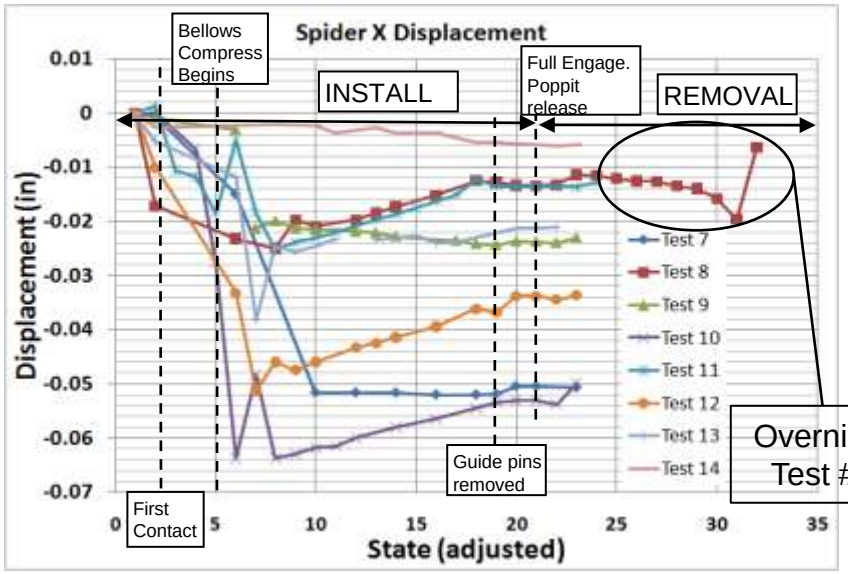

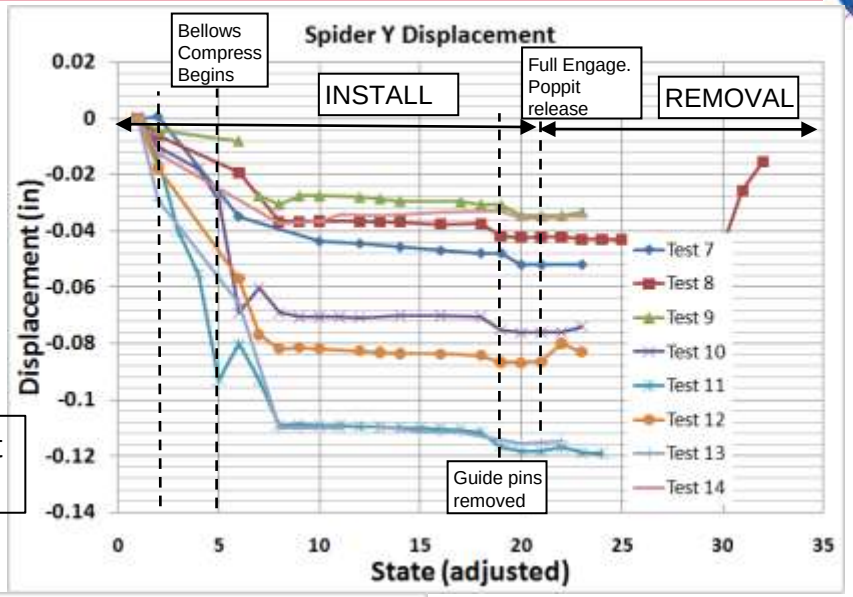

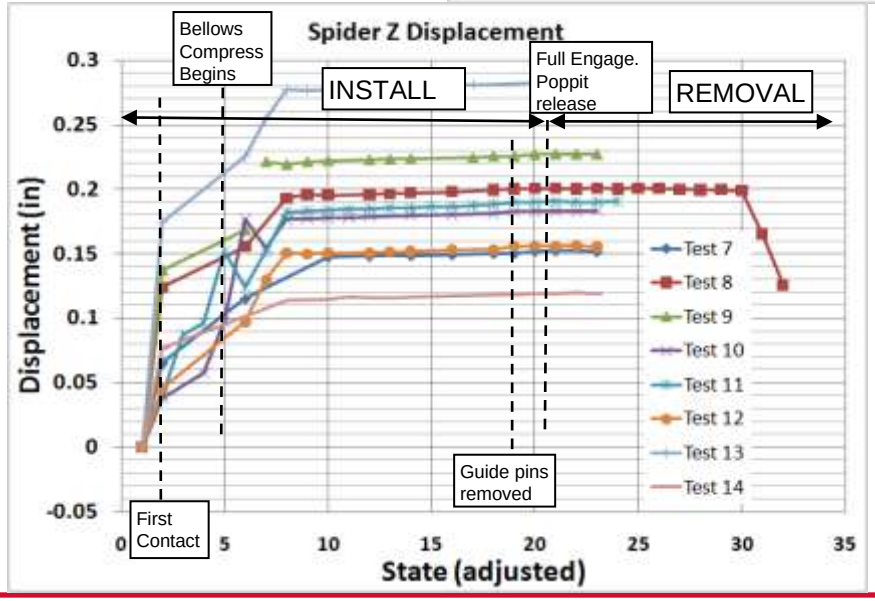

Approach: Photogrammetry Test Blanking Plate

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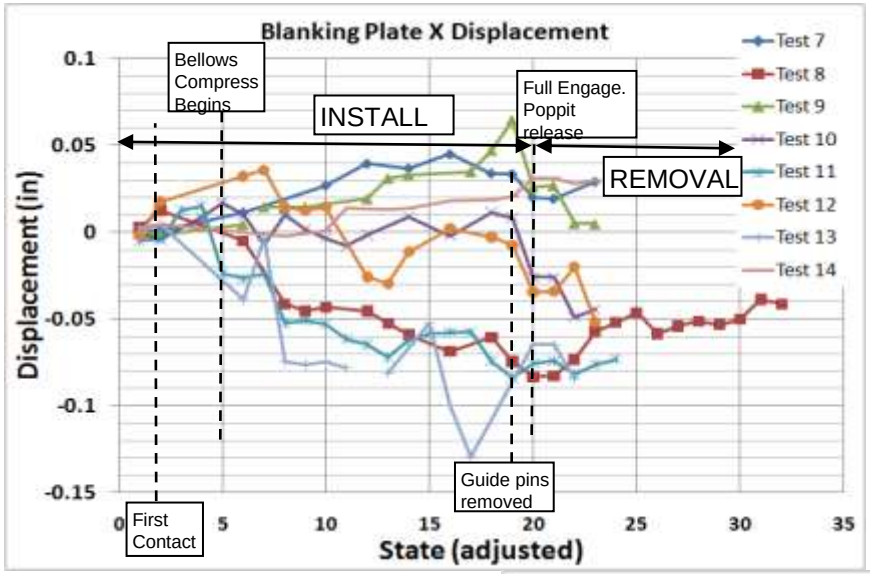

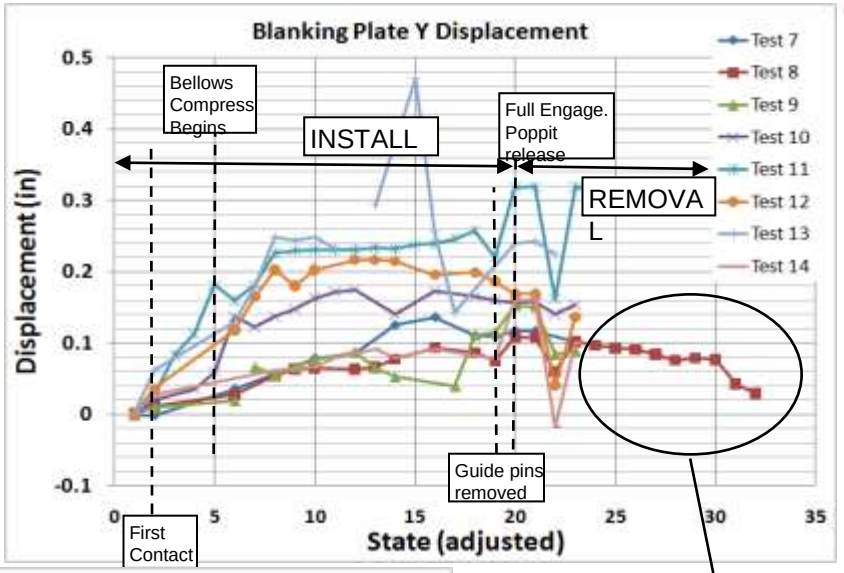

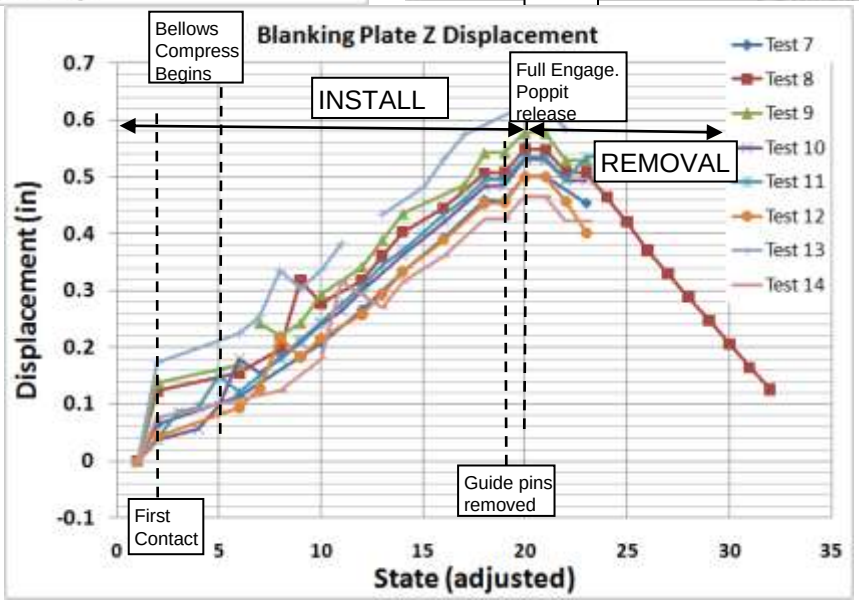

Overnight Test #8

Approach: Photogrammetry Test Carrier Plate

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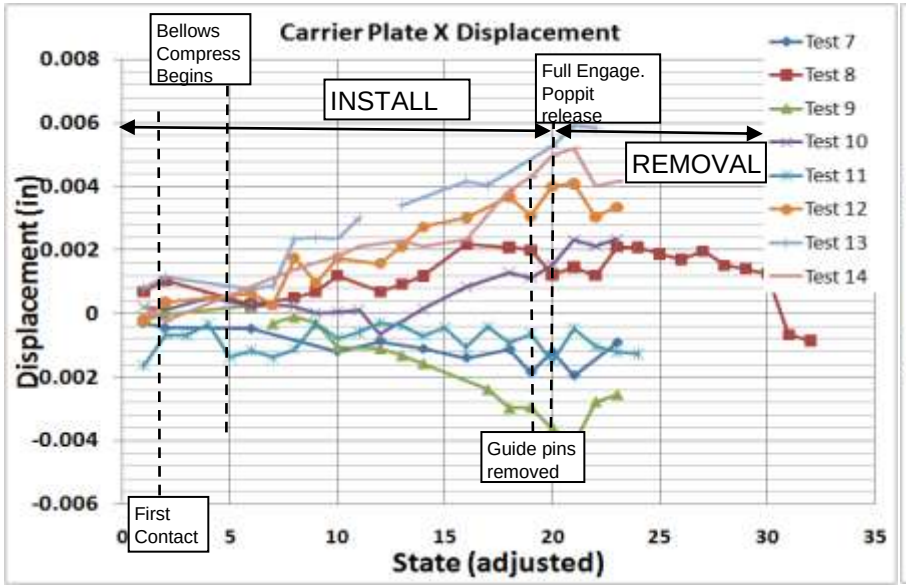
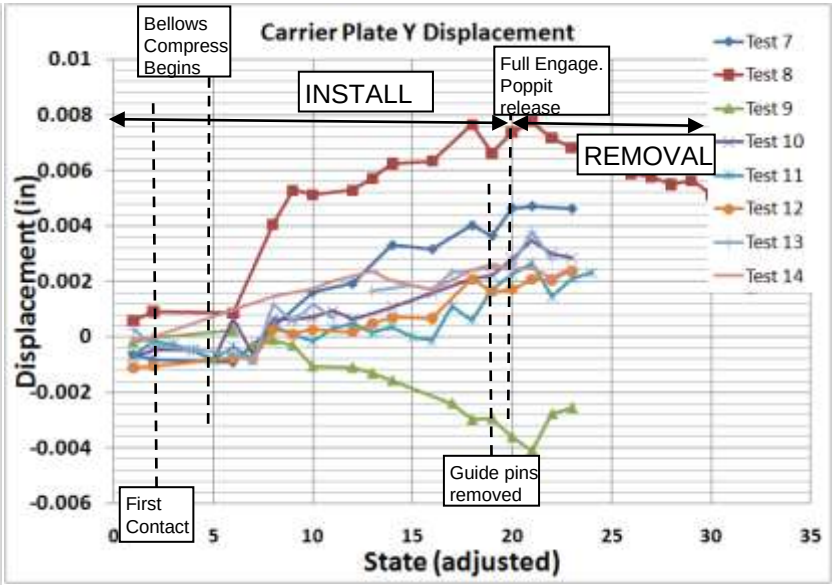
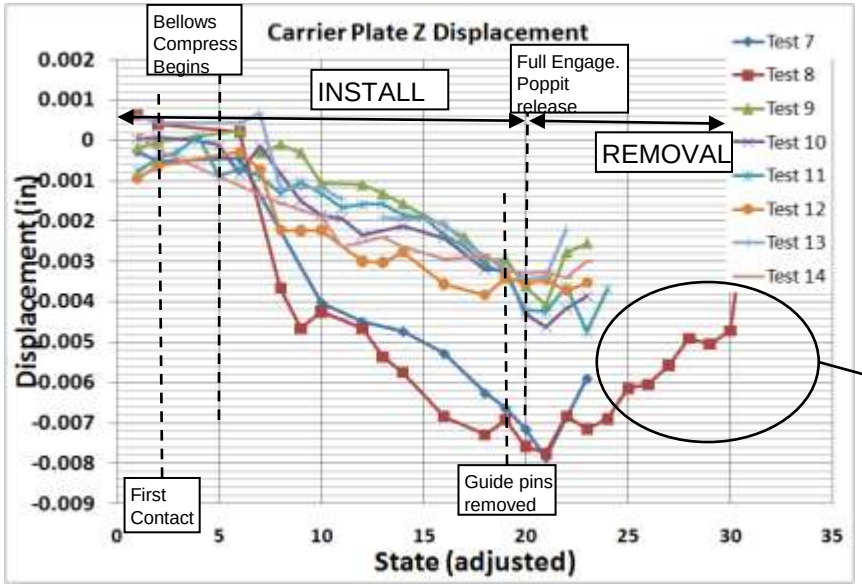
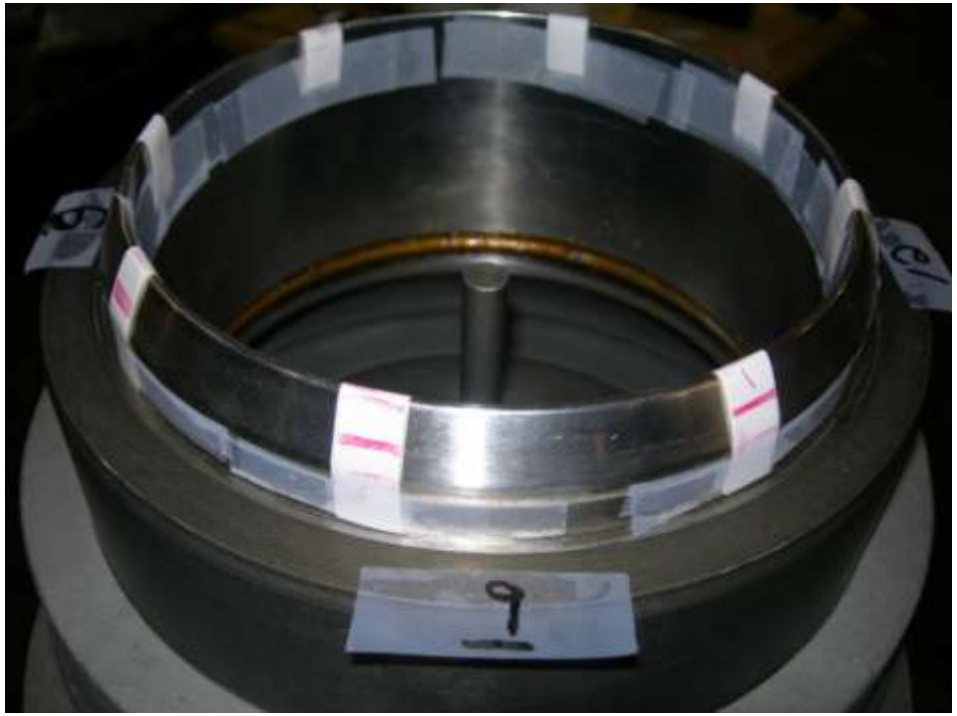


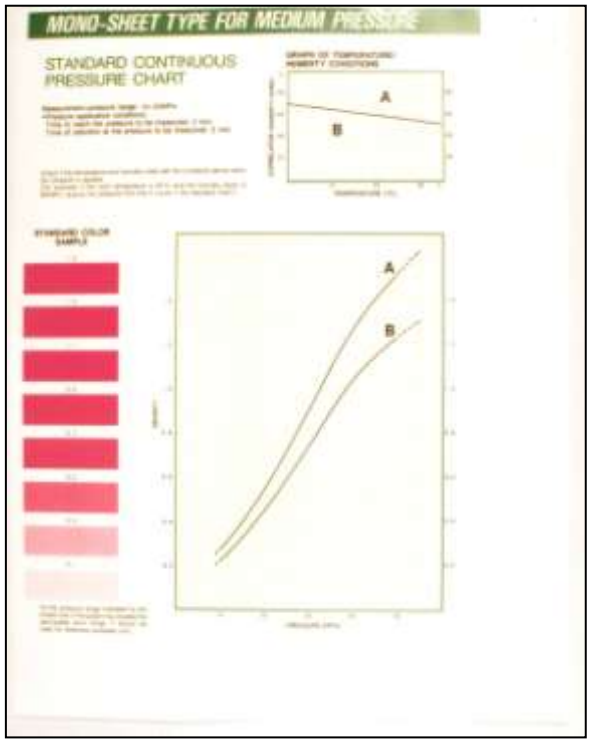




Approach: Pressure Sensitive Film – Test 14

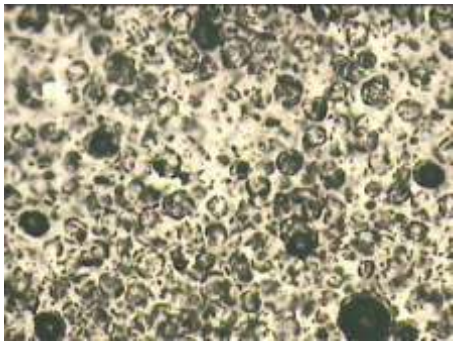
KSC-TA-11539

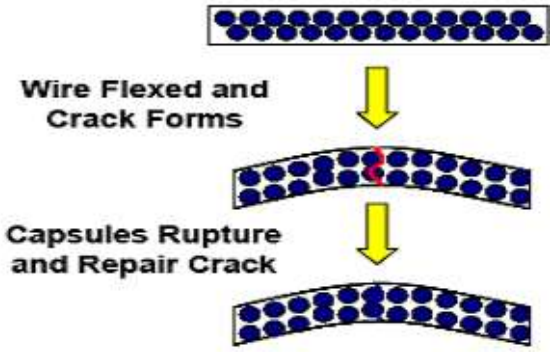




- Pressure Sensitive film (Fuji Pre-scale Film) was taped at different clocking locations on the probe to record the seal contact location, area of engagement and pressure exerted.
- The color change of the film was compared with the Fuji standards using image analysis tools and a rough order of magnitude contact pressure quantified.

Approach: Microencapsulation

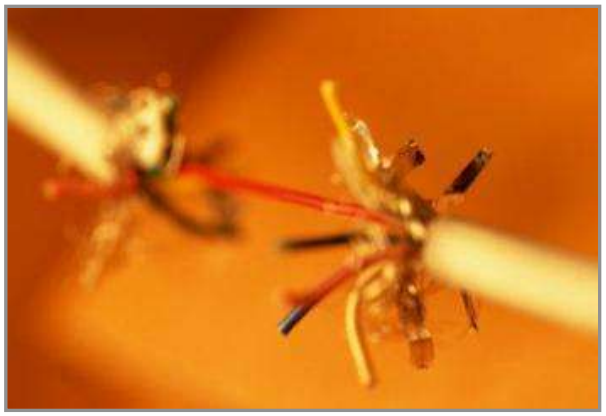




Indicator encapsulated

Elongated microcapsules

Space Shuttle Orbiter

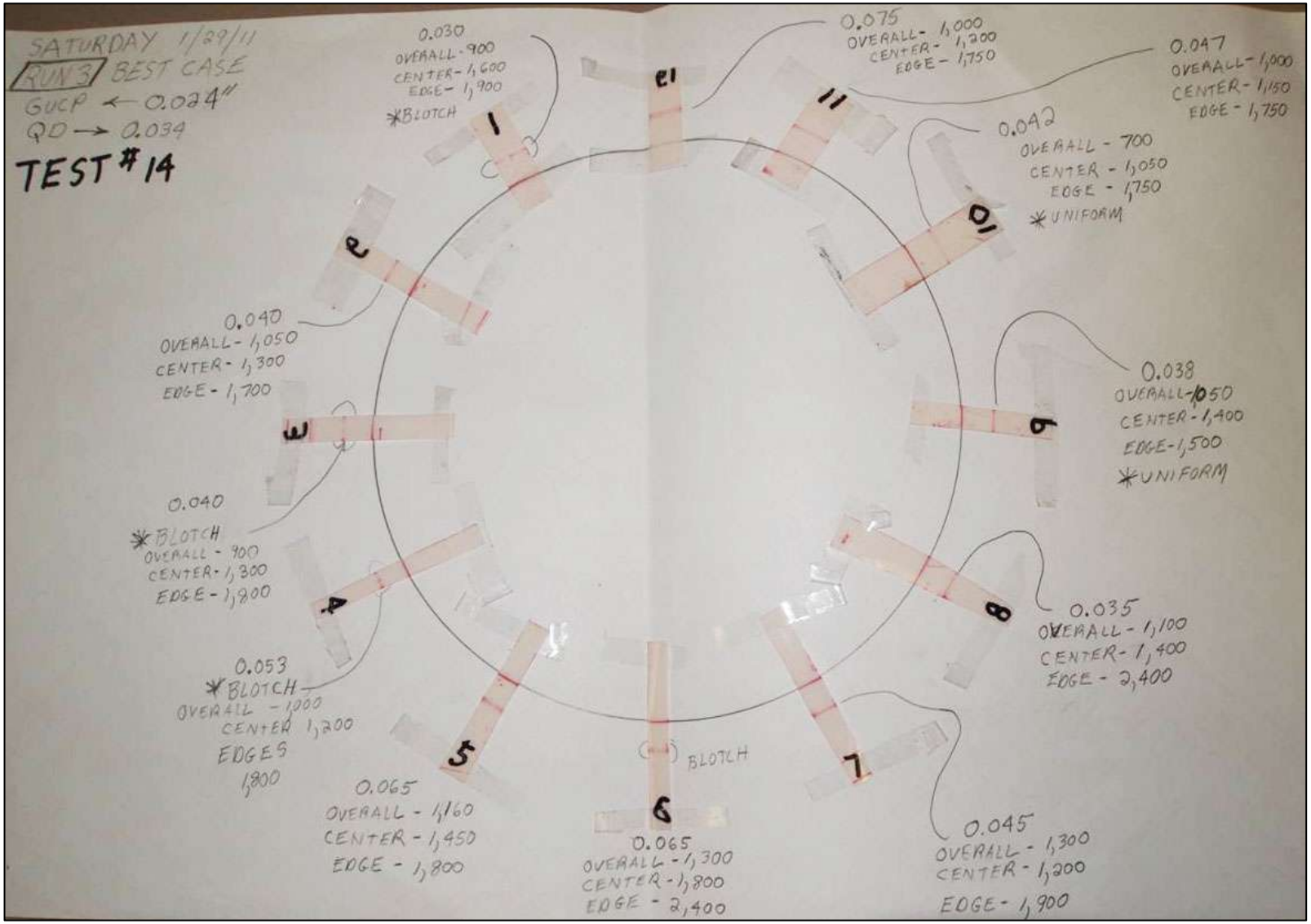


Aged Wire

- Has grounded Orbiter fleet from flying
- More than 183 miles of wiring buried deep within structure of vehicle
- Cracks and frays over time, hard to detect damage
- Extensive maintenance related damage during ground processing work
- Difficult to visually inspect
- It is estimated that only ~10% of Orbiter wiring accessible
- Most common method of finding wiring faults – visual inspection
- Even if accessible discrimination of damaged wire very difficult in small spaces

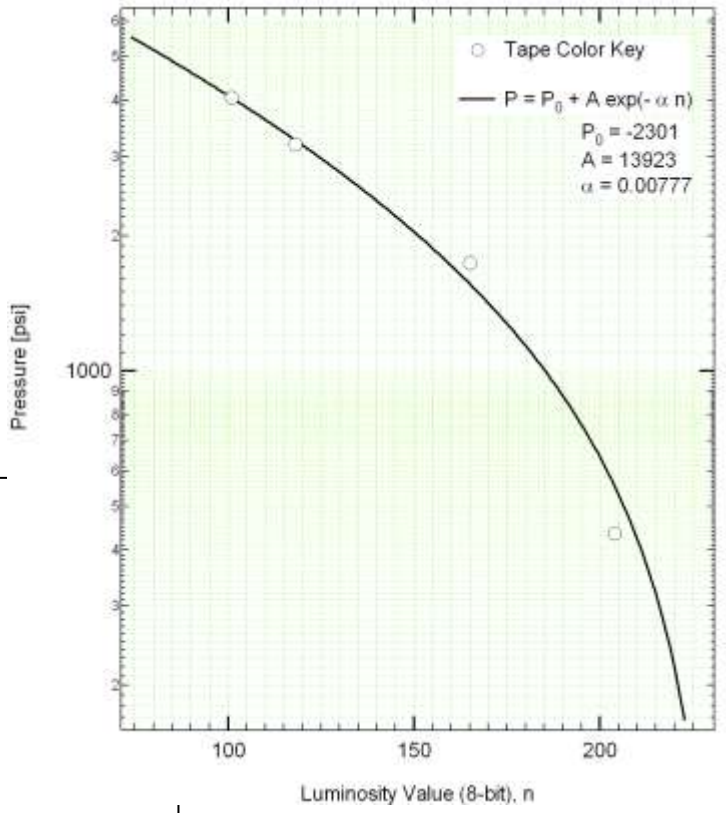
Approach: Pressure Sensitive Film – Test 14

KSC-TA-11539

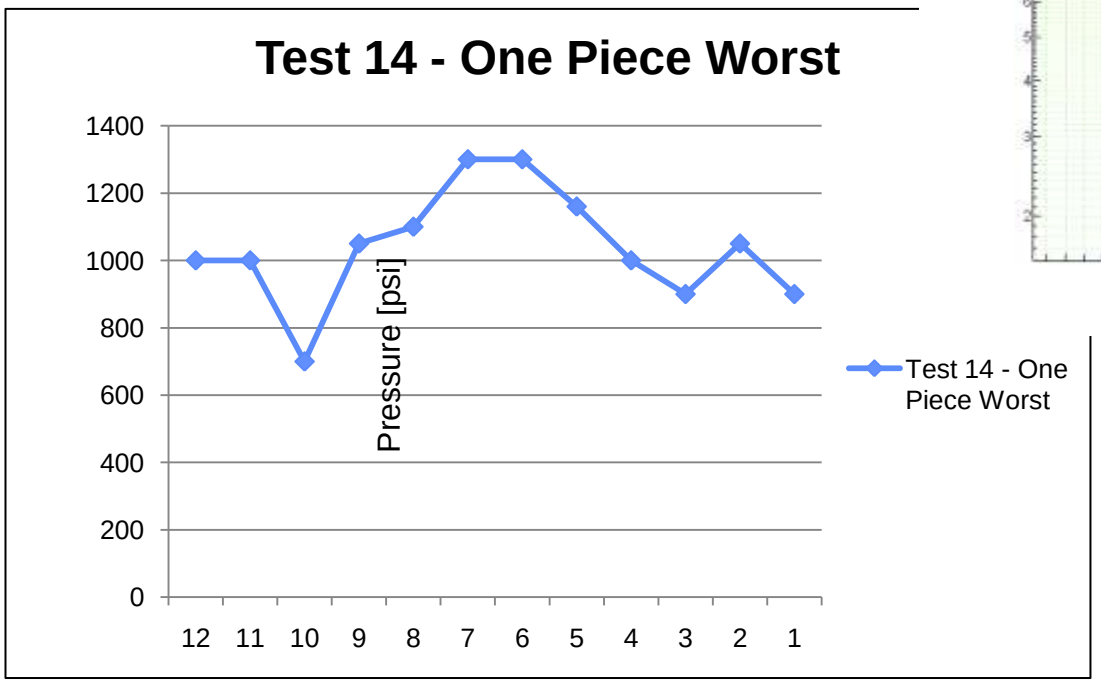


Approach: Pressure Sensitive Film – Test 14

KSC-TA-11539



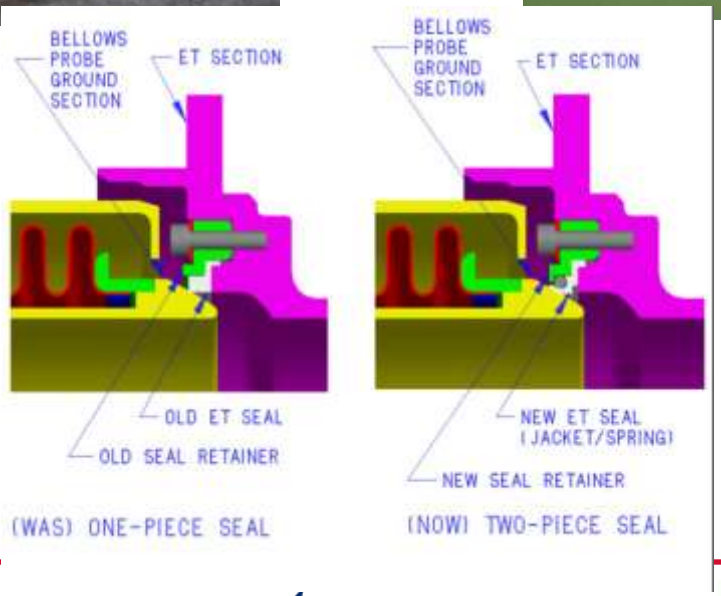
ESC Derived Luminosity Curve



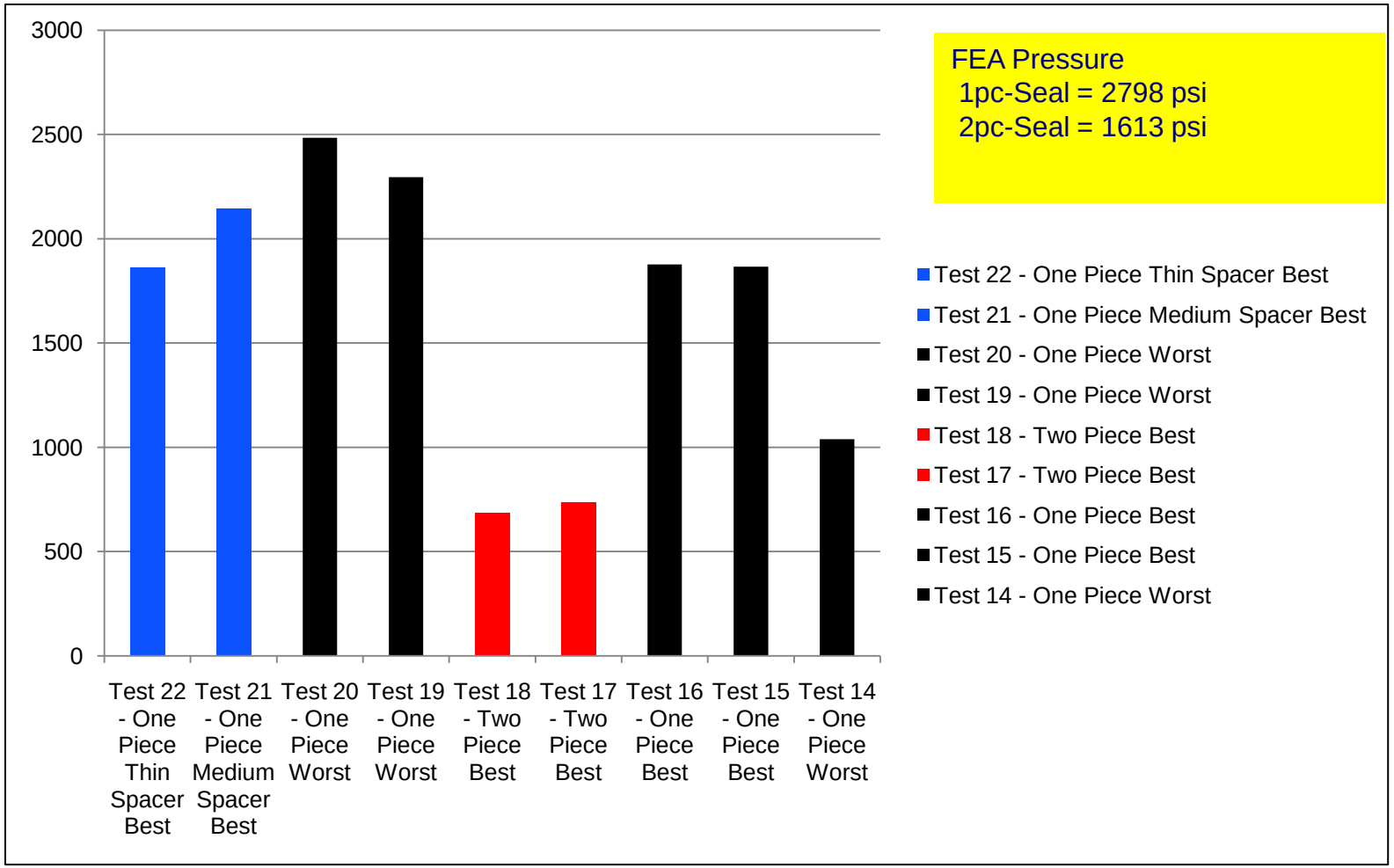
Approach: One Piece vs. Two Piece Seal

One-Piece Seal
(Previous Design)

Two-Piece Seal
(Current Design)

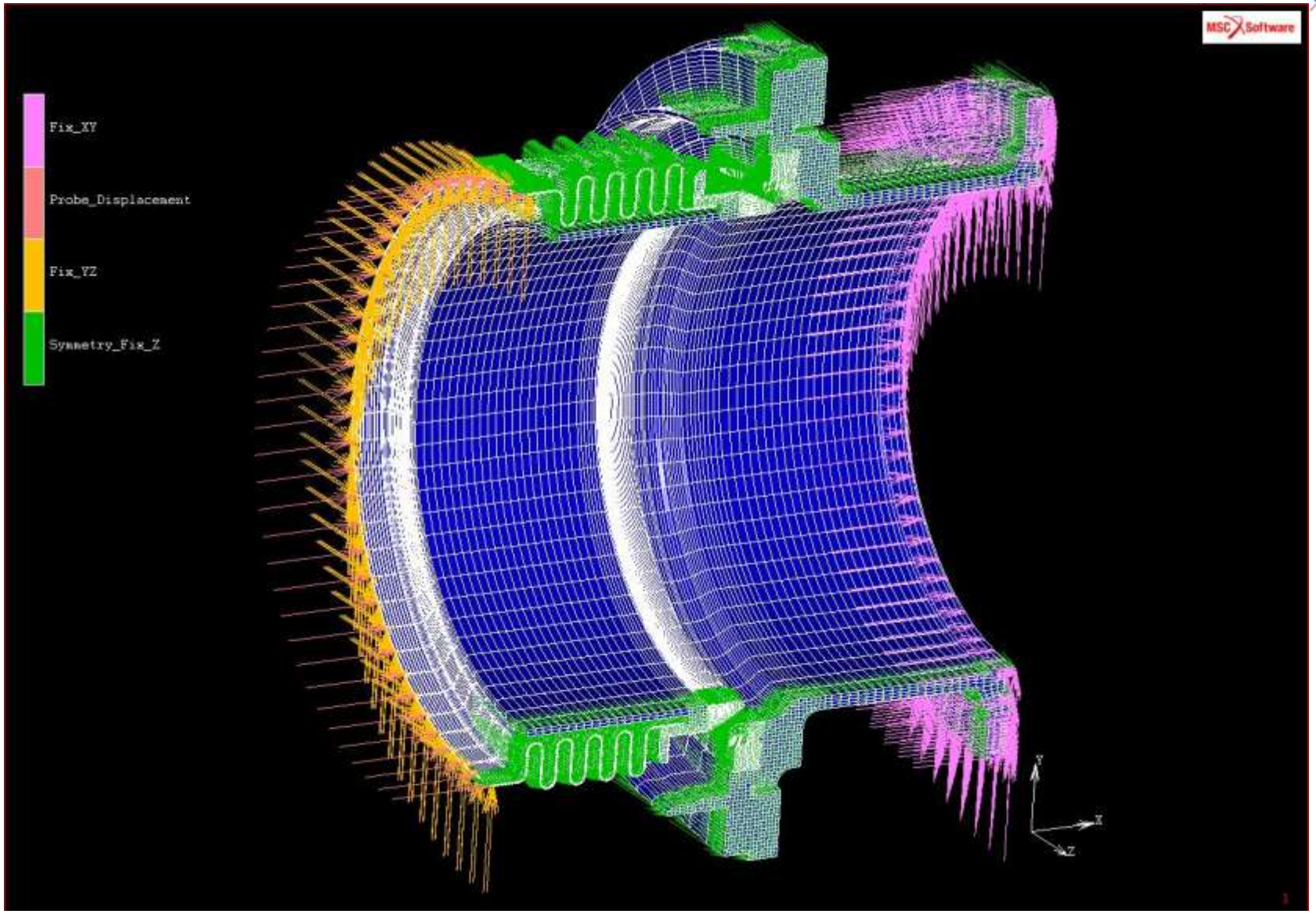


Approach: One Piece vs. Two Piece Seal



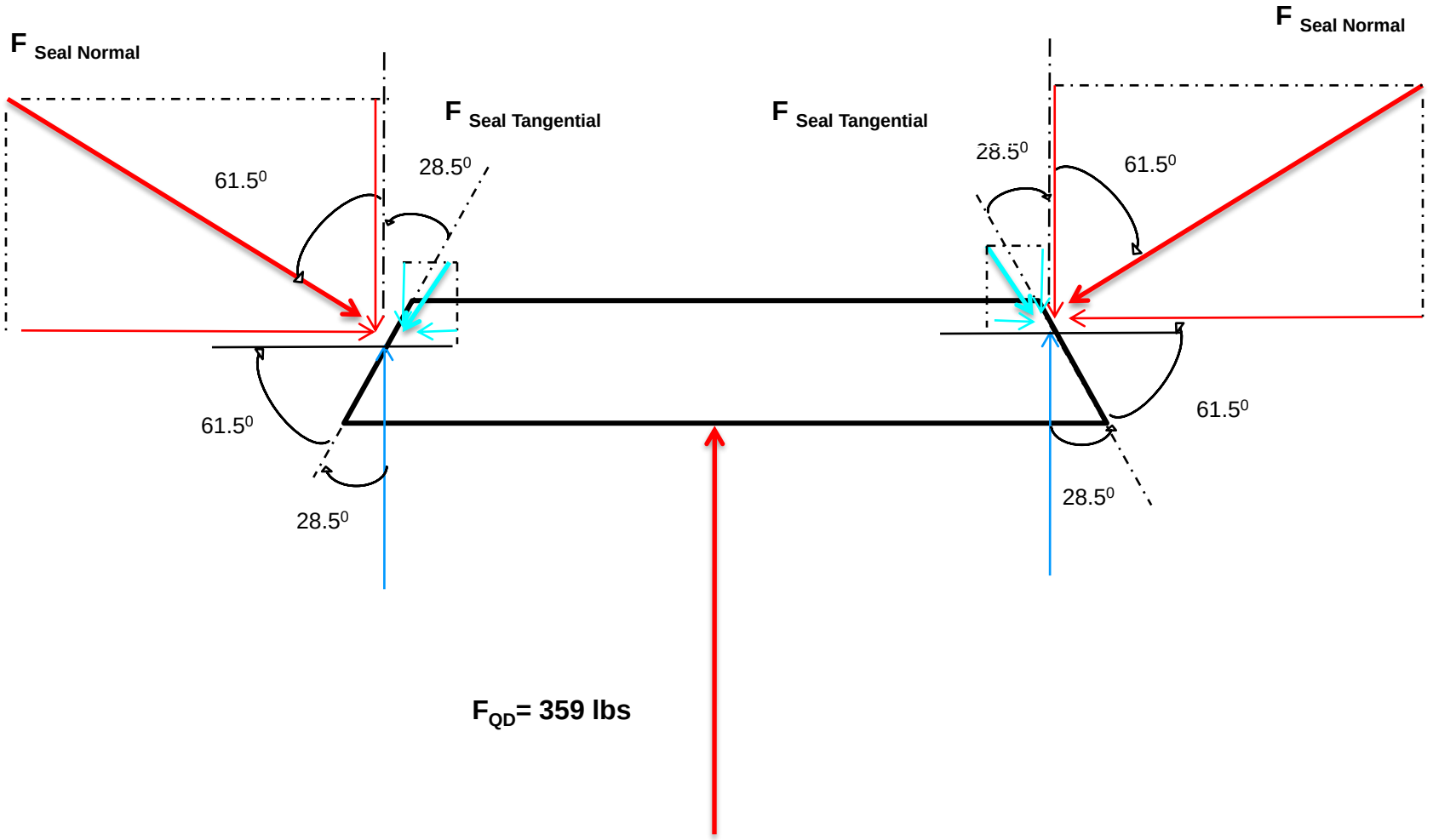
Approach: CAD Simulation and Analysis

KSC-TA-11539

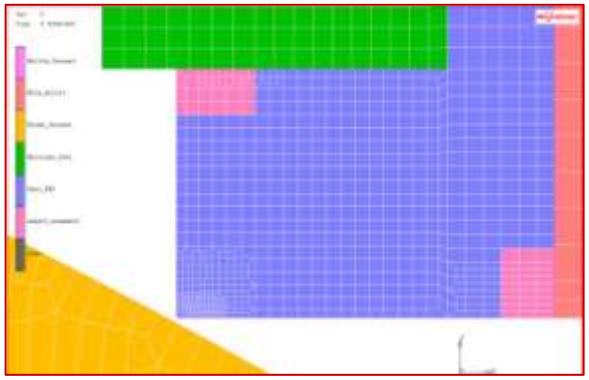


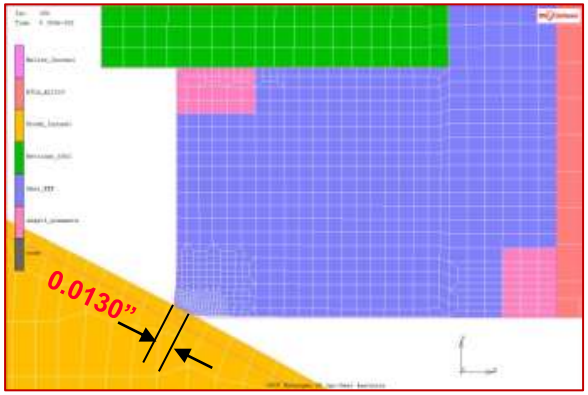
Approach: CAD Simulation and Analysis

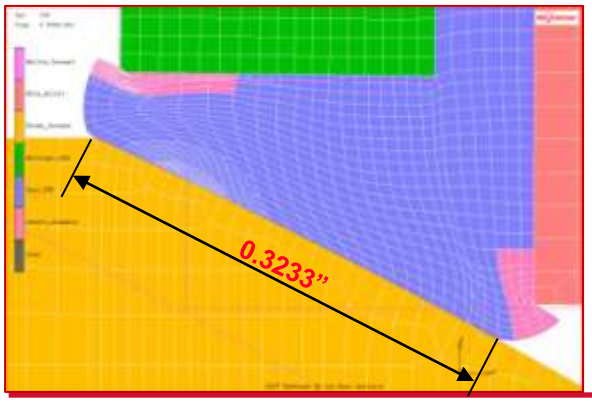
With friction, $F_{Seal\ Tangential} = f * F_{Seal\ Normal}$ and $F_{QD} = F_{y\text{-}Seal\ Normal} + F_{y\text{-}Seal\ Tangential}$



Comparison: 1pc-Seal vs. 2pc-Seal

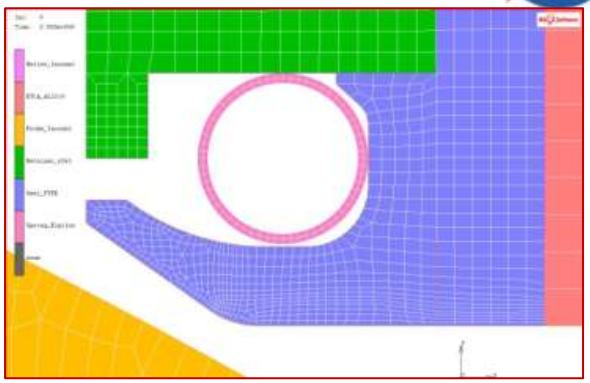


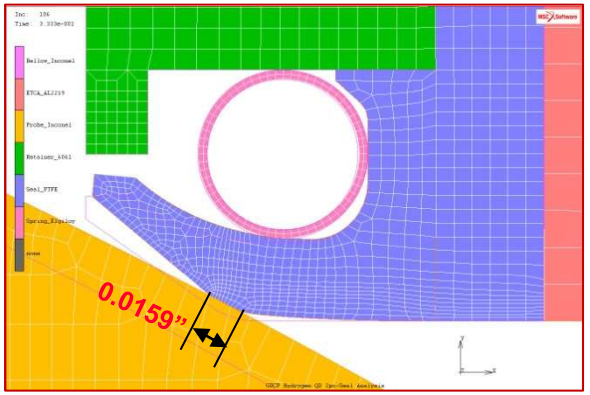


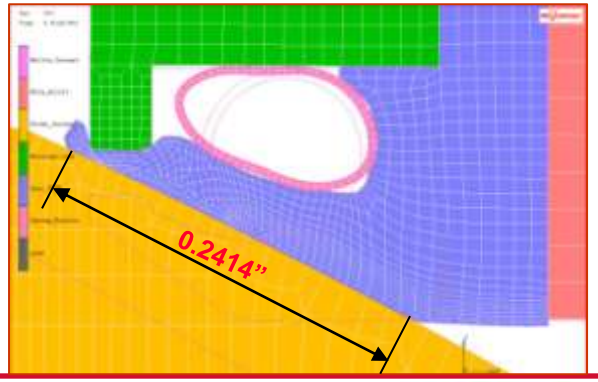


Probe starting position identical
2pc-Seal Initial gap due to material reduction in design

Inc: 106	1pc-Seal	2pc-Seal	Delta
Force (lb)	524	359	46%
Displacement (in)	1.06	1.06	0%
Contact Area (in)	0.0130	0.0159	-18%
Pressure (psi)	2798	1613	73%
Maximum Capability	**1pc-Seal**	**2pc-Seal**	**Delta**
Force (lb)	9922	4345	128 %
Displacement (in)	1.98	1.53	29%
Contact Area (in)	0.3233	0.2414	34%

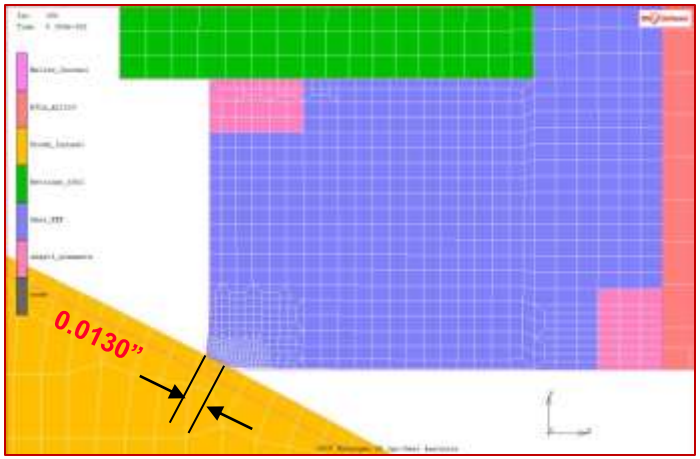


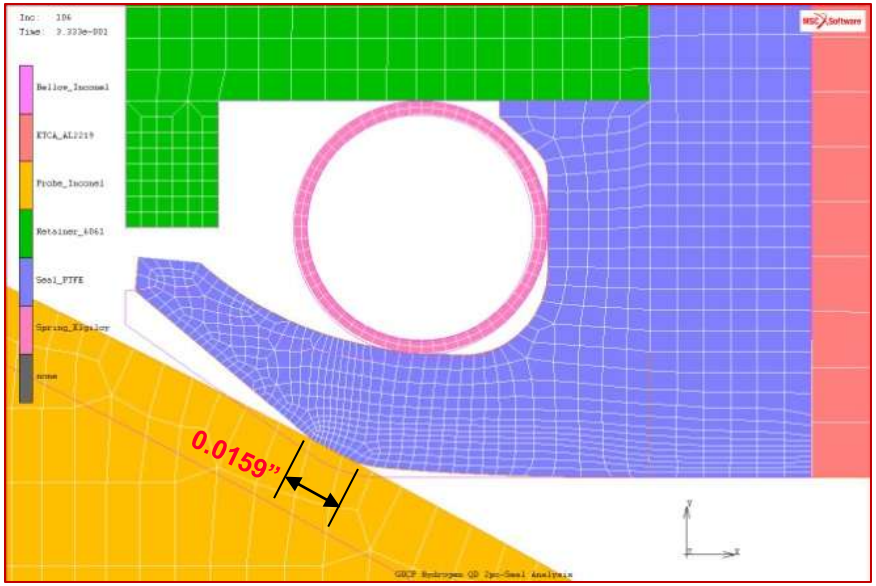




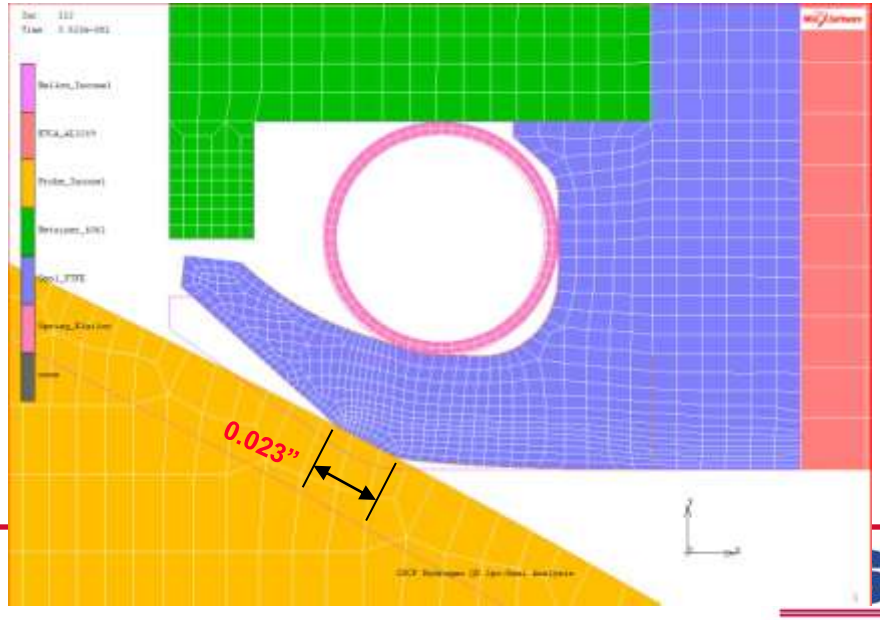
Comparison: 1pc-Seal vs. 2pc-Seal

Inc: 106	1pc-Seal	2pc-Seal	Delta
Force (lb)	524	359	46%
Displacement (in)	1.06	1.06	0%
Contact Area (in)	0.0130	0.0159	-18%
Pressure (psi)	2798	1613	73%



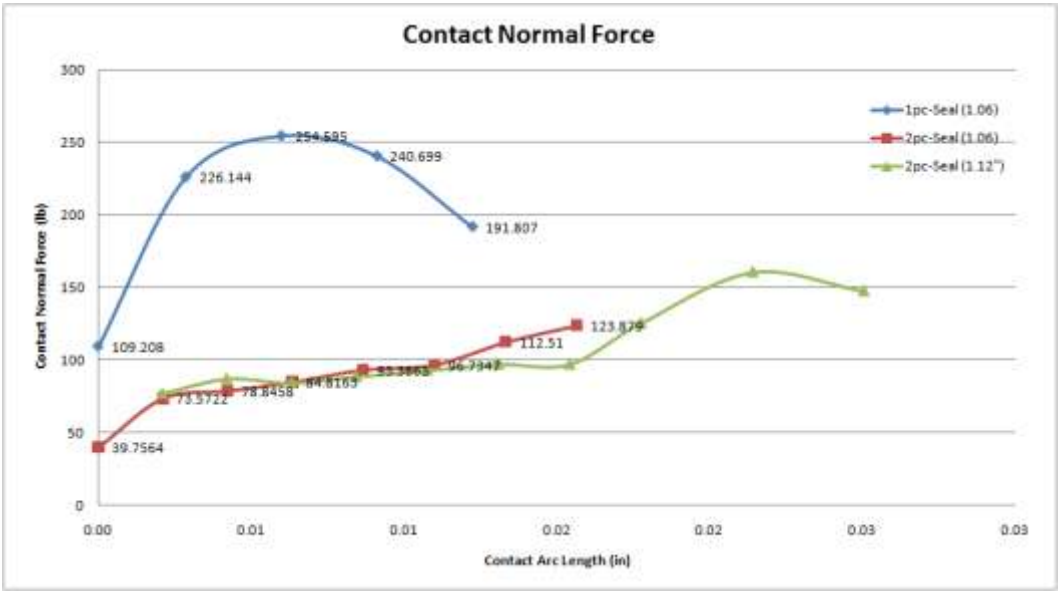


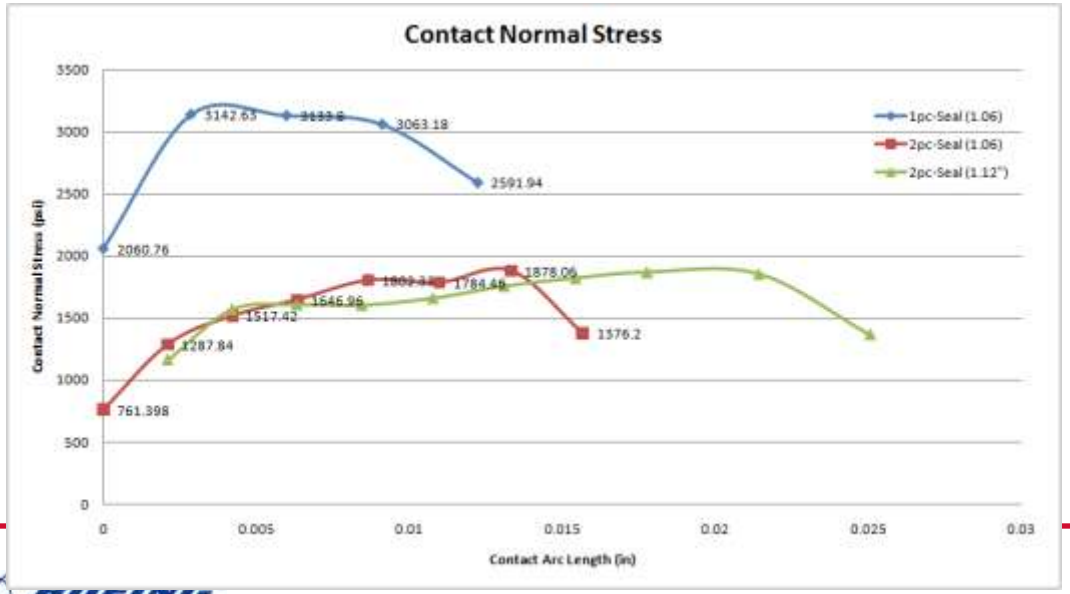
2pc-Seal	Inc: 112	Inc: 106	Delta
Force (lb)	539.15	359	50%
Displacement (in)	1.12	1.06	0.06 in
Contact Area (in)	0.0230	0.0159	44.6%
Pressure (psi)	1717	1613	6.4%

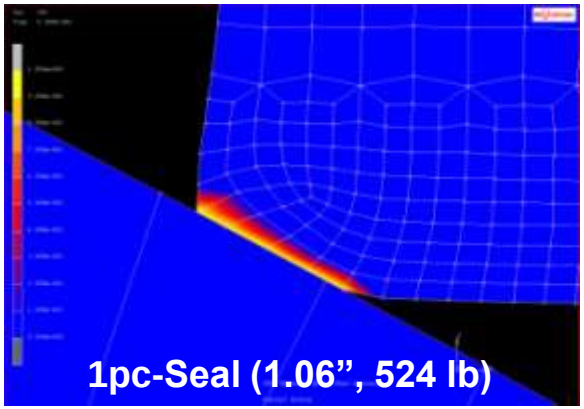


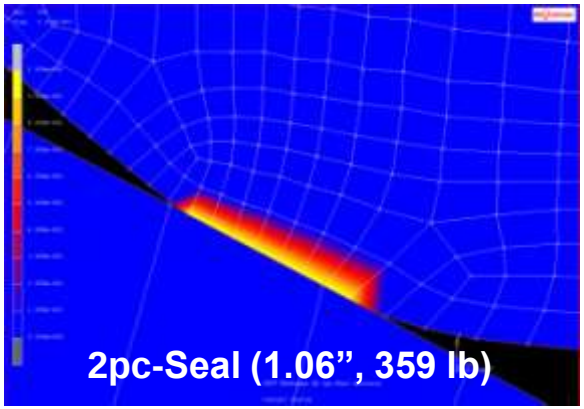
United Space Alliance

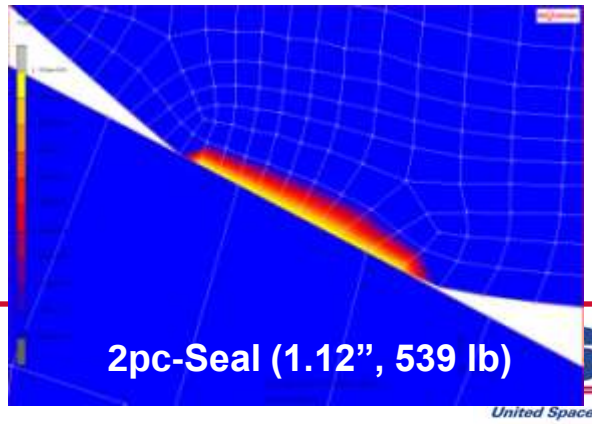
Contact Force & Pressure











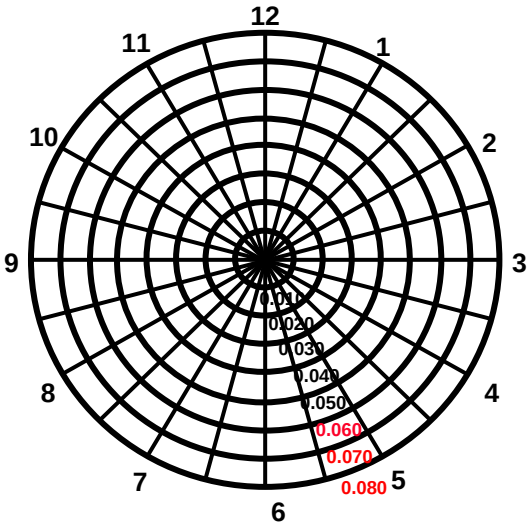
Conclusions:

1. The QD Probe centers itself on the seal early in the installation process (within first 1/16” of bellows compression), leading to the conclusion that the QD Probe secures itself relative to the seal shortly after bellows compression begins, small displacements between the two occur to self-center until mating is complete.
2. After the first 1/16” of bellows compression, the Carrier Plate is displaced from its installed position, as a reaction to the QD bellows spring forces, away from vehicle (0.008”) in one direction and towards the centerline of the ETCA (0.008”) in the other two directions (**direction of “goodness”).**
3. After the first 1/16” of bellows compression, the QD body and Carrier Plate assembly react together to try and center themselves in line with the ETCA seal.
9. The two-piece seal was not permanently deformed after the installation process and did not relax during a 14 hour period post-installation.
10. The QD guide pins, when removed at ¼” before fully mated, help with overall system alignment.
11. Once the QD guide pins are removed, the QD/Carrier plate center themselves towards the “direction of goodness”.
12. Test results substantiate a probe/seal contact sealing area band width of between 0.015 -0.040”.

Conclusions:

13. Test results substantiate a probe/seal contact rub area, created while the probe is self-centering, of greater than 0.200”.
14. The ambient leak test could not reproduce the leaking condition that was present during STS-127 and STS-133 while the system is subjected to cryogenic temperatures.

Probe to seal requirement added to SSP OMRSD for alignment to be < 0.050”



Summary

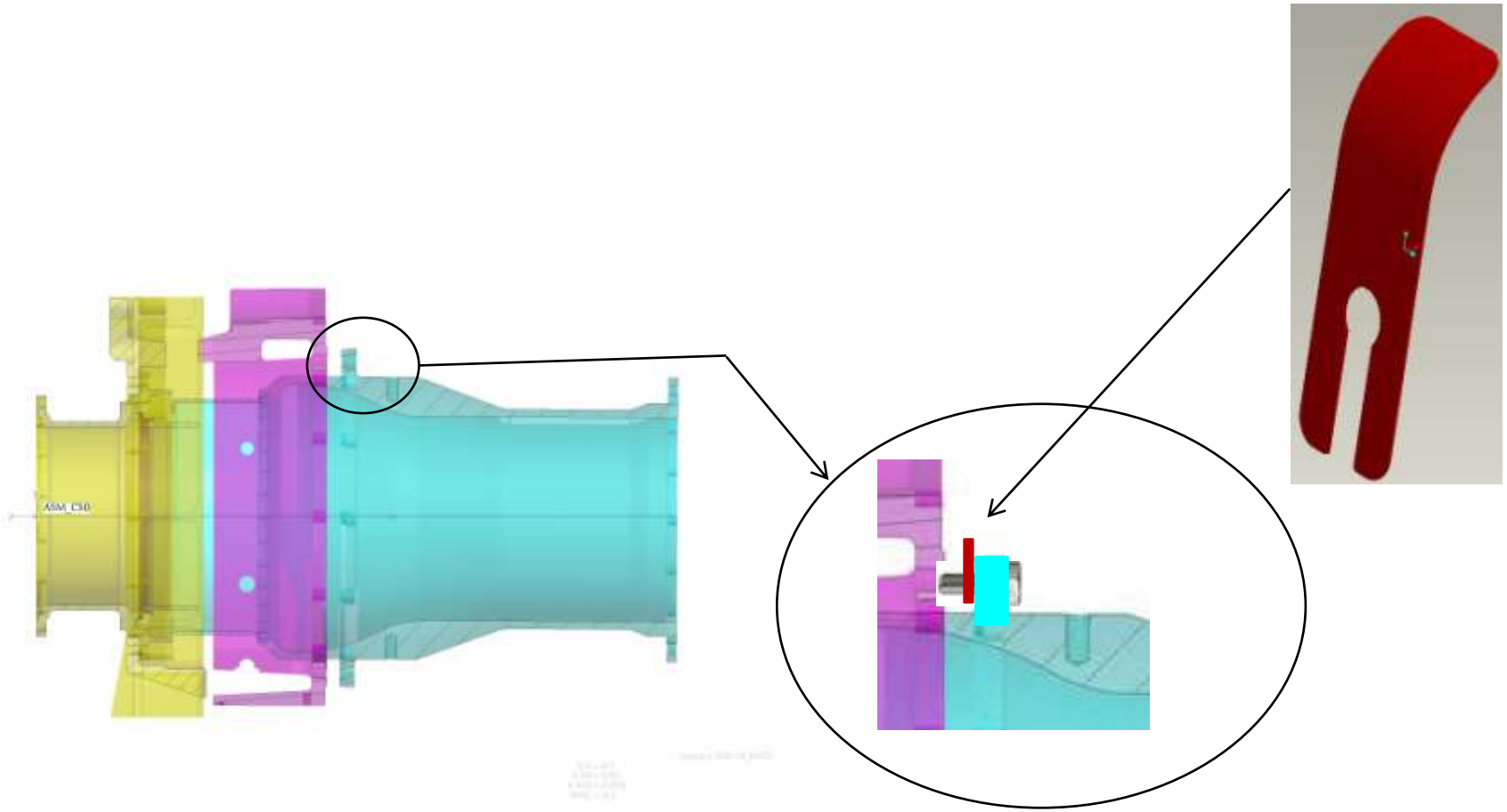
1. The team evaluated the hardware and installation process for connection of the Carrier Plate and Quick Disconnect (QD) ground side assembly to the External Tank Carrier Assembly (ETCA) flight side connection. Some key contributing factors that were determined :
   - The centerline alignment between the ground side and flight side is a key factor in this interface connection.
   - This amount of misalignment is a result of the actual hardware configuration and the amount of parallelism of the two sides during the installation process.
   - The QD probe self centers in the seal early in the installation process, if the misalignment is significant between the ground and flight, the probe and seal pressure will not be uniform.
2. These factors can be corrected by dimension characterization of the hardware, positioning them to result in a “best fit” and optimizing the operations of the installation process to ensure parallelism during mate.

Recommendations

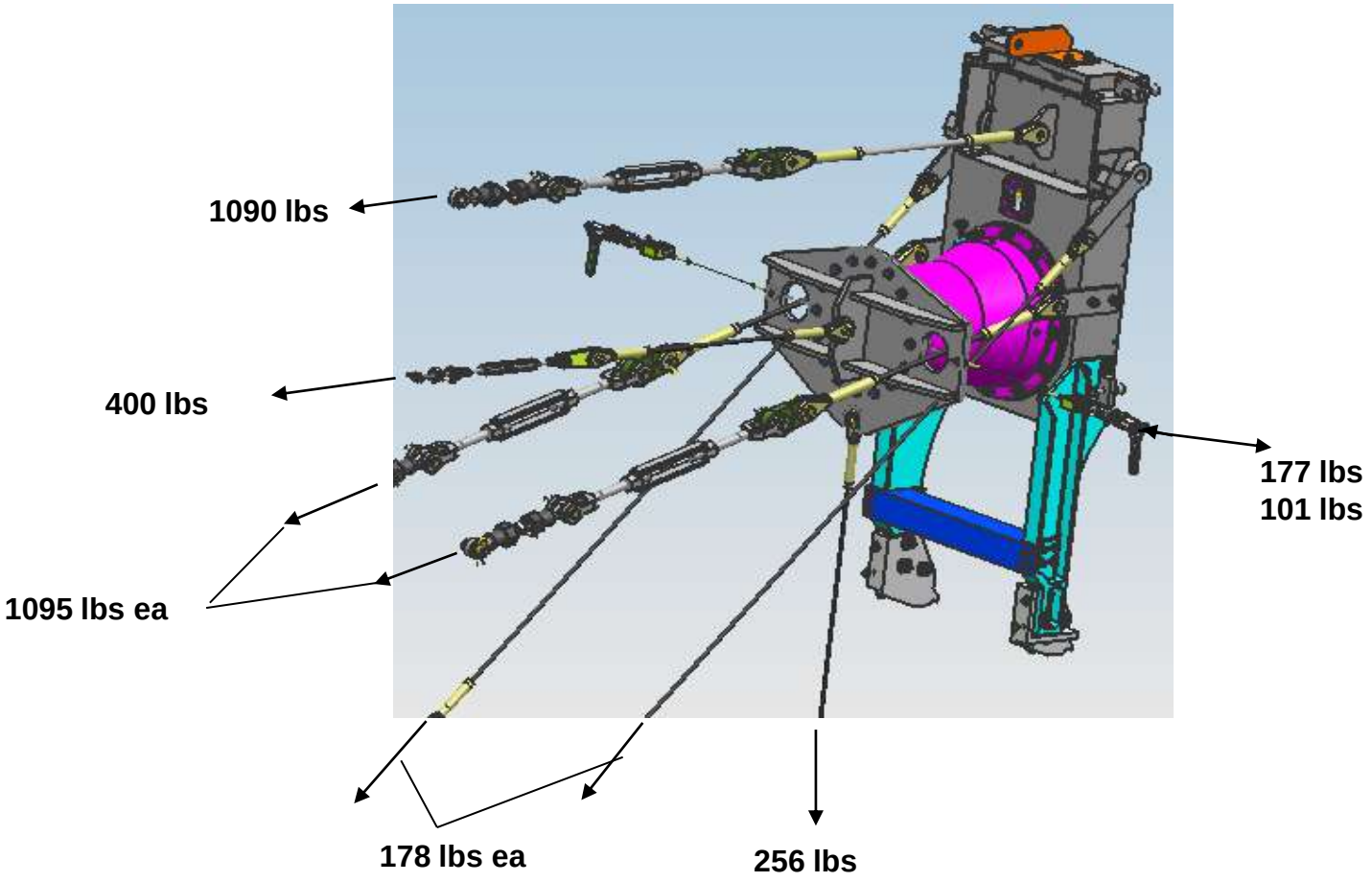
1. The Carrier Plate and QD should be chosen as a “matched pair” that are within 0.020” depending on their respective concentricity measurements relative to the ETCA Seal.
2. ‘Clocking’ of the QD should be done as needed (in 90 degree increments) relative to the ETCA Seal to optimize centerline alignment and result in a “best fit orientation”.
3. Carrier Plate feet should be able to float until QD insertion is complete to allow the components to self-center.
4. The QD installation process (OMI T-1147) should measure for parallelism every 1/16” at **all** 4 installation bolt locations.
5. Final Torque Values should be specified for the bolts that connect the QD to the carrier plate (1/6 turn too subjective).
6. This information should be entered into the NASA Lessons Learned database and be communicated to those performing future vehicle design.
7. Photogrammetry should be pursued as an investigative/analysis tool to help meet current/future KSC needs. Photogrammetry would add several advanced technology techniques to our testing capabilities. A few of its demonstrated uses so far have been to determine test article dynamic changes in position, shape, size, displacement, angles, and stress/strains.

Recommendations

7. An installation GSE bolt with a retainer clip should be considered. This fastener would help maintain parallelism during the installation process by capturing the QD flange on the inside face until QD guide pin removal.



- **Addition of Loads to QD in its installed position to determine the effects of the vent arm umbilical on the seal – probe position and engagement**

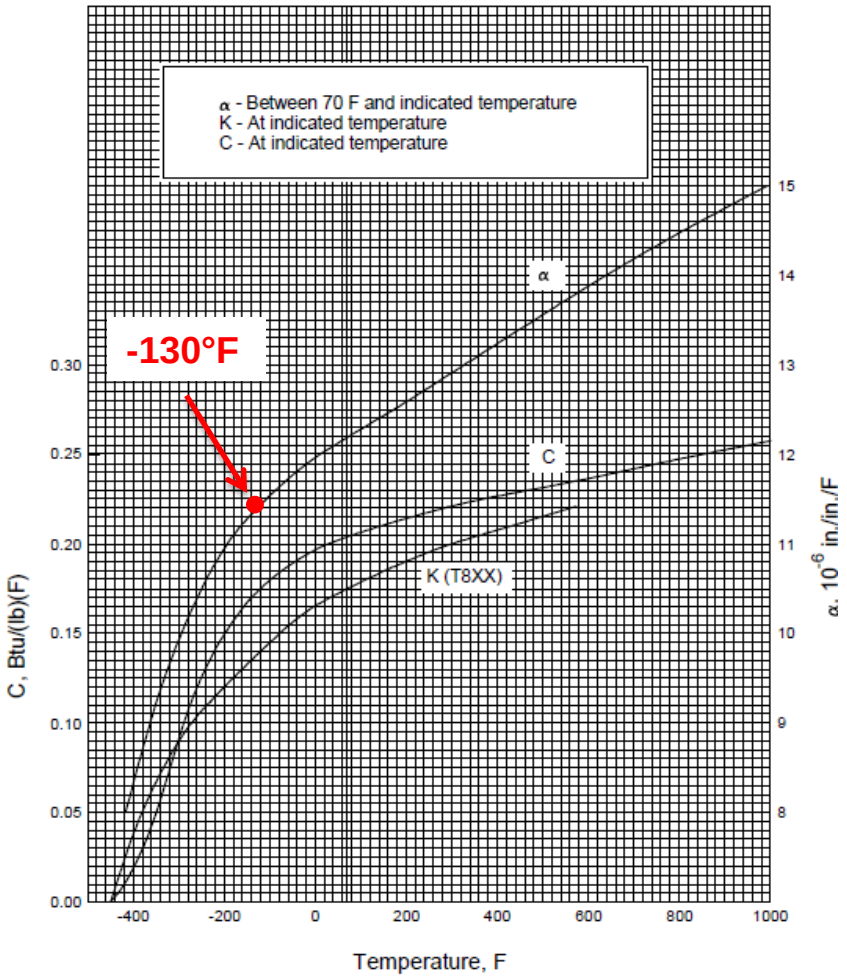


- **Addition of cryogenic conditions**

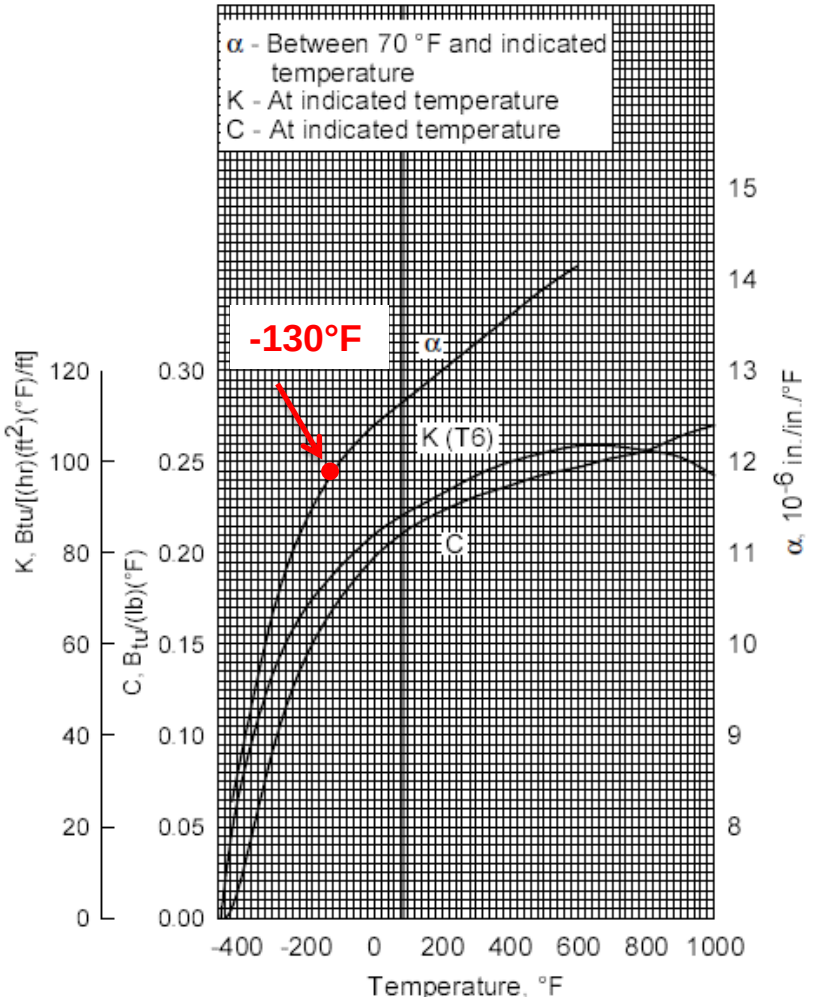
Approach: CAD Simulation and Analysis

KSC-TA-11539

2219 Aluminum Alloy



6061 Aluminum Alloy



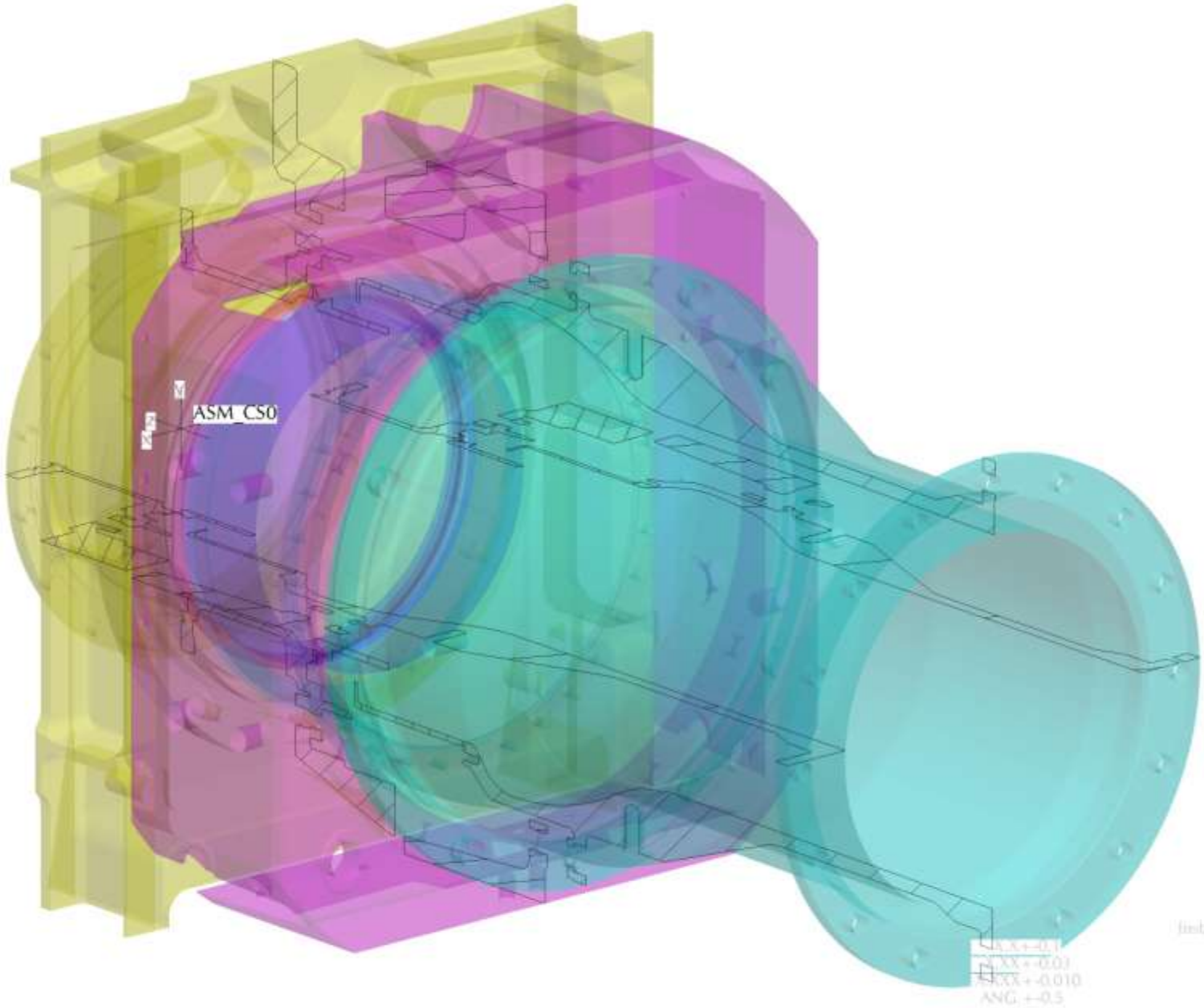
Thermal Coefficient of Expansion at -130°F is in transition region!

Backup

- **Photogrammetry Animation**

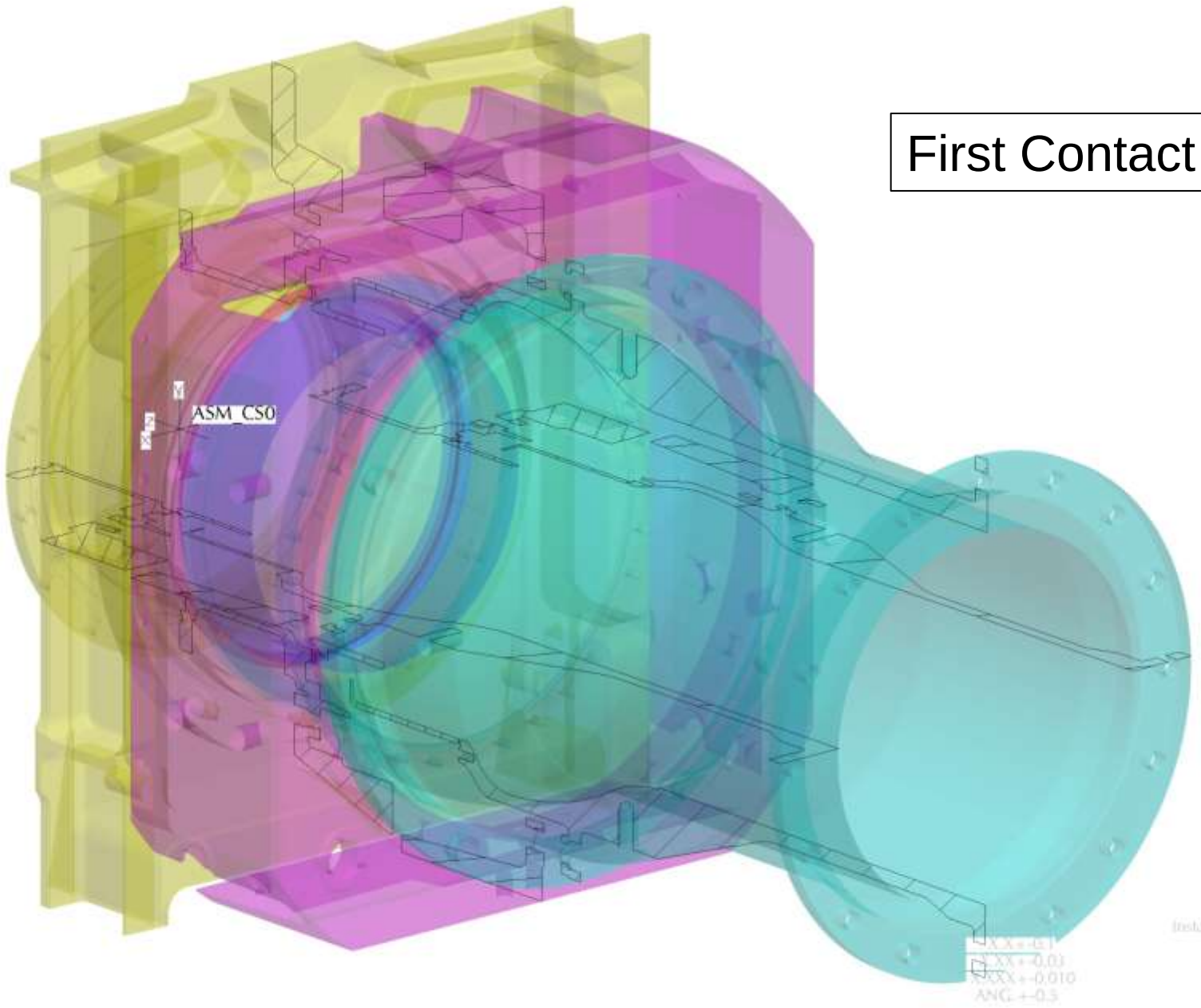
Test 14 – 11/16 Prior to Contact

KSC-TA-11539

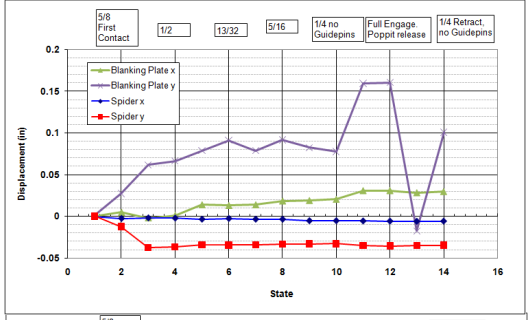


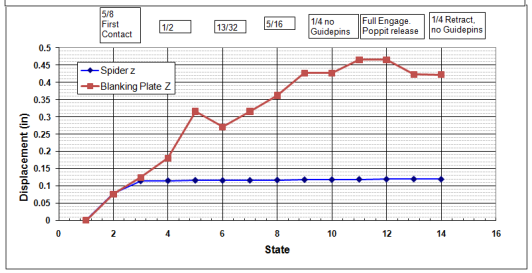
Test 14 – 5/8

KSC-TA-11539



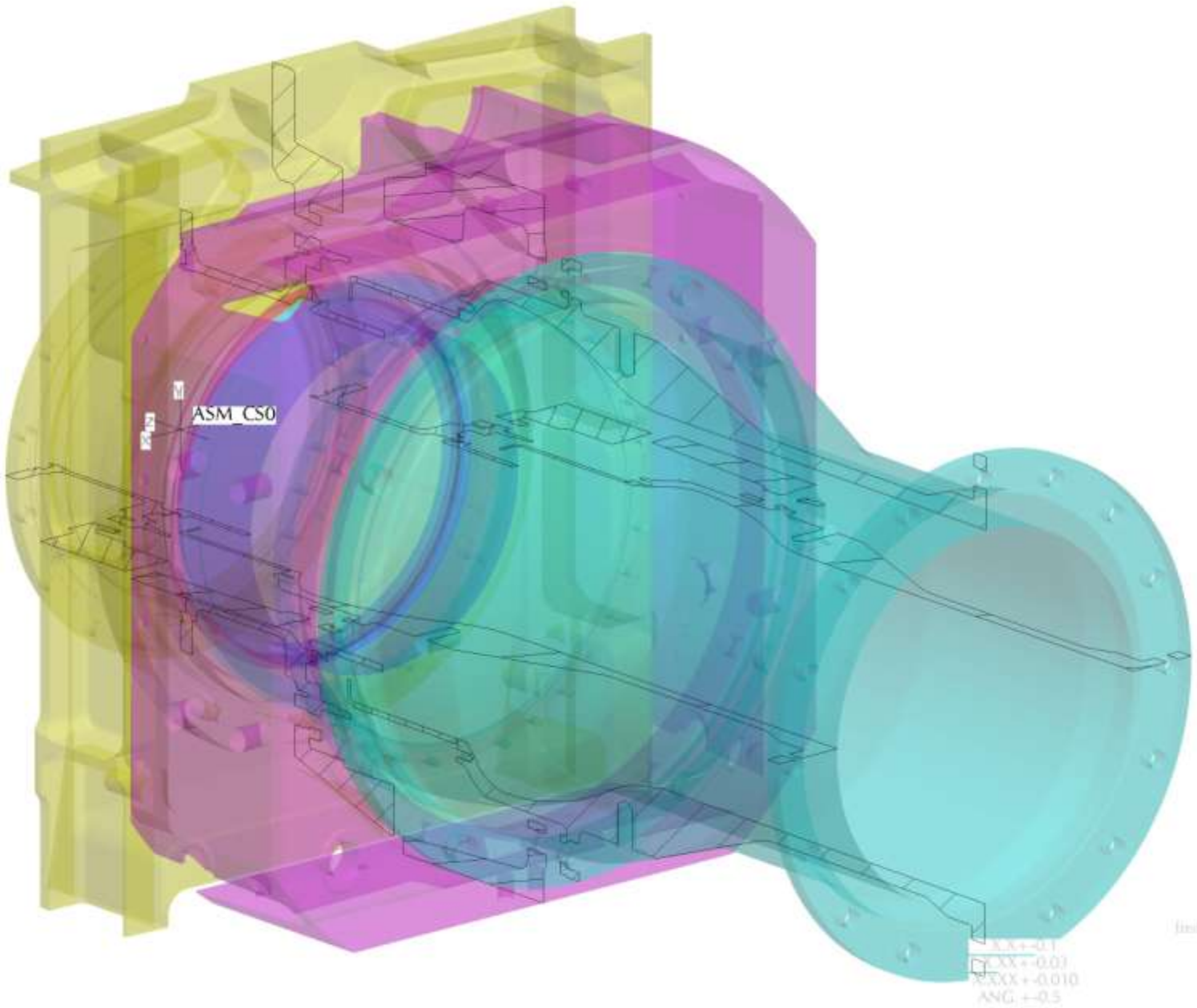
Test 14 – 9/16 Bellows Compression





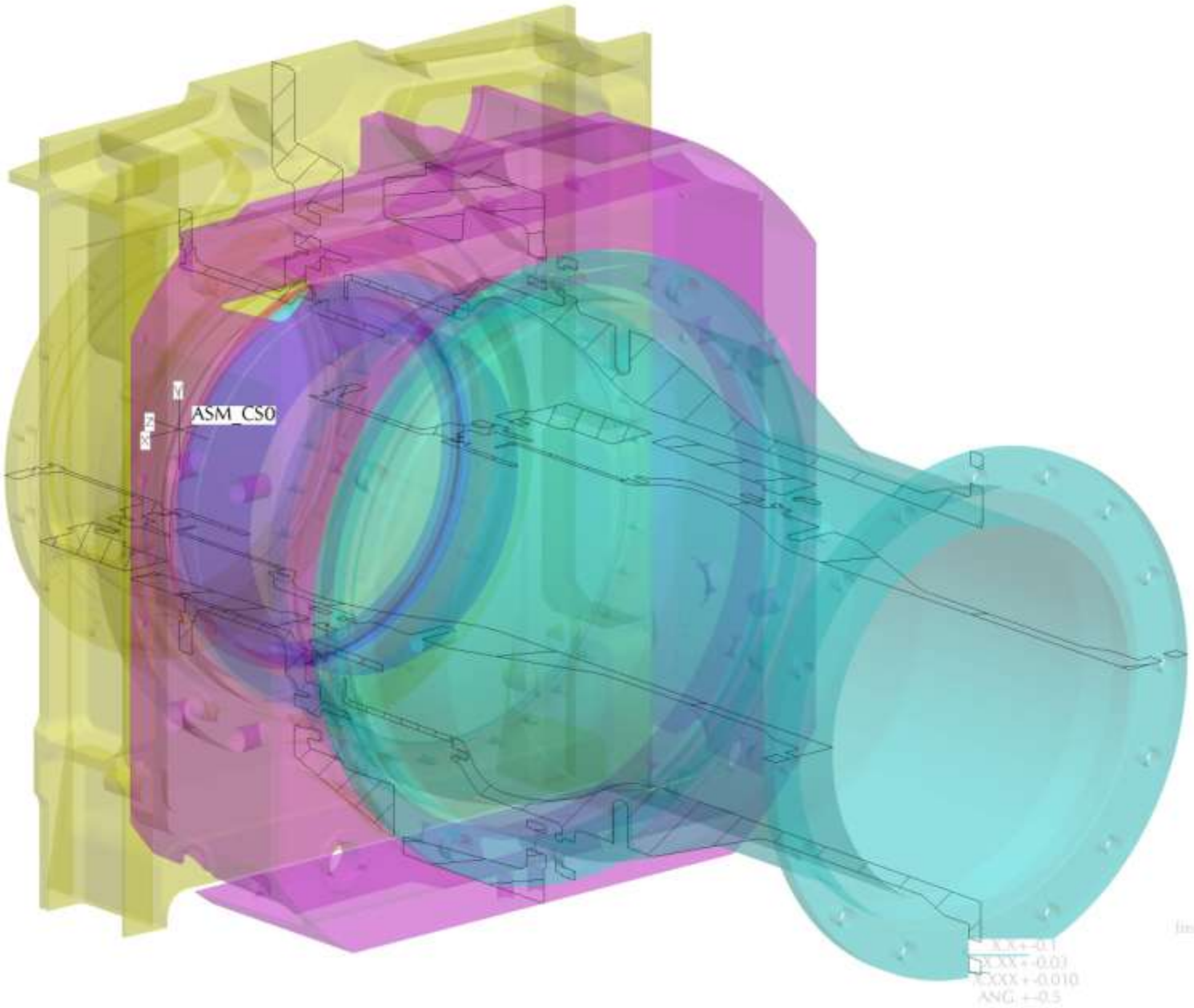
Test 14 – 1/2

KSC-TA-11539



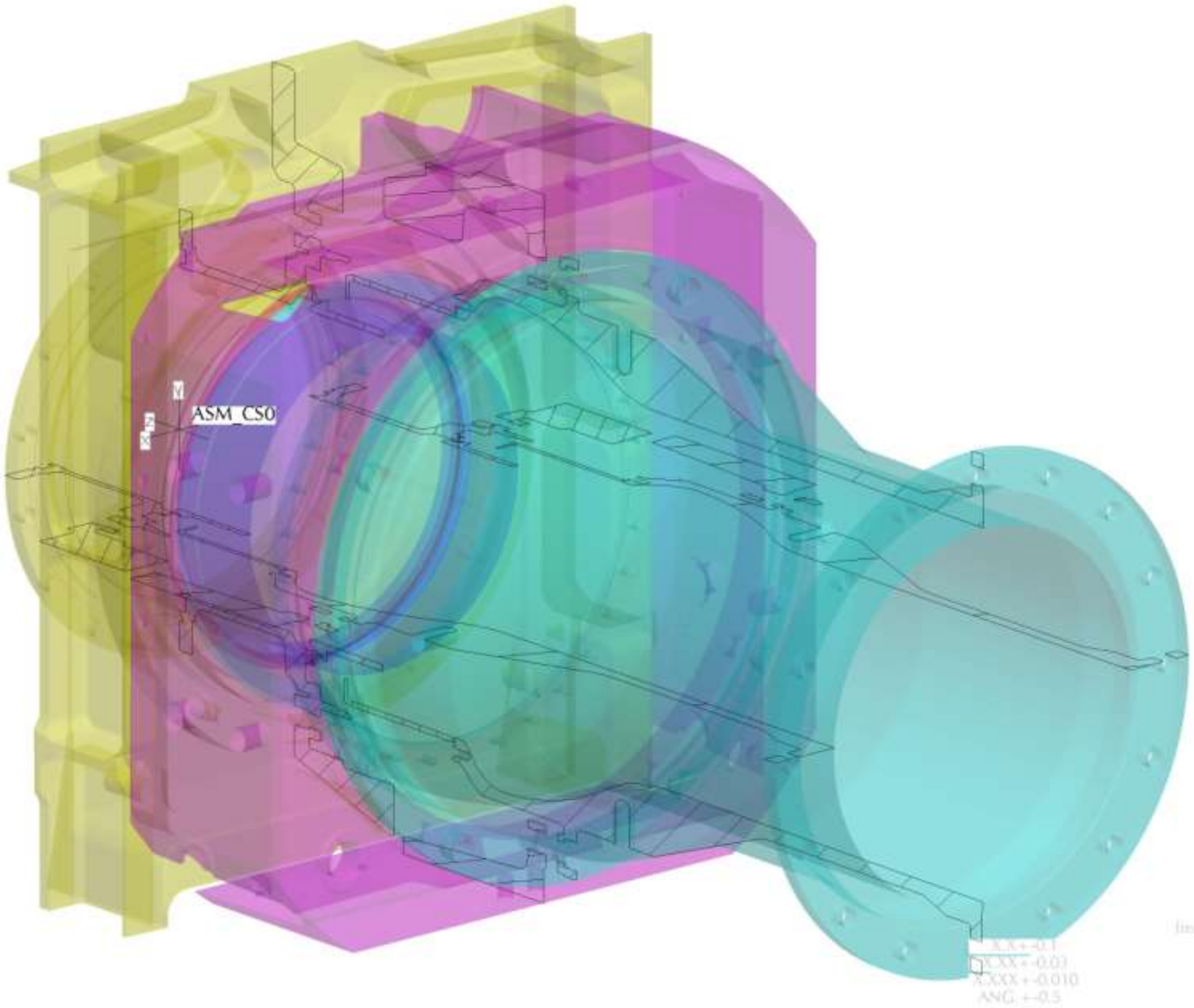
Test 14 – 15/32

KSC-TA-11539



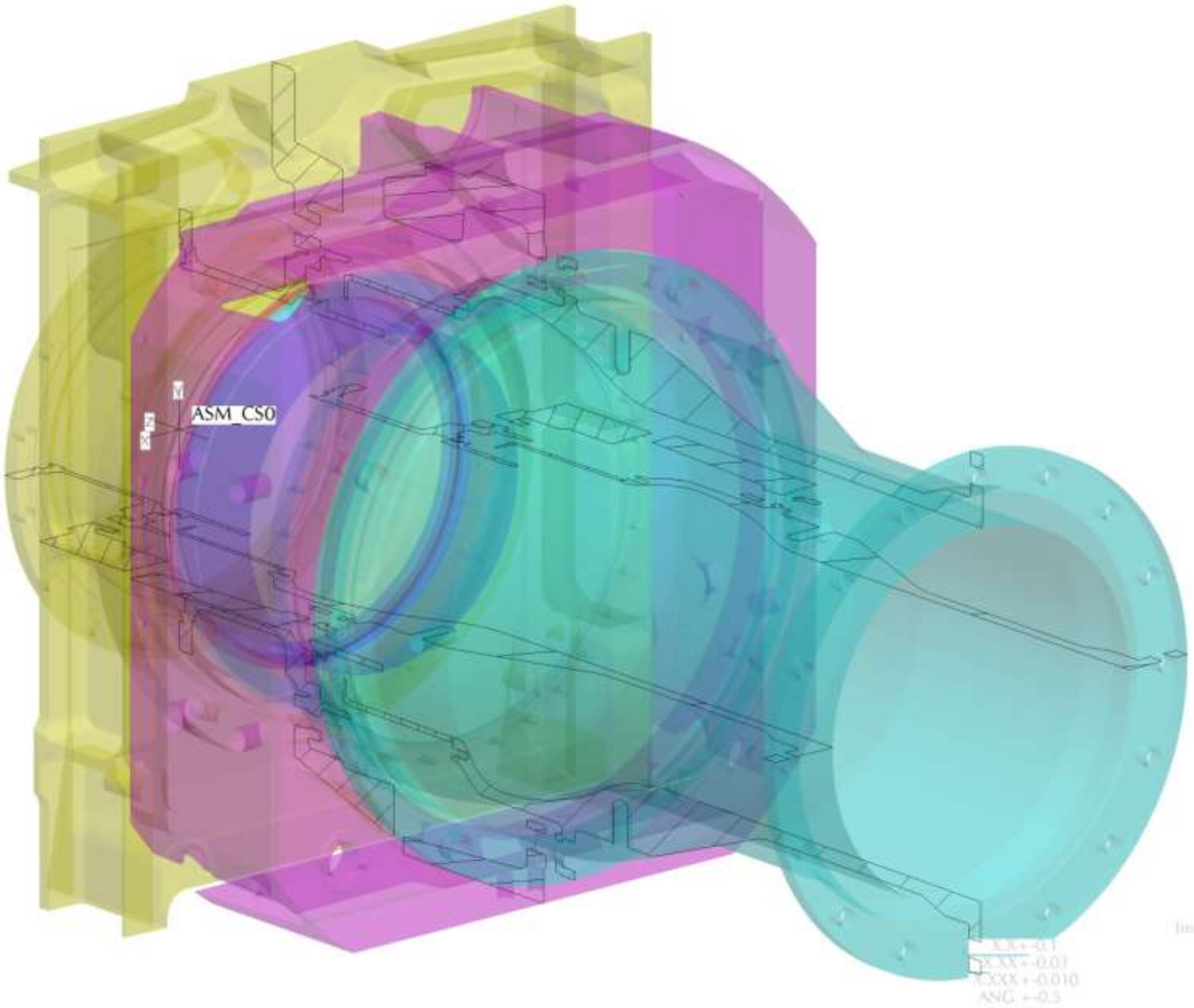
Test 14 – 13/32

KSC-TA-11539

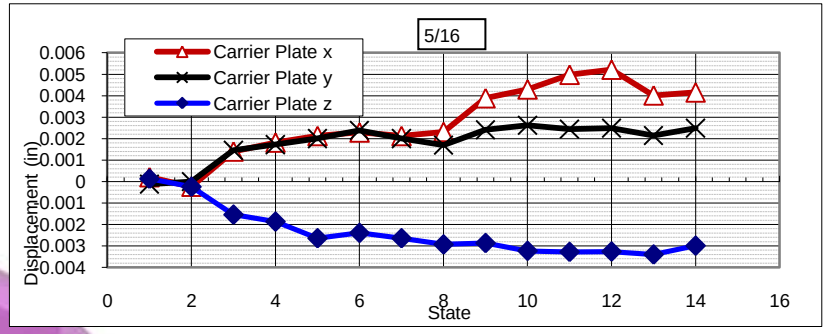


Test 14 – 3/8

KSC-TA-11539



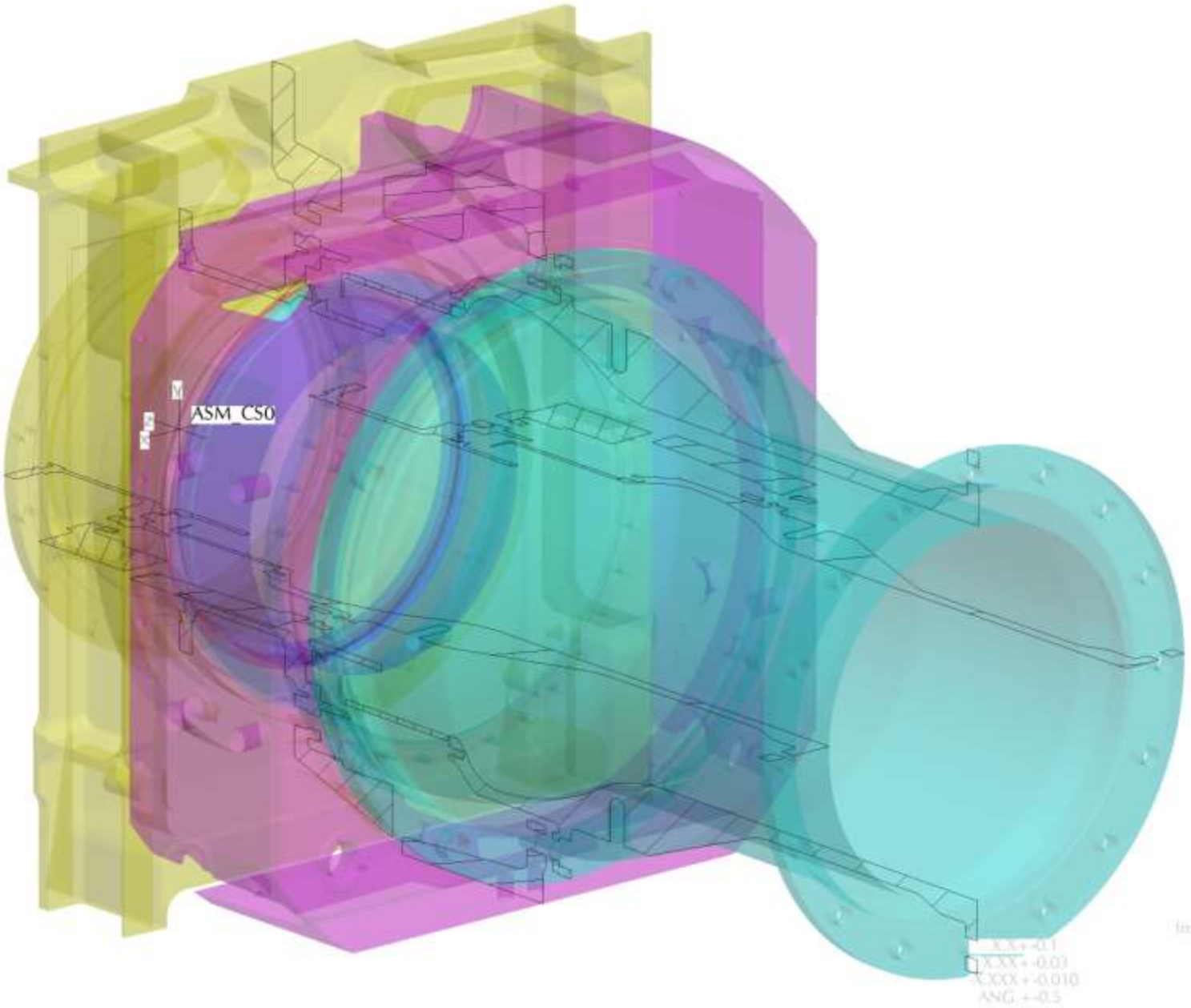
Test 14 – 5/16



CARRIER PLATE MOTION

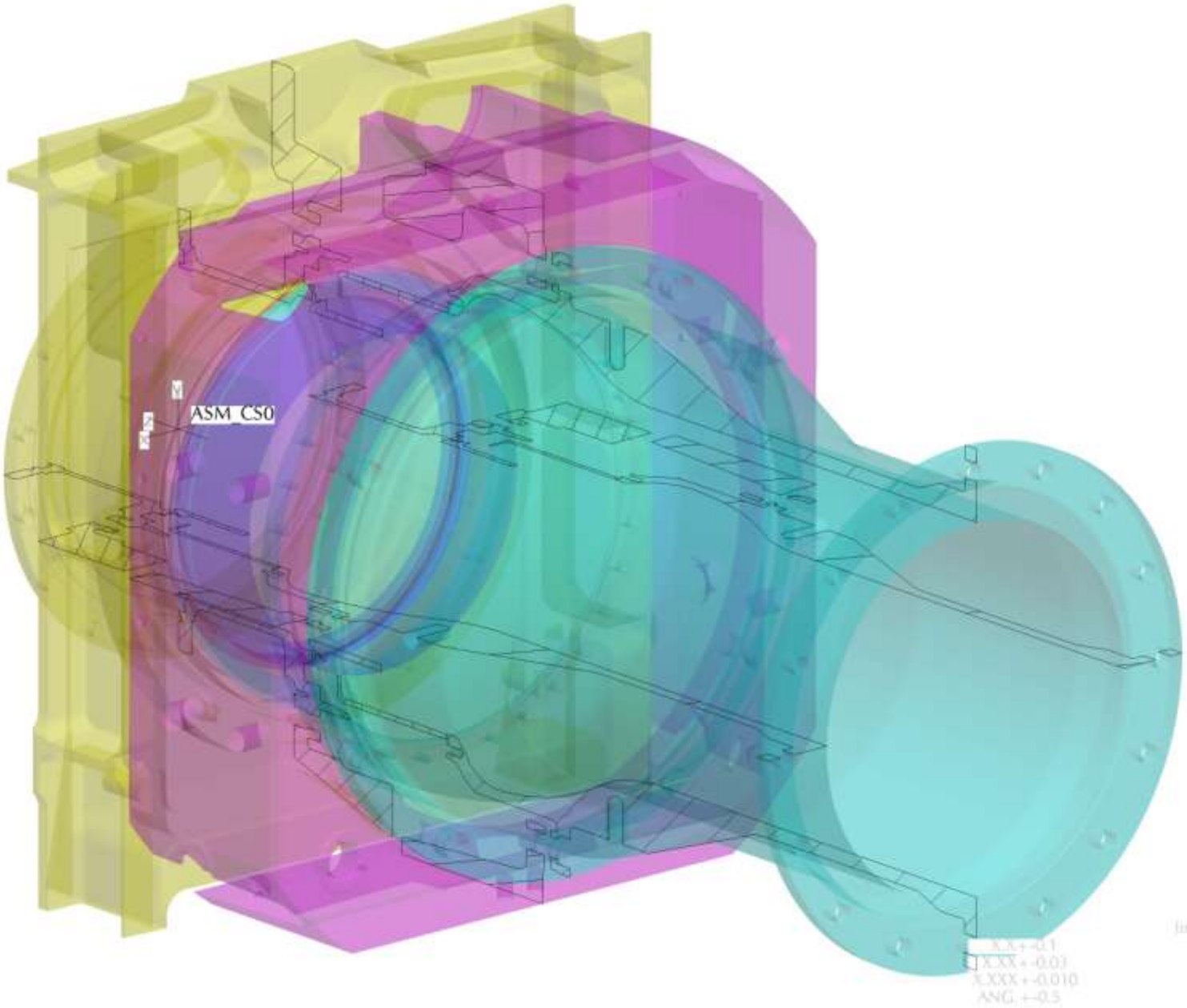
Test 14 – 1/4 Guide Pins Installed

KSC-TA-11539



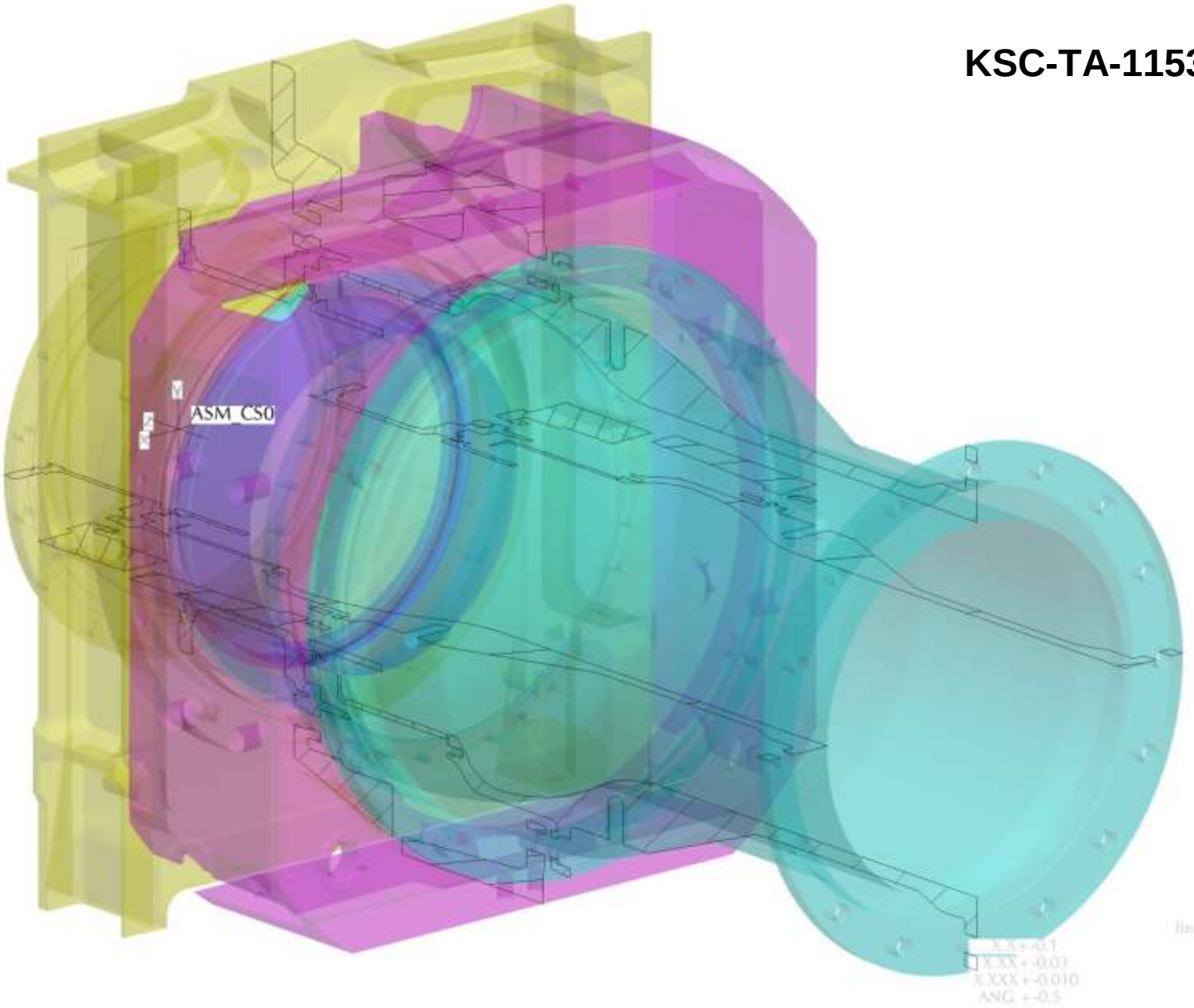
Test 14 – 1/4 Guide Pins Removed

KSC-TA-11539



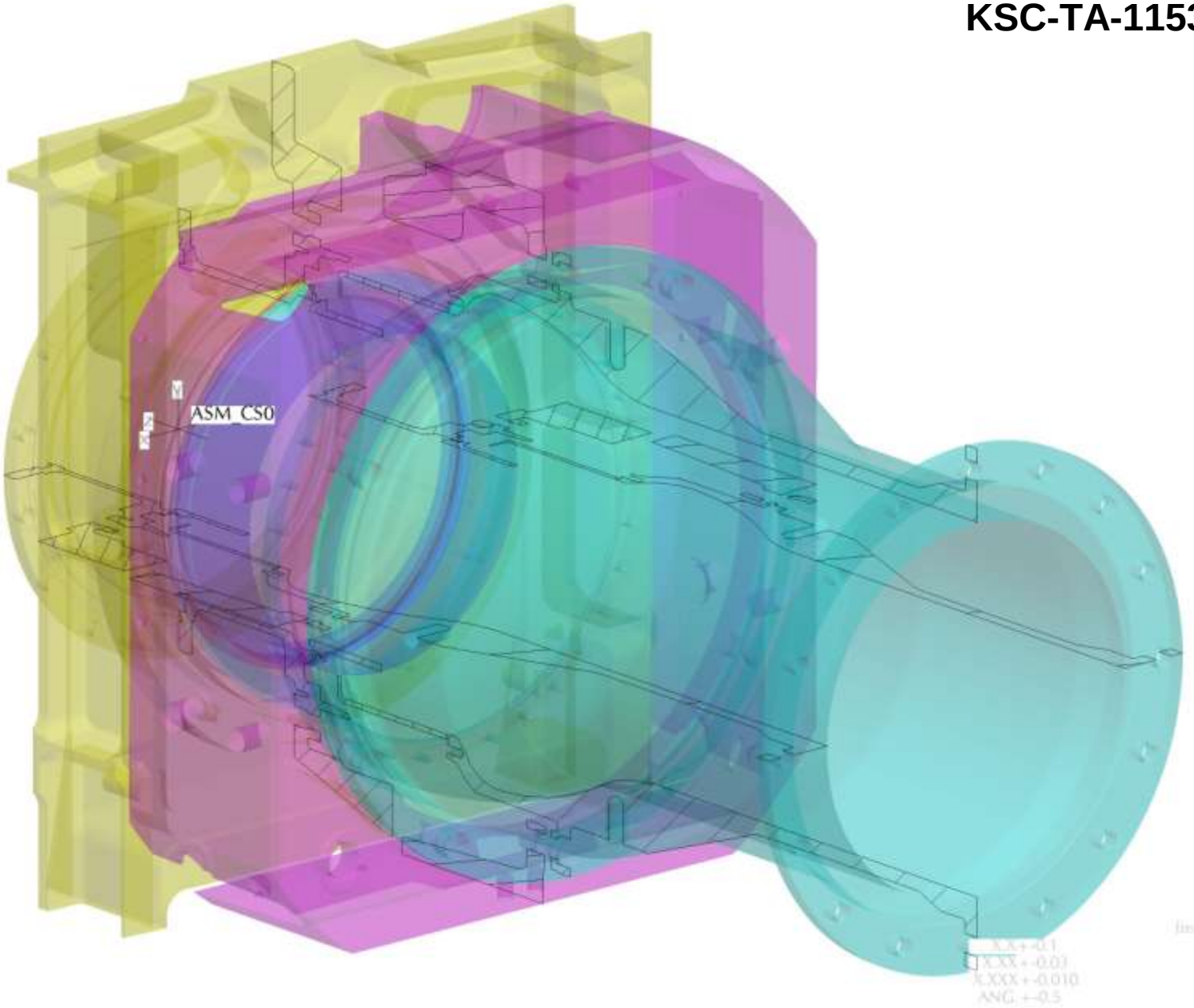
Test 14 – Fully Engaged, Poppet Retracted

KSC-TA-11539



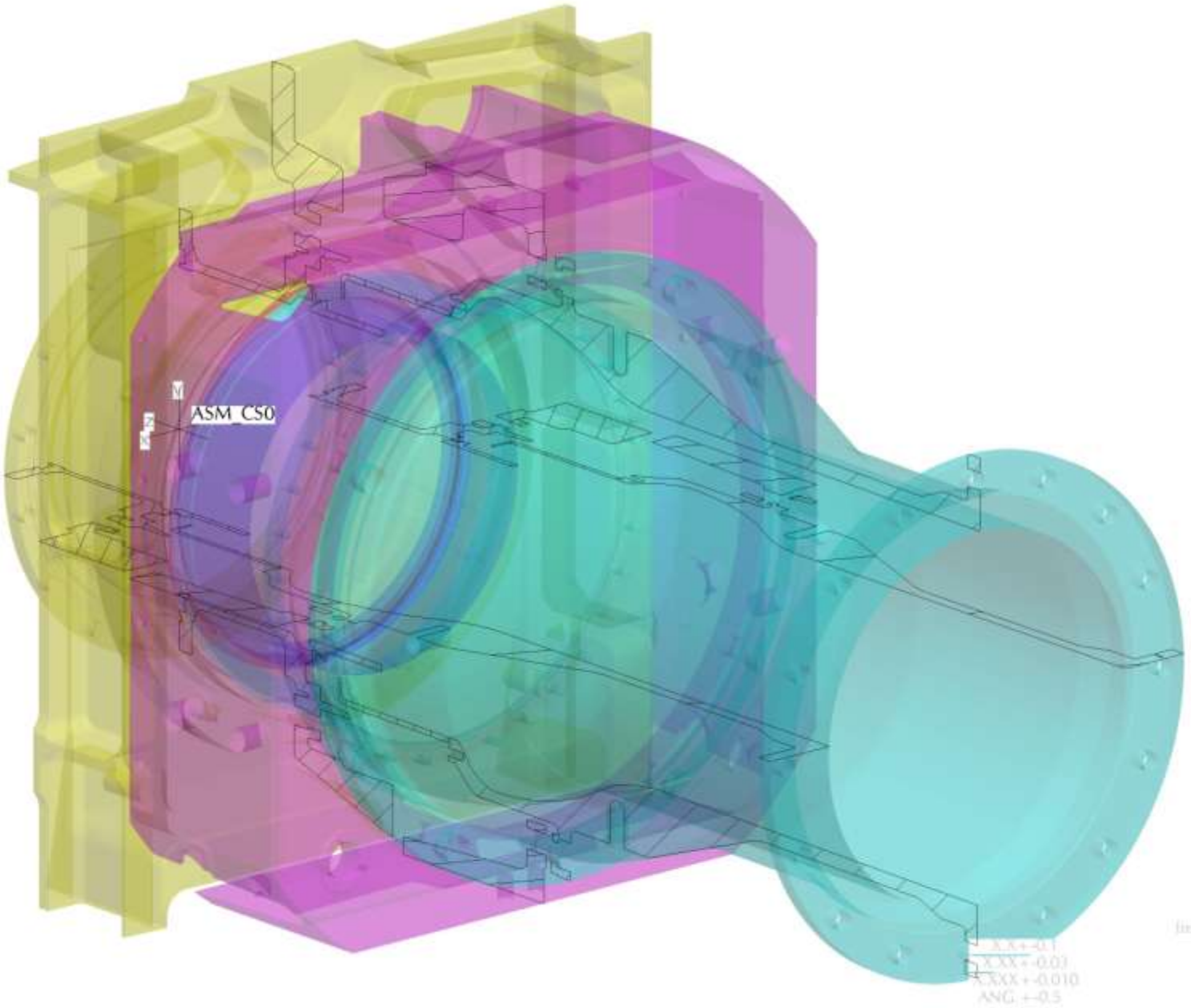
Test 14 – Full Engage, Poppet Released

KSC-TA-11539



Test 14 – 1/4 Retract, No Guide Pins

KSC-TA-11539



Test 14 – 1/4 Retract, Guide Pins

KSC-TA-11539