GUCA GH2 Leak Investigation White Paper

STS-119, 127, & 133

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Executive Summary

In obtaining a successful mate of the GUCA (Ground Umbilical Carrier Assembly) QD (Quick Disconnect) to the External Tank Carrier Assembly (ETCA), the following factors play key roles:

- GUCP (Ground Umbilical Carrier Plate) concentricity
- QD probe/flange concentricity
- 2 Piece Seal
- GUCA QD's Inconel Bellows
- Vent Line Loads
- ETCA flight carrier plate alignment
- Hinge Support Brackets Alignment
- Pyrotechnic Bolt

Of these 8 factors, the following 2 factors can be adjusted within limitations

- GUCP concentricity
- QD probe/flange concentricity

The first GH_2 leak occurred on March 11, 2009 during the STS-119/ET-127 cryogenic loading for flight and was repaired with a "fix-to-fly" approach by replacing the flight seal and GUCA QD. There was no time spent at the Pad prior to the repair on any detailed forensics to determine the cause. An Anomaly Resolution team was assembled after the launch to determine the long term approach.

The following mission, STS-125/ET-130, was loaded without a GH_2 leak. The preemptive replacement of the flight seal and GUCA QD were the only major measures taken prior to the cryogenic loading for flight.

During the subsequent mission, STS-127/ET-131, the team had challenges with the installation of the GUCP. The team had to remove the initial GUCP and install a second one with a modified right hand pivot assembly that had 0.100" shaved from its outboard side. The cause for the alignment adjustment was found to be due to an out-of-family installation of the ETCA foot brackets. The remaining External Tanks at Michoud Assembly Facility (MAF) were measured to determine what will need to be done to facilitate the subsequent GUCP installations at Kennedy Space Center (KSC).

The second series of GH_2 leaks occurred on June 12th and 16th, 2009 during the STS-127/ET-131 cryogenic loadings for flight. The first scrub was addressed like STS-119 with the addition of adjustments made to both pivot assemblies. The modified right hand pivot assembly had an additional 0.025" shim added and the left hand pivot assembly had 0.100" shaved from its inboard side. Unfortunately the second launch attempt was scrubbed due to GH_2 leak and the STS-119 Anomaly Resolution Team was augmented and was allowed to perform detailed forensics to reach a resolution.

Detailed disassembly plan was developed to methodically determine the root cause. Step by step dimensions were taken as well as strain gage and LVDT measurements. Borescope inspections and Optics (via Faro Arm) measurements were performed to record configuration and changes during the

disassembly process. As a result of the disassembly and knowledge gained from the STS-119 Anomaly Resolution Team's ongoing investigation the following enhancements were implemented:

- Concentricity tool – Verifies proper alignment of the GUCP
- Higher Tolerance Alignment pins (0.485" to 0.518" dia) – Verifies concentricity is maintained
- Manufactured customized Pivot Assembly Feet to ET-131 geometry
- Installed washers on the Pivot Assembly Pins to limit movement
- Replace the current one-piece flight seal with a two-piece seal
    - Improves system compliance
    - Previously used on STS-116 and 117

On 7/1/09, a Tanking Test was performed and the GUCA performed nominally with essentially no leakage detected (~50 ppm, which is the bottom of the detectability limit for HUMS). The GUCA configuration was not disturbed prior to subsequent launch attempts. GUCA performed nominally with again essentially no leakage (~50 ppm) during the next 3 cryogenic loadings and launch:

- 7/12/09 Attempt (Scrubbed due to weather)
- 7/13/09 Attempt (Scrubbed due to weather)
- 7/15/09 Launch

The GUCA performed nominally for the next 8 cryogenic loadings which encompassed missions STS-128 through STS-132 (ET-132 through ET-136, respectively). During STS-130 (ET-134) and STS-132 (ET-136), used pivot assemblies that were or had to be modified as follows:

- STS-130
    - LH Pivot Assembly was shaved 0.100" from the outboard side
    - RH Pivot Assembly that was shaved 0.100" from the outboard side
        - Previously used on STS-127/ET-131
- STS-132
    - LH Pivot Assembly that was shaved 0.100" from the outboard side
        - Previously used on STS-130/ET-134

The third flow to experience a GH_2 leak occurred on November 5, 2010 during the STS-133/ET-137 cryogenic loading for flight. Ground Umbilical Carrier Plate (GUCP) Investigation Team was reconvened and a detailed disassembly of the Ground Umbilical Carrier Assembly (GUCA) and Vent Line Assembly was performed. No anomalies were observed in the vent line assembly. However the team did observe that the GUCP had shifted since the final measurements taken prior to S0007. The plate was originally offset (0.049") to the 8 o'clock position and had shifted an additional amount toward the 7 to 8 o'clock position. The first post disassembly concentricity value was 0.061" to the 8 o'clock position. After the GUCA QD was removed, it was measured via FARO arm and found that its probe had an offset of 0.024" to the 6 o'clock position as compared to the QD flange center.

GH_2 vent system being composed of numerous components (flight & ground) combined together on STS-133 to provide a tolerance stack-up towards the 7-8 o'clock position

- GUCP to ETCA Concentricity

- GUCP to QD Concentricity
- ETVAS static loading

Previous GUCP investigations have uncovered tendency for the Pad A ground GH2 vent line loads to affect carrier plate position by pulling the plate towards the 7-8 o'clock. In addition, the previously unaccounted for variable of QD concentricity discovered during STS-133 GUCP leak investigation is a significant factor in providing a concentric mate. The clocking of the GUCA QD prior to installation uses this variable to our advantage. The team now clocks the GUCA QD in reference to the GUCP concentricity to achieve an alignment as close to the ETCA QD center as possible.

Off-line testing was performed on an ETCA/GUCP Mock-up in the VAB using similar equipment and procedures which validated the premise of clocking the GUCA QD to optimize its probe offset (Ref – Space Shuttle External Tank Hydrogen Vent System: Ground Umbilical Carrier Plate to Hydrogen Quick Disconnect Alignment Test Plan Rev A. & KSC-TA-11539 ET Hydrogen Vent QD/GUCP Alignment Investigation Team Final Report).

By controlling the variables the team can optimize (GUCP & QD concentricity) in a manner that helps mitigate the loading (7-8 o'clock) on the assembly while providing greater compliance to the system as a whole.

The GUCA performed nominally for the rest of the program (6 loadings) which encompassed missions STS-133 through STS-135 (ET-137, ET-122, & ET-138). During STS-134 (ET-122) and STS-135 (ET-138), used pivot assemblies that were or had to be modified as follows:

- STS-134
    - RH Pivot Assembly that was shaved 0.100" from the outboard side
        - Previously used on STS-127/ET-131 and STS-130/ET-134
- STS-135
    - LH Pivot Assembly that was shaved 0.100" from the outboard side
        - Previously used on STS-130/ET-134 and STS-132/ET-136
    - RH Pivot Assembly was shaved 0.100" from the inboard side

GUCA Processing Summary Since STS-119/ET-127

STS-119/ET-127

On March 11, 2009 GH2 leakage at GUCA during topping portion of loading resulted in LCC violation/scrub (>40,000 ppm, calculated to ~61,000 ppm). IPR 119V-0070 (PR SS20-1-0106) was initiated. The same QD/seal design was used for 31 loadings with one previous leak within LCC requirements (13,500 ppm, STS-120/ET-120). The vent line was demated to allow the suspect GUCA QD (s/n 3) and the one-piece flight seal to be removed. There were no off-nominal conditions noted during the removal of the QD. However, the flight seal from leaking assembly had two nicks and a greater than expected depressed area between the 5 and 7 o'clock position. No correlative data is available to quantify the level of leakage to the amount of seal imperfections. The rolled edge (depressed area) is an indicator of misalignment and asymmetric loading on the seal. The cause of the nicks was indeterminable. Experience has shown that seals with similar nicks would not have experienced any leakage.

The replacement GUCA QD (s/n 4) which was ready for installation was torn down and meticulously rebuilt with new seals. The QD rebuilt was performed to re-baseline the assembly and verify optimum hardware for launch support. A new one-piece flight seal was installed and torque to a revised method to help support a quicker scrub turnaround (3 Hour/3 Hour re-torque vs.12 Hour re-torque). The replacement GUCA QD (s/n 4) was installed and the vent line connected.

On March 15, 2009 the GUCA performed nominally during S0007 and supported a successful launch.

STS-125/ET-130

There were no issues noted during the mating of the GUCP (s/n 6) to ET-130. As a precaution, in the VAB, the GUCA QD (s/n 6), which was installed on Dec. 18, 2008, was removed on March 18, 2009 and the one-piece flight seal which was installed for 3 months was replaced. The replacement one-piece flight seal was hand-picked from available stock due to barely visible fibers.

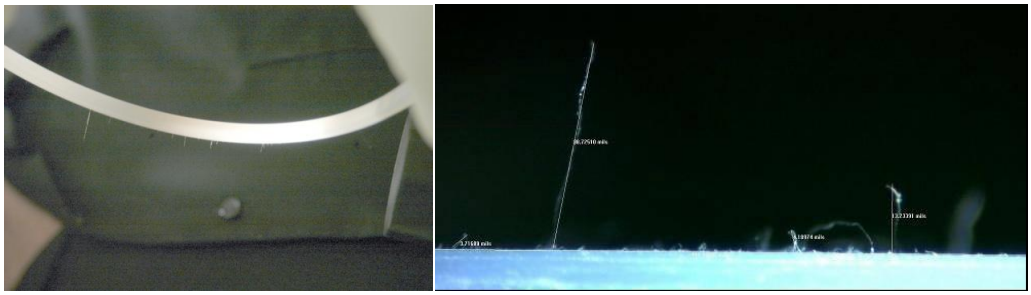
During ET-130 flight seal change-out, barely visible fibers were noted on the flight seals. USA Materials and Process Laboratory performed a detailed analysis (Ref. – IL MSZ-008-09MP). Three seals were analyzed:

- ET-127/STS-119 removed seal involved in GH2 leak
- ET-130/STS-125 removed seal
- Spare seal as a control

All three seals had fibers present. The fibers had an approximate thickness range of 1 to 8 micrometers with most being less than 12 mils long. The fibers appeared to be relatively uniform around the circumference of the material, not favoring one side of the seal over the other side on the same edge/surface. The spare seal had the most concentration of fibers. ET-127 appears to have the least amount of fibers, while the ET-130 has the most. The fibers on the Spare seal ring appeared to be longer on average than the ones on the other seals.

A review of the one-piece seal design and material was performed to assess the effect of the fiber whiskers on the sealing capability of the assembly. The actual GUCA interface seal is formed as the seal material (FEP) cold flows under the pressure of the Inconel bellows probe (225 - 370 lbf). The

amount of cold flow was estimated using the results of engineering tests performed for similar materials (Cold Flow and Creep Testing of PTFE and PCTFE Test Report" dated Feb. 4, 2002). Greater than 2% seal compression (conservative estimate) is expected due to the sealing force applied by the bellows probe. At 2% compression, the seal deflection is ~0.0034". The expected seal deflection (>10x max. observed fiber diameter) would provide sufficient relative motion to either liberate the fibers or to compress and 'flow' the fibers into the parent material. Liberated fibers pose no issue as they would be transported by the vented gases to the burn stack.



The replacement GUCA QD (s/n 8) which was ready for installation was torn down and meticulously rebuilt with new seals as a precaution as well. GUCA QD (s/n 8) was installed on March 20, 2009 while in the VAB. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad A, detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on March 31, 2009, detailed checks, measurements, and leak checks were performed again with nominal results. In addition, detailed checks and measurements were performed pre- & post-Payload installation to analyze the influence payload installations could have on the GUCA. The results showed that there were no notable changes.

On May 11, 2009 the GUCA performed nominally during S0007 and supported a successful launch.

STS-127/ET-131

During the initial installation of the GUCP in the VAB, the team had challenges aligning the GUCP due to out-of-family configuration of the ETCA and Pivot Assembly brackets. The remaining External Tanks at Michoud Assembly Facility (MAF) were measured to determine what will need to be done to facilitate the subsequent GUCP installations at Kennedy Space Center (KSC).

The initial GUCP (s/n 10) was replaced with GUCP (s/n 8) and the right hand pivot assembly had to be modified to allow the GUCP to be installed onto ET-131. Per MAF AR K09014M2, the right hand pivot foot was shaved by 0.100”. The one-piece flight seal was inspected per normal procedures and found to be discrepant, an indention was noted. As a result the flight Seal was replaced (using the last flight spare at that time). Additional one-piece seals were eventually made available.

The replacement GUCA QD (s/n 9) which was ready for installation was torn down and meticulously rebuilt with new seals and subsequently installed in the VAB on April 7, 2009. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad B for LON (Launch on Need), detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected detailed checks, measurements,

and leak checks were performed again with nominal results. Upon release of the LON requirement, disconnected the vent line and installed GUCP guide pins for transfer to Pad A. Upon arrival to Pad A, detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected detailed checks, measurements, and leak checks were performed again with nominal results.

On June 12, 2009, STS-127's first launch attempt was scrubbed due to GUCA leaking approximately 61,000 ppm.

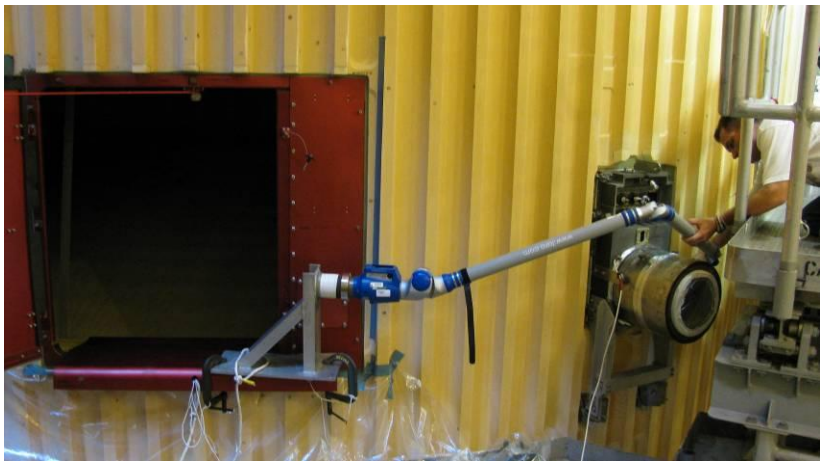
The vent line was demated and the GUCA QD (s/n 9) was removed and sent out for inspection and teardown. The inspection and the teardown of the QD did not reveal any anomalies. The GUCP (s/n 8) was realigned and the pivot assemblies were modified to allow for better alignment as follows:

- LH Pivot Assembly foot was shaved by 0.100" on the inboard side
- RH Pivot Assembly previously modified on the outboard side had a 0.025" shim installed

The replacement GUCA QD (s/n 5) was installed (QD was rebuilt per the post STS-119 inspections) and the vent line was connected.

On June 15, 2009, STS-127's second launch attempt was scrubbed due to GUCA leaking approximately 41,700 ppm

Detailed disassembly plan was developed to methodically determine the root cause. Step by step dimensions were taken as well as strain gage and LVDT measurements. Borescope inspections and Optics (via Faro Arm) measurements were performed to record configuration and changes during the disassembly process.



As a result of the disassembly and knowledge gained from the STS-119 Anomaly Resolution Team's ongoing investigation the following enhancements were implemented:

- Concentricity tool – Verifies proper alignment of the GUCP
- Higher Tolerance Alignment pins (0.485" to 0.518" dia) – Verifies concentricity is maintained
- Manufactured customized Pivot Assembly Feet to ET-131 geometry
- Installed washers on the Pivot Assembly Pins to limit movement

- Replace the current one-piece flight seal with a two-piece seal
    - Improves system compliance
    - Previously used on STS-116 and 117

The GUCA QD (s/n 5) was removed and inspected with nominal results. The QD's probe height and concentricity were verified and found to be within the specifications and experience base. The one-piece flight seal was removed and sent to MAF for analysis. The results were similar to previous analysis done on flight seals that experienced leakage. It was decided to installed the two-piece flight seal which was previously used on STS-116 and STS-117. The use of the two-piece flight seal was to improve the compliance in the GUCA and vent line systems to the normal excursions experienced during processing and loading.

The team developed a concentricity tool that attached to the flight seal retainer's bolt holes when the flight seal and retainer are not installed. The tool facilitated the optimization of the installation of the GUCP by measuring the GUCP's concentricity to the ETCA QD. In addition, higher tolerance GUCP alignment pins were manufactured that replaced the single dimensioned pins (0.485" dia) with a range of pins (0.485" to 0.518" dia). The higher tolerance pins assisted in verifying that the GUCP to ETCA QD concentricity was maintained throughout the processing of the GUCA. Using the higher tolerance alignment pins and the concentricity tool, the GUCP (s/n 8) was realigned.

Once the GUCP was aligned it was determined that the standard pivot assemblies or the modified pivot assemblies were not able to be used due to the positioning of the ETCA hinge brackets on ET-131. Therefore, customized pivot assembly feet had to be manufactured. Additionally, the installation of washers onto the ETCA hinge brackets to limit the movement of the pivot assembly feet was incorporated. Thus the customized pivot assembly feet along with washers on the hinge brackets were installed. The measurements of the GUCP verified concentric alignment and GUCA QD (s/n 5) was reinstalled. Post QD mate measurements of the GUCP verified concentric alignment was maintained and the vent line was connected. The final detailed checks, measurements, and leak checks were performed with nominal results and a "go for tanking" was given.

On July 1, 2009, Tanking Test was performed and the GUCA performed nominally with essentially no leakage detected (~50 ppm, which is the bottom of the detectability limit for HUMS). The GUCA configuration was not disturbed prior to subsequent launch attempts.

GUCA performed nominally with essentially no leakage during the next 3 cryogenic loadings:

- July 12, 2009 Attempt (Scrubbed due to weather)
- July 13, 2009 Attempt (Scrubbed due to weather)
- July 15, 2009 Launch

<u>STS-128/ET-132</u>

There were no issues noted during the mating of the GUCP (s/n 7) to ET-132 in the VAB. GUCA QD (s/n 7) which was originally installed on May 20, 2009 in the VAB was removed on July 8, 2009 to allow the replacement of the one-piece flight seal with the new 2-piece flight seal. GUCA QD (s/n 7) was installed on July 13, 2009 while in the VAB. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad A, detailed checks and measurements

were performed prior to vent line connection with nominal results. Once the vent line was connected on Aug 5, 2009, detailed checks, measurements, and leak checks were performed again with nominal results.

GUCA performed nominally with again essentially no leakage during the next 3 cryogenic loadings:

- Aug 24, 2009 Attempt (Scrubbed due to weather)
- Aug 25, 2009 Attempt (Scrubbed due to PV12 did not indicate close when going into reduced fill)
- Aug 28, 2009 Launch

STS-129/ET-133

The two-piece flight seal was replaced due to failing the pre-installation inspection. There were no issues noted during the mating of the GUCP (s/n 6) to ET-133 in the VAB.

A second generation concentricity tool was developed and used during this GUCP installation. The improved tool can be used with the flight seal and retainer installed. The tool uses the ETCA protective cover bolt holes as the attach points. The second generation tool was used for all the subsequent GUCP installations.

GUCA QD (s/n 10) was installed on Aug 18, 2009 while in the VAB. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad A, detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on Oct 15, 2009, detailed checks, measurements, and leak checks were performed again with nominal results.

On Nov 16, 2009 the GUCA performed nominally during S0007 and supported a successful launch.

STS-130/ ET-134

During the mating of the GUCP (s/n 5) to ET-134 in the VAB it was noted that both the left and right hand pivot assemblies were contacting the ETCA hinge brackets on the outboard side. Therefore, the installation used pivot assemblies that were or had to be modified as follows:

- LH Pivot Assembly was shaved 0.100” from the outboard side
- RH Pivot Assembly that was shaved 0.100” from the outboard side
    - Previously used on STS-127/ET-131

GUCA QD (s/n 5) was installed on Nov 16, 2009 while in the VAB. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad A, detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on Jan 7, 2010, detailed checks, measurements, and leak checks were performed again with nominal results.

GUCA performed nominally with again essentially no leakage during the next 2 cryogenic loadings:

- Feb 6, 2010 Attempt (Scrubbed due to weather)
- Feb 7, 2010 Launch

STS-131/ ET-135

During the mating of the GUCP (s/n 8) to ET-133 in the VAB after the initial installation of the pyrotechnic bolt assembly, the nominal parallelism and axial displacement measurements were not being achieved even though the pyrotechnic bolt was torqued to its nominal value. An engineering inspection of the alignment pins discovered that the top (0.515) guide pin was bound up. The binding was freed up and a re-check of the pyrotechnic bolt torque showed that it had dropped 35 inch pounds. Engineering made the decision to initiate a PR (ET-135-ST-0004) to remove the bolt, remove the GUCP, inspect the hardware, and perform a reinstallation taking additional measurements to assure the top pin is aligning correctly with the alignment pin hole. It was suspected that upon initial installation that the GUCP was installed at a slight angle causing the binding. All inspections of the hardware were nominal and the reinstallation was preformed with no problems. All of the axial displacement and parallelism measurements were nominal. An initial concentricity check showed the max concentric offset to be 0.044 inches and within our 0.050 requirement. Proceeded into pivot assembly gaps and washer stacks with nominal results. The guide pins were removed with no binding (all locations 0.515 inch pins) and a second set of concentricity measurements were performed. The measurements of the final max concentric offset prior to QD installation were calculated and determined to be 0.0395 inches at the 4 o'clock position.

GUCA QD (s/n 8) was installed on Jan 9, 2010 while in the VAB. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad A, detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on March 3, 2010, detailed checks, measurements, and leak checks were performed again with nominal results.

On April 4, 2010 the GUCA performed nominally during S0007 and supported a successful launch.

STS-132/ ET-136

The two-piece flight seal was replaced due to failing the pre-installation inspection. A nick was discovered that was visible and tactilely evident at the 6 o'clock position across the sealing surface.

During the mating of the GUCP (s/n 7) to ET-136 in the VAB it was noted that the left hand pivot assembly was contacting the ETCA hinge brackets on the outboard side. Therefore, the installation used a pivot assembly that was modified as follows:

- LH Pivot Assembly that was shaved 0.100" from the outboard side
    - Previously used on STS-130/ET-134

In addition, during the installation of the modified LH pivot assembly, raised metal was discovered on the ETCA hinge bracket which was subsequently removed.

GUCA QD (s/n 7) was installed on March 19, 2010 while in the VAB. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad A, detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on April 22, 2010, detailed checks, measurements, and leak checks were performed again with nominal results.

On May 14, 2010 the GUCA performed nominally during S0007 and supported a successful launch.

STS-133/ ET-137

During the installation of GUCP (s/n 2), the initial concentricity was over the requirement (was 0.0501" s/b ≤ 0.050"). An inspection was performed and second set of measurements were taken. The second set was slightly less than the first and within limits at 0.050". GUCP installation proceeded with pivot assembly adjustment and a third set of measurements were taken. The final "as installed" concentricity measurement was 0.0488" which was within the drawing limit of 0.050".

GUCA QD (s/n 4) was installed on May 19, 2010 while in the VAB. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad A, detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on Sep 21, 2010, detailed checks, measurements, and leak checks were performed again with nominal results.

On Nov 5, 2010, during reduced fast fill to topping of the LH2 tank a leak exceeding 40,000 PPM was detected on LD's 23 and 25 and IPR 133V-0068 was initiated. The Ground Umbilical Carrier Plate (GUCP) Investigation Team was reconvened and a detailed disassembly of the Ground Umbilical Carrier Assembly (GUCA) and Vent Line Assembly was performed.

No anomalies were observed in the vent line assembly. However the team did observe that the GUCP had shifted since the final measurements taken prior to S0007. The plate was originally offset (0.049") to the 8 o'clock position and had shifted an additional amount toward the 7 to 8 o'clock position. The first post disassembly concentricity value was 0.061" to the 8 o'clock position.

After the GUCA QD was removed, it was measured via FARO arm and found that its probe had an offset of 0.024" to the 6 o'clock position as compared to the QD flange center. On the probe it was observed that there was a witness mark of the flight seal. Two minor contaminations marks were also observed outside of the sealing surface. Sample were taken for analysis but were inconclusive. The GUCA QD (s/n 4) was then disassembled and inspected but no anomalies were uncovered.

As for the flight seal observations, both tactile and visual inspections were performed by three independent, experienced individuals. The inspections found some circumferential deformation at the 7 to 9 o'clock position. In addition, the gap of the seal edge to retainer ring appeared smaller at the 7 to 9 o'clock position. These observations reinforced the initial finding that the GUCP had shifted toward the 7 to 8 o'clock position.

GUCP (s/n 2) was removed and 3-D scanned. The results yielded no anomalies and the plate met all drawing requirements. The 3-D data that was gathered was used in some later modeling effort.

Flight seal was removed and sent to the KSC lab for analysis (ref. – KSC-MSL-20 10-0349). Chemical and Nondestructive examination revealed no anomalies that would have contributed to the leak.

- Magnified visual inspection of both pieces of the flight seal (PTFE and Spring) revealed no anomalies
- Chemical analysis of the wipes taken during tactile examination revealed unidentifiable materials that were organic in nature. Debris analysis from the seal removal revealed a

variety of small metallic and organic particles. Analysis of the swabs taken from the QD thin film did not indicate the presence of organic constituents. After a review of these results with the engineering team, none were determined to be contributory to the leak.

- Dimensional analysis of the PTFE jacket found one minor dimension to be slightly undersized. Analysis of the metallic spring found its outer thickness to be slightly undersized. Additional analysis determined this observation to be consistent around the spring, indicating that the spring was not out-of-round. The engineering team reviewed these results and determined all observations to be insignificant.

Flight seal was then sent to MAF for further evaluation and possible destructive evaluation but later determined to be of little value since nothing was discovered at the KSC lab and the team had developed a leak mitigation strategy.

The flight sealing surfaces on the External Tank Carrier Assembly (ETCA) were inspected and found to have no anomalies. A new two-piece flight seal was installed.

The findings from the investigations revealed that the GUCA QD probe offset needed to be taken into account when determining the optimum system concentricity. The initial STS-133 configuration that leaked during cryogenic loading had the GUCP offset to the 7 to 8 o'clock direction and the GUCA QD offset to the 6 o'clock position which was compounded by the vent line resultant loads in the 7 to 8 o'clock direction. These offsets by themselves in the GUCP and GUCA QD would not have been detrimental if the magnitudes of the offsets were smaller. With the initial GUCP offset of 0.049" in the 8 o'clock and the GUCA QD of 0.024" in the 6 o'clock position, the resultant GUCA offset was 0.065" in the 7:20 o'clock direction. This resultant offset well exceeded the GUCP installation concentricity requirement of 0.050". As stated earlier, the vent line resultant load further exasperated the misalignment.

The decision was made not to use GUCP (s/n 2) due to its significant offset (0.049") when mated to ET137. GUCP (s/n 3) was selected since it had been previously fit-checked on ET-137 at MAF. The concentricity was 0.011" to the 9:00 o'clock position at MAF. The final installation concentricity for GUCP (s/n 3) at the Pad was 0.014 to the 9:00 o'clock position.

Two spare GUCA QD's (s/n 7 & 8) were measurement via the FARO arm and GUCA QD (s/n 8) was selected due to its probe offset of 0.025" to the 9:00 o'clock position. The GUCA QD's are able to be clocked during installation in 90 degree intervals. Therefore, to achieve the optimum resultant concentricity GUCA QD (s/n 8) was clocked 180 degrees so that the QD offset was at the 3:00 o'clock position yielding a final resultant concentricity of 0.011" to the 3:00 o'clock position

Off-line testing was performed on an ETCA/GUCP Mock-up in the VAB using similar equipment and procedures which validated the premise of clocking the GUCA QD to optimize its probe offset (Ref – Space Shuttle External Tank Hydrogen Vent System: Ground Umbilical Carrier Plate to Hydrogen Quick Disconnect Alignment Test Plan Rev A. & KSC-TA-11539 ET Hydrogen Vent QD/GUCP Alignment Investigation Team Final Report).

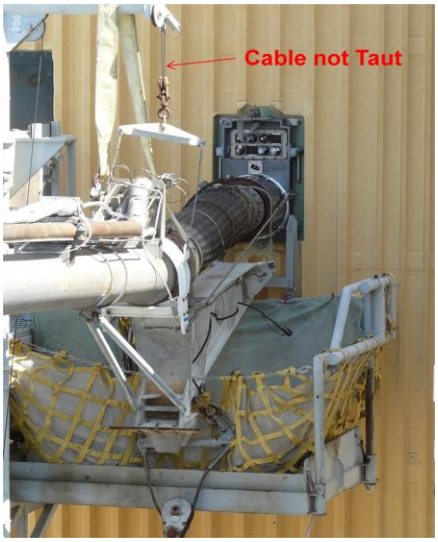
GUCA QD (s/n 8) was installed on Nov 16, 2010. Detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on Nov 16, 2010, detailed checks, measurements, and leak checks were performed again with nominal results.

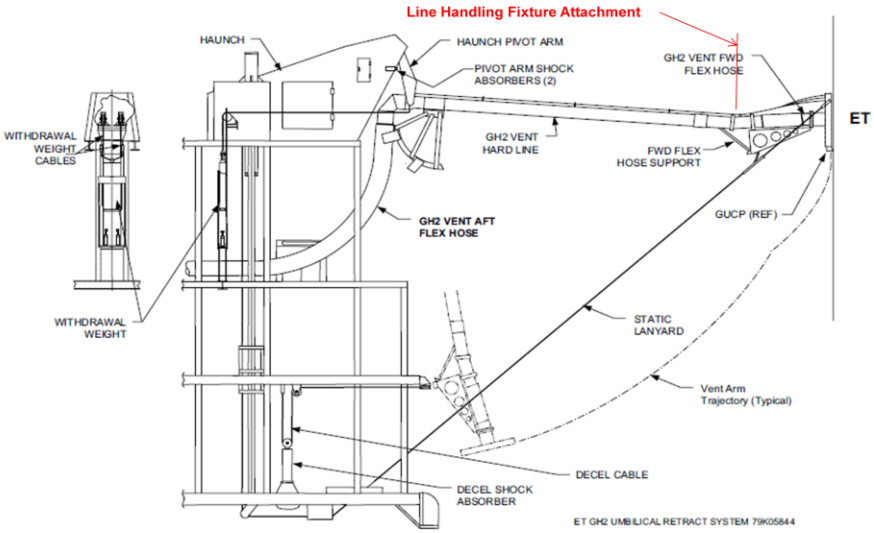
The high fidelity GUCP alignment pins were inadvertently left installed after the completion of the vent line connection measurement checks and prior to the withdrawal weight application. Subsequently the withdrawal weight was applied and GUCP measurements (Operation 500) were performed. Comparison of GUCP measurements showed that there was no movement before and after the withdrawal weight application. The guide pins threaded out without any binding before and after withdrawal weight operation. Cursory inspection of the GUCP after guide pin removal revealed no visible damage to the GUCP or ETCA. The guide pins were inspected and optically checked and verified to have no damage. A caution was added to the procedure to stress the importance and bring attention to the fact that the guide pins need to be removed prior to any vent line operations while at the Pad.

On Dec 17, 2010, Tanking Test was performed and the GUCA performed nominally with essentially no leakage detected. Photogrammetry dots were also placed on the GUCP and the surrounding TPS and were monitored during the tanking test. 2-D analysis (in plane of GUCP) of GUCP/ETCA relative motion indicated small vibrations during some vent valve cycles, with low-level baseline motion. Analysis was inconclusive as to whether motion was a potential contributor to the GH_2 leakage. Current camera views did not support 3-D analysis therefore plate separation data was unattainable.

During the initial post scrub inspections cracks in the intertank stringers at the LO_2 flange area where discovered. Repairs to the stringers were accomplished and were evaluated after the tanking test. The decision was made to rollback to the VAB in order to perform detailed NDE on all accessible intertank stringers at the LO_2 and LH_2 flange areas. As a result, the vent line was demated on Dec 20, 2010 in preparation for the vehicle to rollback to the VAB.

During the performance of the ET GH2 Vent Umbilical demate on 2nd shift on Dec 20, 2010, Swing Arms technicians immediately noticed that the vent line and line handling fixture hoist sling were lower by about 1.5 inches immediately after they had raised the withdrawal weight. Film coverage was also used that showed the Vent Line lowered 1.9-inches at the forward flex hose to hard line interface when the withdrawal weight load was removed. PADA-2980 was initiated and it was determined that the line handling fixture had slack when the withdrawal weight was raised allowing the vent line to lower until the line handling hoist wire ropes were taut. Engineering on site believed due to the small amount of movement of the vent line that no adverse loads were applied to the GUCP assembly. The withdrawal weight was lowered and line handling fixture hoist was raised and made taut. ET Mechanical/GUCP personnel came out and performed their planned checks and measurements on the GUCP and confirmed that there was no GUCP movement.

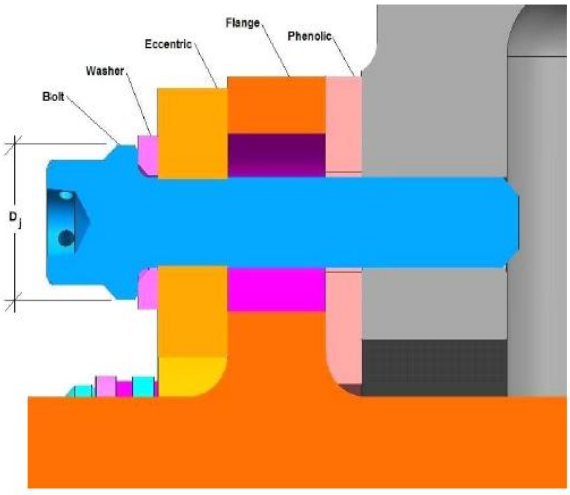




On Dec 22, 2010, OV103 rolled back to the VAB due to the ET Stringer Crack investigation. Detailed post-rollback and pre-VAB rollout checks and measurements were performed with nominal results.

On Jan 31, 2011, OV103 rolled out to Pad A. Detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on Feb 1, 2011, detailed checks, measurements, and leak checks were performed again with nominal results.

ET Project became concerned about the vent line loads that were experienced on Dec 20, 2010 when the withdrawal weight was raised while the line handling fixture wire ropes were not taut. A loads analysis was performed by USA (United Space Alliance) ground system engineering design. The analysis showed that there were no structural concerns for the GUCA and vent line assembly. However, ET Project was uncomfortable with the load experienced at the GUCA QD and GUCP interface. Lockheed Martin (LM) performed a joint analysis and came up with a factor of safety (FS_{ult}) of 1.86 which was insufficient to meet the contractual requirement of 3.00. The calculations were conservative since the coefficient of friction used was for Teflon versus phenolic and a dynamic uncertainty factor of 2.0 was applied.



GUCA QD/GUCP Interface

The decision was made to demate the vent line and GUCA QD to verify the system's integrity. On Feb 8, 2011 the vent line and GUCA QD (s/n 8) were demated to support the GUCA alignment and flight seal verifications. The measurements and inspections that were performed verified that the GUCA alignment and flight seal were not affected by the loads that were imparted.

Off-line testing was performed to determine the actual coefficient of friction for phenolic and recalculate the resultant factor of safety. The phenolic's coefficient of friction was determined to be 0.26981 versus the Teflon's coefficient of 0.04 that was used in the joint analysis by LM. Maintaining the same level of conservatism (dynamic uncertainty factor of 2.0), the corrected factor of safety was calculated to be 5.5 which is well above the contractual requirement of 3.00.

The probe offset of the GUCA QD (s/n 8) was re-measured and found to be 0.029" to the 1:30 o'clock position. The GUCP (s/n 3) concentricity was also re-measured and found to be 0.009 to the 9:00 o'clock position. Therefore the resultant concentricity was 0.025" to the 1:00 o'clock position.

GUCA QD (s/n 8) was installed on Feb 9, 2011. Detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on Feb 9, 2011, detailed checks, measurements, and leak checks were performed again with nominal results.

On Feb 24, 2011 the GUCA performed nominally during S0007 and supported a successful launch.

<u>STS-134/ ET-122</u>

During the mating of the GUCP (s/n 8) to ET-122 in the VAB it was noted that the right hand pivot assembly was contacting the ETCA hinge brackets on the outboard side. Therefore, the installation used a pivot assembly that was modified as follows:

- RH Pivot Assembly that was shaved 0.100" from the outboard side
    - Previously used on STS-127/ET-131 and STS-130/ET-134

The concentricity of GUCP (s/n 8) was then measured and found to be 0.030 to the 12:00 o'clock position. Detailed checks and measurements were performed with nominal results.

GUCA QD (s/n 10) was installed on Oct 21, 2011 while in the VAB. Detailed checks and measurements were performed with nominal results.

Due to the finding from the STS-133 GH_2 leak investigation, the GUCA QD (s/n 10) was removed on Jan 14, 2011 to measure the QD's probe offset. Upon the removal, a minor scratch was identified on the bellows probe. The scratch was lapped and the QD was deemed acceptable for installation. The QD probe offset was measured before and after the lapping operation with the following results:

- Before lapping
    - 0.005 to the 1:00 o'clock position
- After lapping
    - 0.005 to the 3:00 o'clock position

The GUCP (s/n 8) was realigned and the new concentricity was 0.032 to the 12:00 o'clock position.

In addition to GUCA QD (s/n 10), three spare GUCA QD's (s/n 3, 6 & 11) were measurement via the FARO arm and GUCA QD (s/n 6) was selected due to its probe offset of 0.025" to the 12:30 o'clock position. The GUCA QD's are able to be clocked during installation in 90 degree intervals. Therefore, to achieve the optimum resultant concentricity GUCA QD (s/n 6) was clocked 180 degrees so that the QD offset was at the 6:30 o'clock position yielding a final resultant concentricity of 0.010" to the 10:30 o'clock position.

The two-piece flight seal was replaced and GUCA QD (s/n 6) was installed on March 4, 2011 while in the VAB. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad A, detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on March 11, 2011, detailed checks, measurements, and leak checks were performed again with nominal results.

GUCA performed nominally with again essentially no leakage during the next 2 cryogenic loadings:

- April 29, 2011 Attempt (Scrubbed due to ALCA2 Failure – APU1 heaters)
- May 15, 2011 Launch

<u>STS-135/ ET-138</u>

The original installed two-piece flight seal was replaced due to failing the pre-installation inspection. A visual defect was noted on the sealing surface at the 2 o'clock position. Three additional spare flight seals were also rejected for defects on the sealing surface prior to selecting the replacement flight seal.

During the mating of the GUCP (s/n 5) to ET-138 in the VAB it was noted that the left hand pivot assembly was contacting the ETCA hinge brackets on the outboard side and right hand pivot assembly was contacting the ETCA hinge brackets on the inboard side. Therefore, the installation used pivot assemblies that were or had to be modified as follows:

- LH Pivot Assembly that was shaved 0.100" from the outboard side
    - Previously used on STS-130/ET-134 and STS-132/ET-136
- RH Pivot Assembly was shaved 0.100" from the inboard side

The concentricity of GUCP (s/n 5) was then measured and found to be 0.021 to the 4:00 o'clock position. Detailed checks and measurements were performed with nominal results.

GUCA QD (s/n 5) was installed on Aug 11, 2010 while in the VAB. Detailed checks and measurements were performed with nominal results.

Due to the finding from the STS-133 GH_2 leak investigation, the GUCA QD (s/n 5) was removed on April 4, 2011 to measure the QD's probe offset. The QD probe offset was measured as 0.036 to the 4:30 o'clock position. It is important to note that if the initial STS-135 configuration was not reverified, the resultant concentricity would have been 0.057" to the 4:20 o'clock position exceeding our initial GUCP installation concentricity requirement of ≤ 0.050".

The GUCP (s/n 5) was realigned and the new concentricity was 0.018 to the 3:00 o'clock position.

In addition to GUCA QD (s/n 5), four spare GUCA QD's (s/n 3, 8, 10 & 11) were measurement via the FARO arm and GUCA QD (s/n 8) was selected due to its probe offset of 0.015" to the 8:00 o'clock position. The GUCA QD's are able to be clocked during installation in 90 degree intervals. Therefore, to achieve the optimum resultant concentricity GUCA QD (s/n 8) was not clocked yielding a final resultant concentricity of 0.009" to the 4:45 o'clock position.

The two-piece flight seal was replaced and GUCA QD (s/n 8) was installed on April 8, 2011 while in the VAB. Detailed pre-VAB rollout checks and measurements were performed with nominal results. Upon arrival to Pad A, detailed checks and measurements were performed prior to vent line connection with nominal results. Once the vent line was connected on June 1, 2011, detailed checks, measurements, and leak checks were performed again with nominal results. In addition, the vent line bridle cables were modified and instrumented to measure the loads during Pad operations, weather events and the Tanking Test.

On June 15, 2011, the Tanking Test, which was for the Intertank Stringer evaluation, was performed and the GUCA performed nominally with essentially no leakage detected. The bridle cable data verified that all the loads were within the ICD limits.

On July 8, 2011 the GUCA performed nominally during S0007 and supported a successful launch.

Appendix A

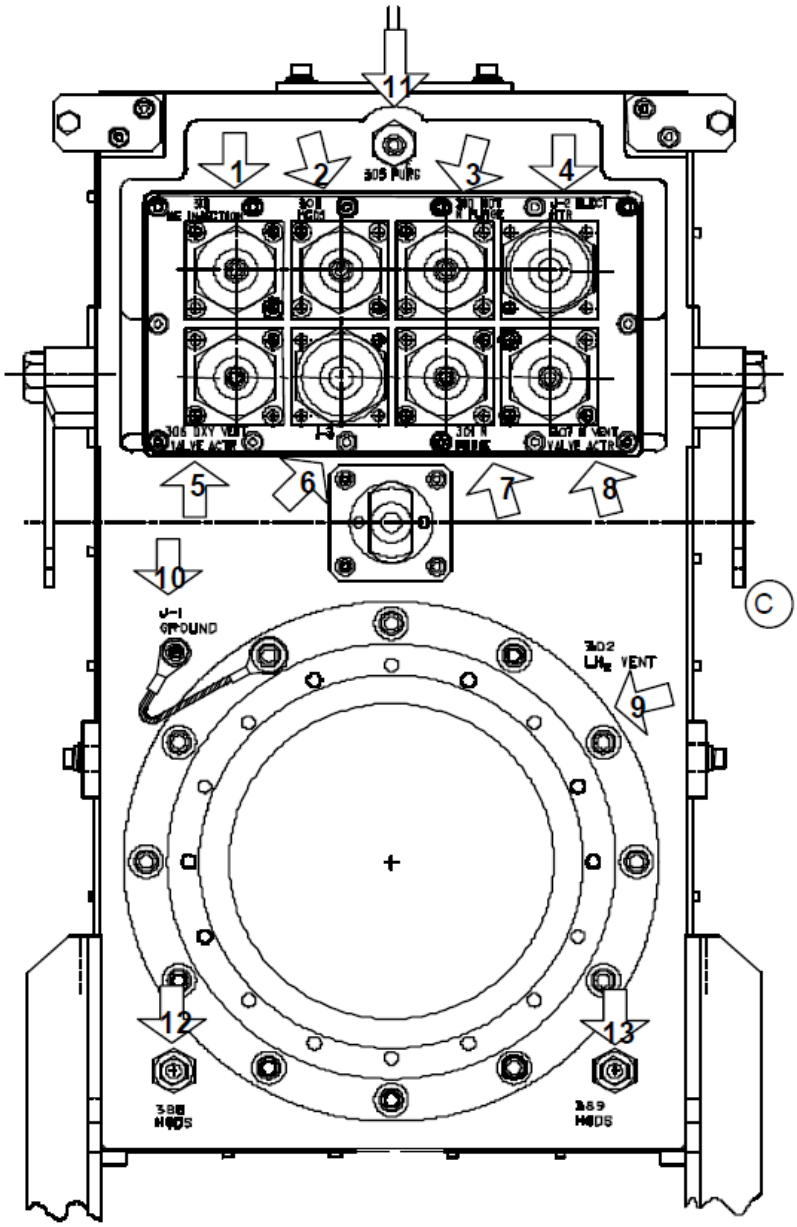
GUCA (Ground Umbilical Carrier Assembly), GH_2 Vent Line Assembly, and Associated Components and Assemblies

GUCA QD

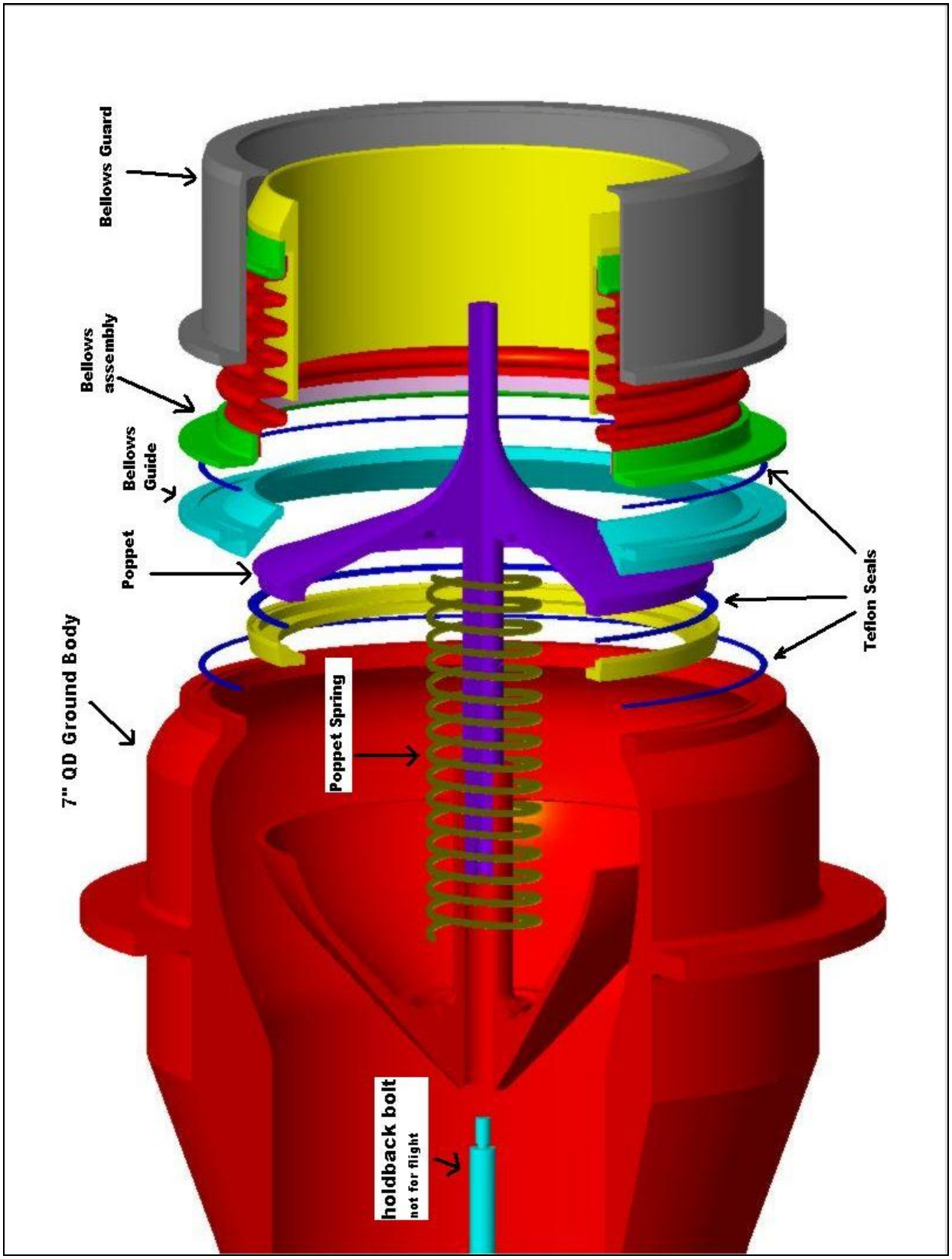
GUCP Installed

GUCA Installed

GUCA Connections

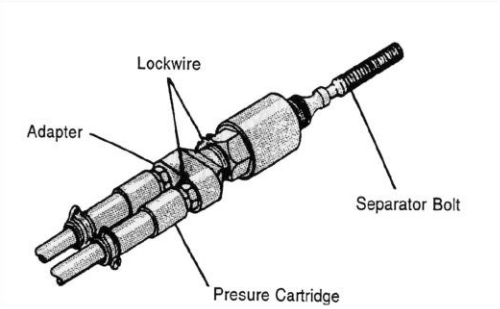


Arrow No.		Arrow No.	
1.	313 He Injection (Bubbling)	7.	301 GN2 Purge (Intertank)
2.	308 HAZ Gas Detection	8.	307 H2 Vent Valve Actuation
3.	310 Hot GN2 Purge (Nose Cone)	9.	302 H2 Vent Quick Disconnect
4.	J-2 Bipod Heater	10.	J-1 Ground Terminal
5.	306 Oxygen Vent Valve Actuation	11.	305 He Purge (GUCP Cavity)
6.	J-3 Instrumentation (Ullage Press and Temp)	12.	388 HGDS Gas Detection Sys.
		13.	389 HGDS Gas Detection System

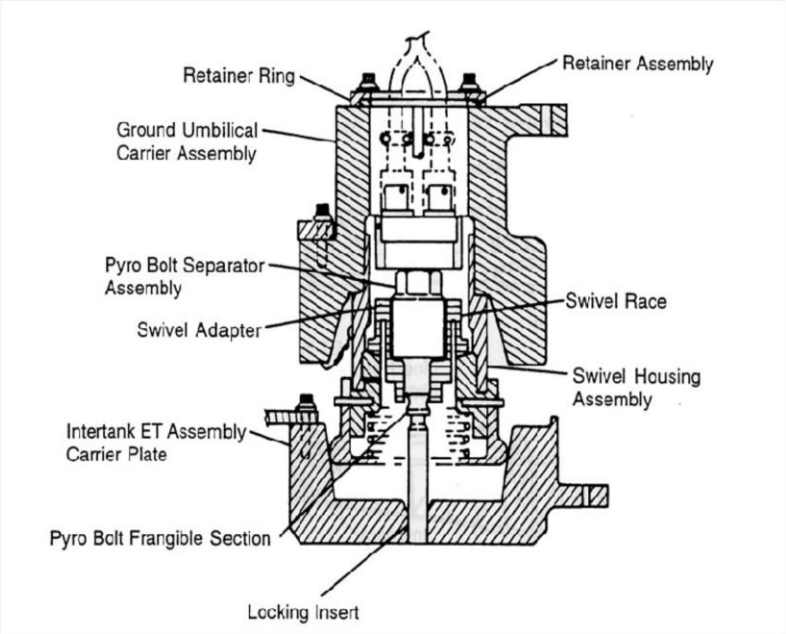


GUCA QD Exploded View

Pyro Bolt & Separation Assembly Installation



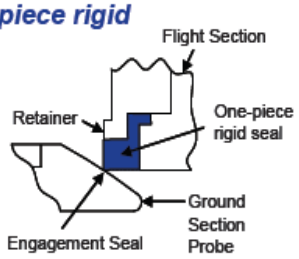
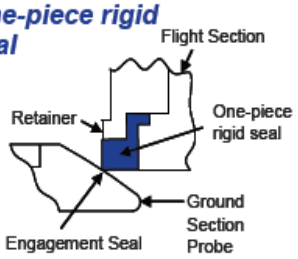
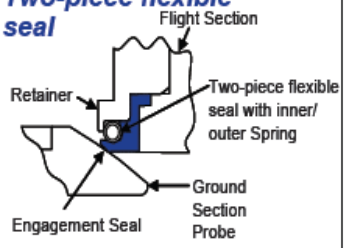
Pyrotechnic bolt (Pyro Separator Assembly)



ETCA (External Tank Carrier Assembly) QD

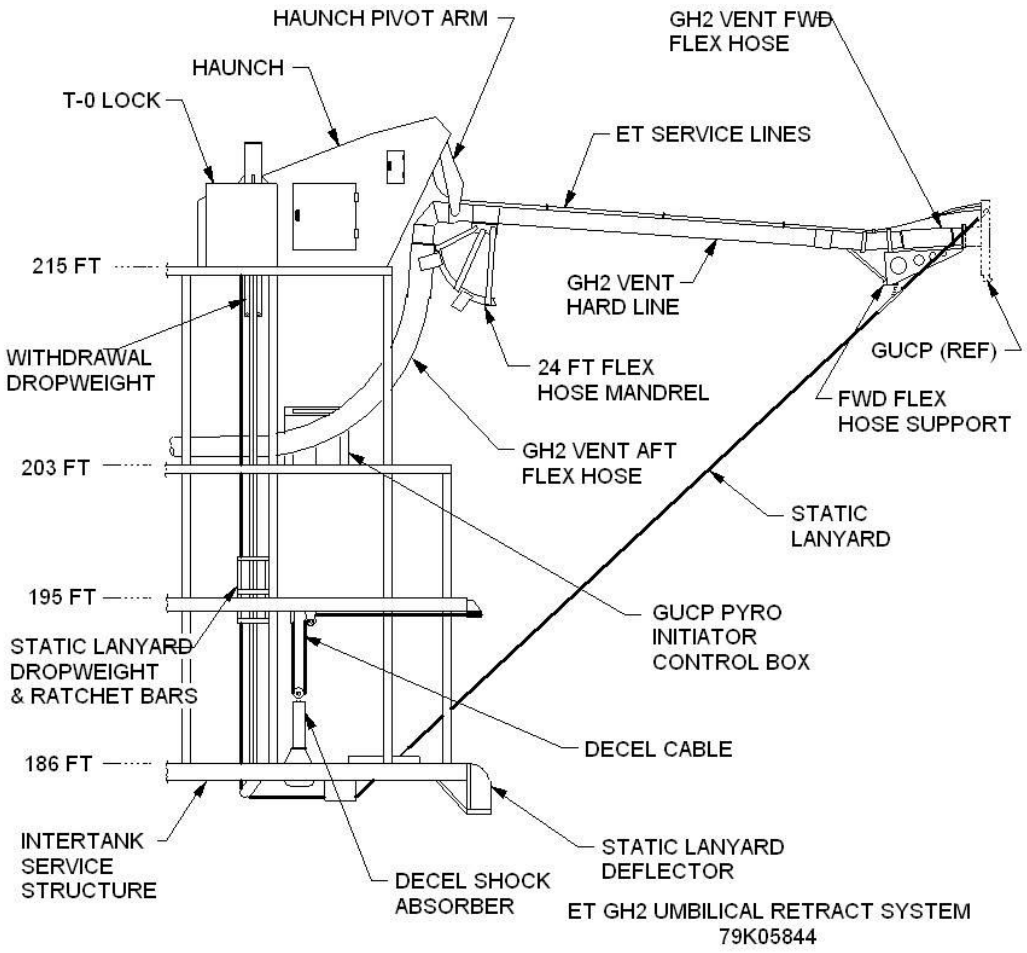
LM GUCP Configuration and Performance History

- STS-116 / ET-123 was first use of new ground umbilical disconnect flight seal design
  - One-piece seal replaced with two-piece seal to accommodate misalignment during installation

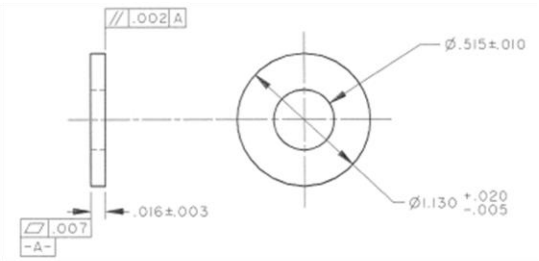
	STS-27 through STS-105 (>120 loadings)	***STS-108 through STS-115 (19 loadings)***	***STS-116/ET-123 (2 loadings)***
Design History			
• ***Ground Side Bellows Probe***	***Material:*** *CRES 321* ***Spring Force:*** *165 lbs min.*	***Material:*** *Inconel 718* ***Spring Force:*** *225 lbs min.*	***Material:*** *Inconel 718* ***Spring Force:*** *225 lbs min.*
• ***Flight Seal Design***	***One-piece rigid seal*** 	***One-piece rigid seal*** 	***Two-piece flexible seal*** 
Leakage History			
	(11) occurrences of leakage. Contingency procedures required on (4) occurrences to reduce / control leakage	***No leakage observed***	***(2) occurrences of leakage. Contingency procedures not required***

Returned to STS-108 through STS-115 configuration following STS-116 leaks - No leaks with current design until STS-119 (31 loadings)

ET GH_2 Umbilical Retract System

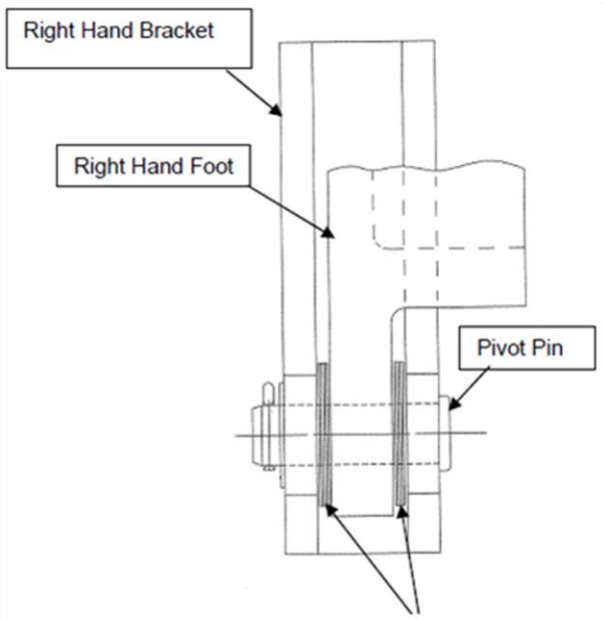


Pivot Assembly Washer Installation



80913000443-014 Washer – Pivot Assembly Pin

	Minimum	Maximum
Washer	0.013"	0.019"
Foot Width	0.490"	0.510"
Bracket Opening	0.740"	0.760"
# of Washers	12	20
Shaved Foot Width	0.390"	0.410"
# of Washers w/ Shaved Foot	17	28

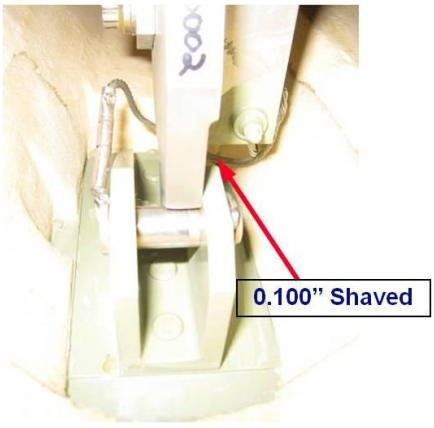


80913000443-014 Washers

Pivot Assembly Feet Modifications

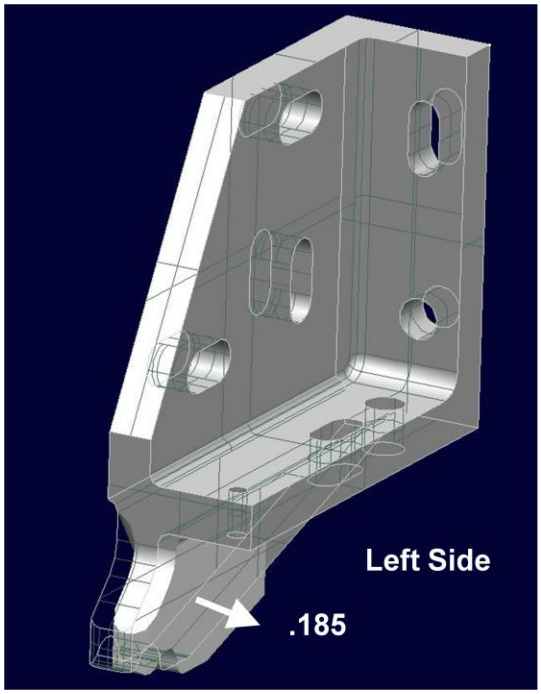
Shaved Right Pivot Foot - MR

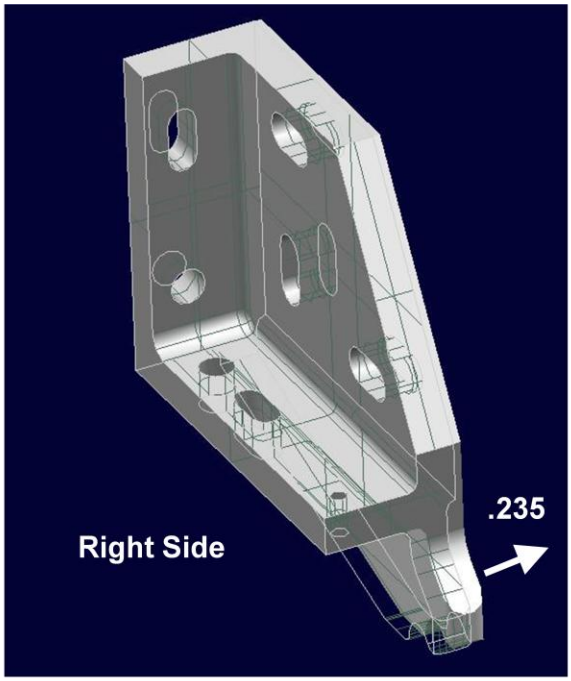
Shaved Right Pivot Foot - Installed



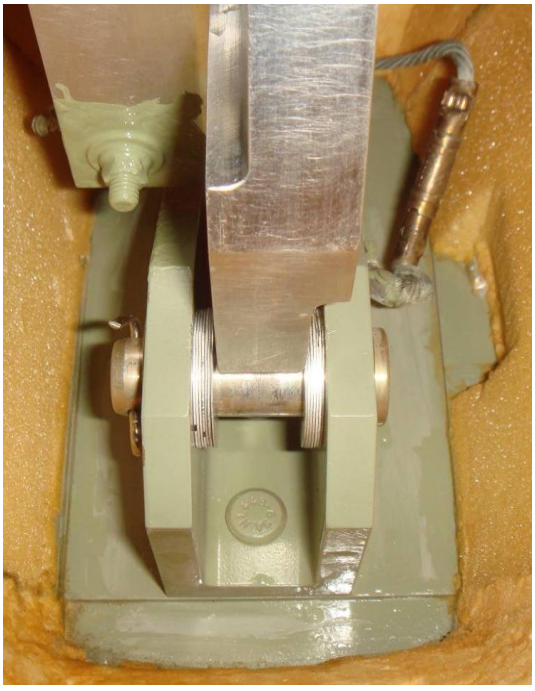
Shaved Left Pivot Foot - Installed

Customized Pivot Feet Assemblies



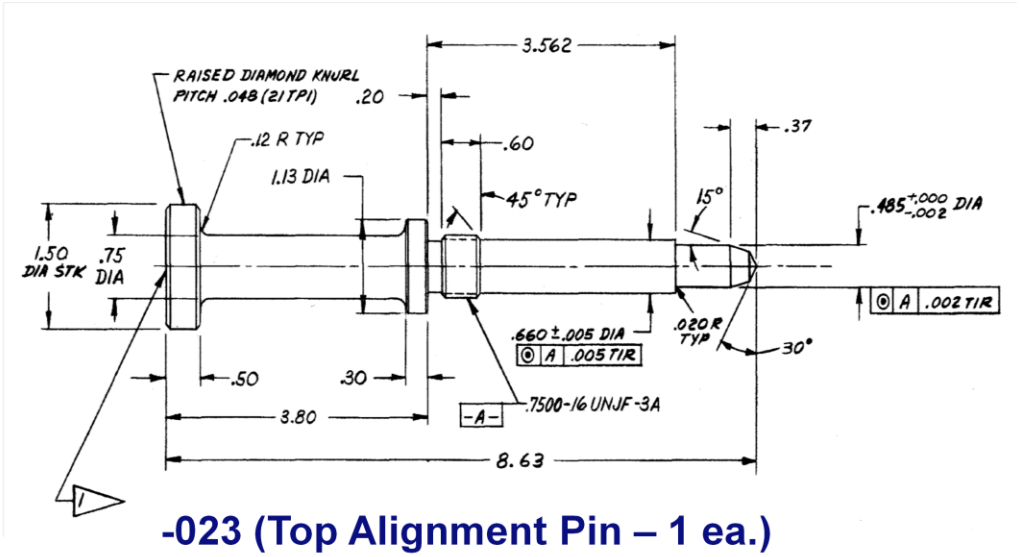


Current configuration shown in outline, modified configuration shown shaded

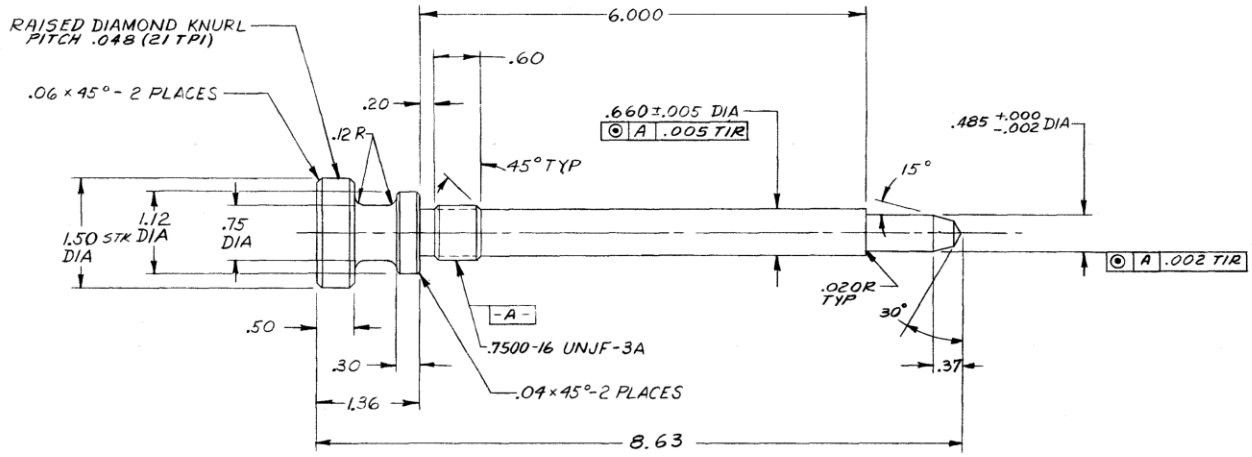


Installed onto STS-127/ET-131

GUCP Alignment Pins – Original 82629021003-023/-024

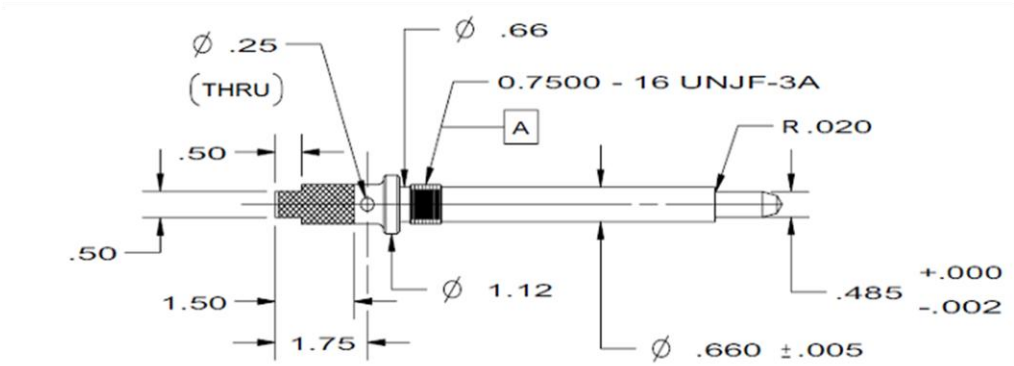


-023 (Top Alignment Pin – 1 ea.)

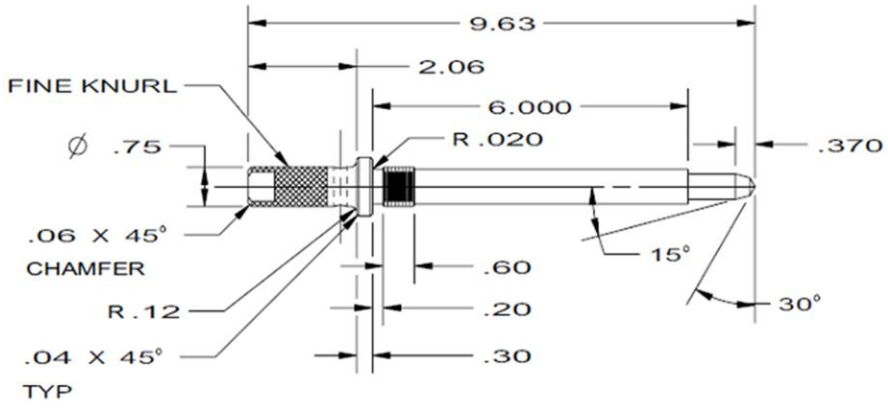


-024 (Bottom Alignment Pin – 2 ea.)

GUCP Lower Alignment Pin Mod – 80K54666-21



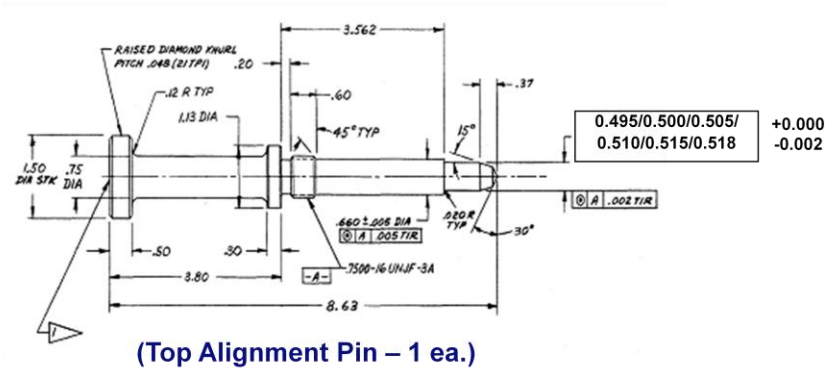
Modified due to interference with Ice Shroud



GUCP Alignment Pins – 80K54666 Tighter Tolerance

Based on 82629021003-023

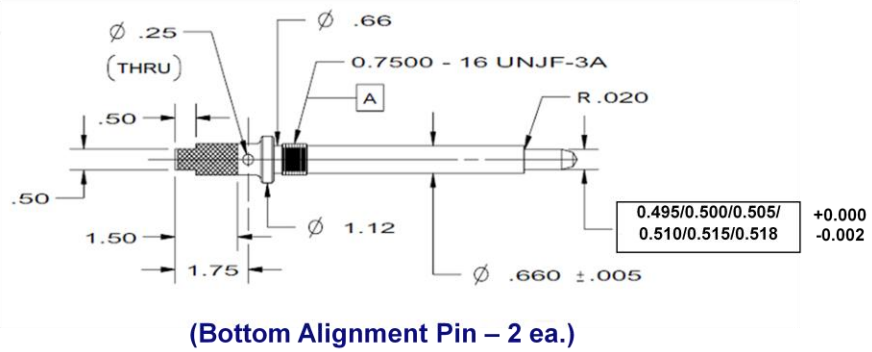
80K54666	
-28	0.495
-29	0.500
-30	0.505
-31	0.510
-32	0.515
-33	0.518



(Top Alignment Pin – 1 ea.)

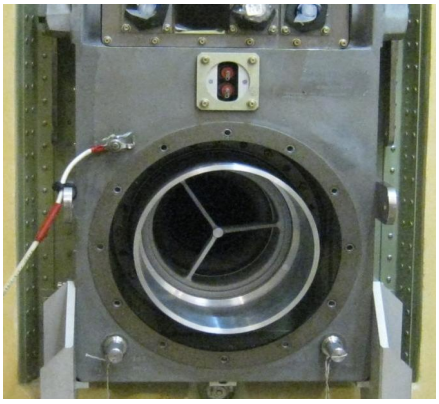
Based on 80K54666-21

80K54666	
-22	0.495
-23	0.500
-24	0.505
-25	0.510
-26	0.515
-27	0.518

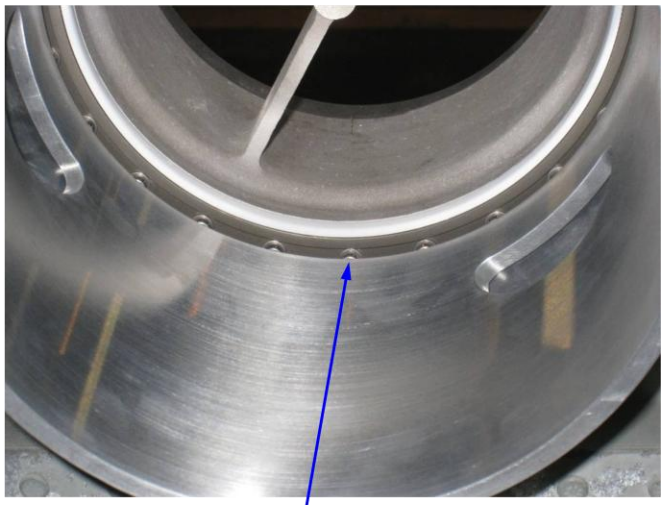


(Bottom Alignment Pin – 2 ea.)

First Generation Concentricity Tool



Second Generation Concentricity Tool



The tool is not resting on the retainer bolt heads, there is plenty of clearance. The tool rests on the QD flange outside of the mounting bolts

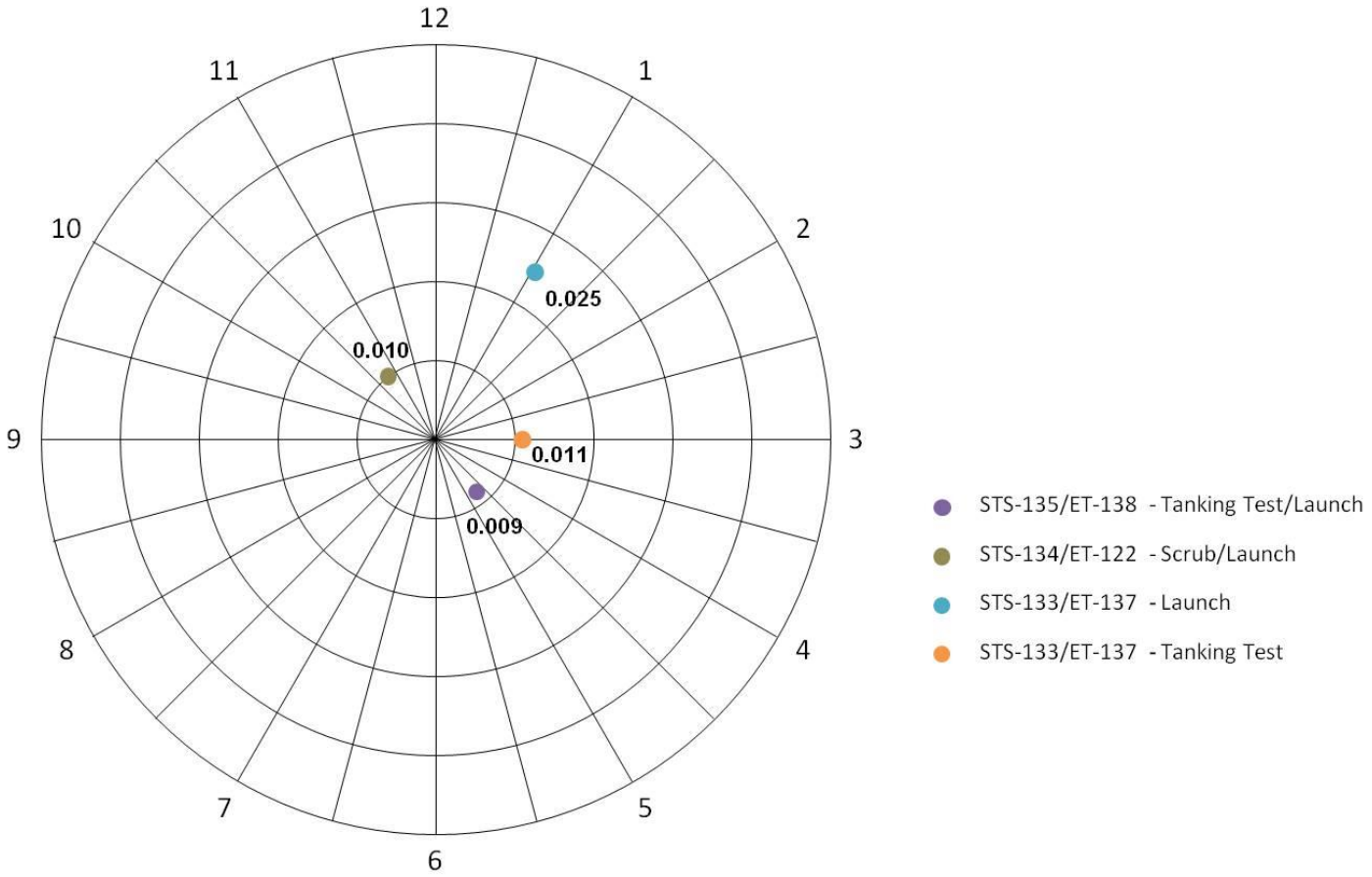
Appendix B

GUCP Concentricity History,
Resultant Concentricity History
and
GUCA QD Offset History

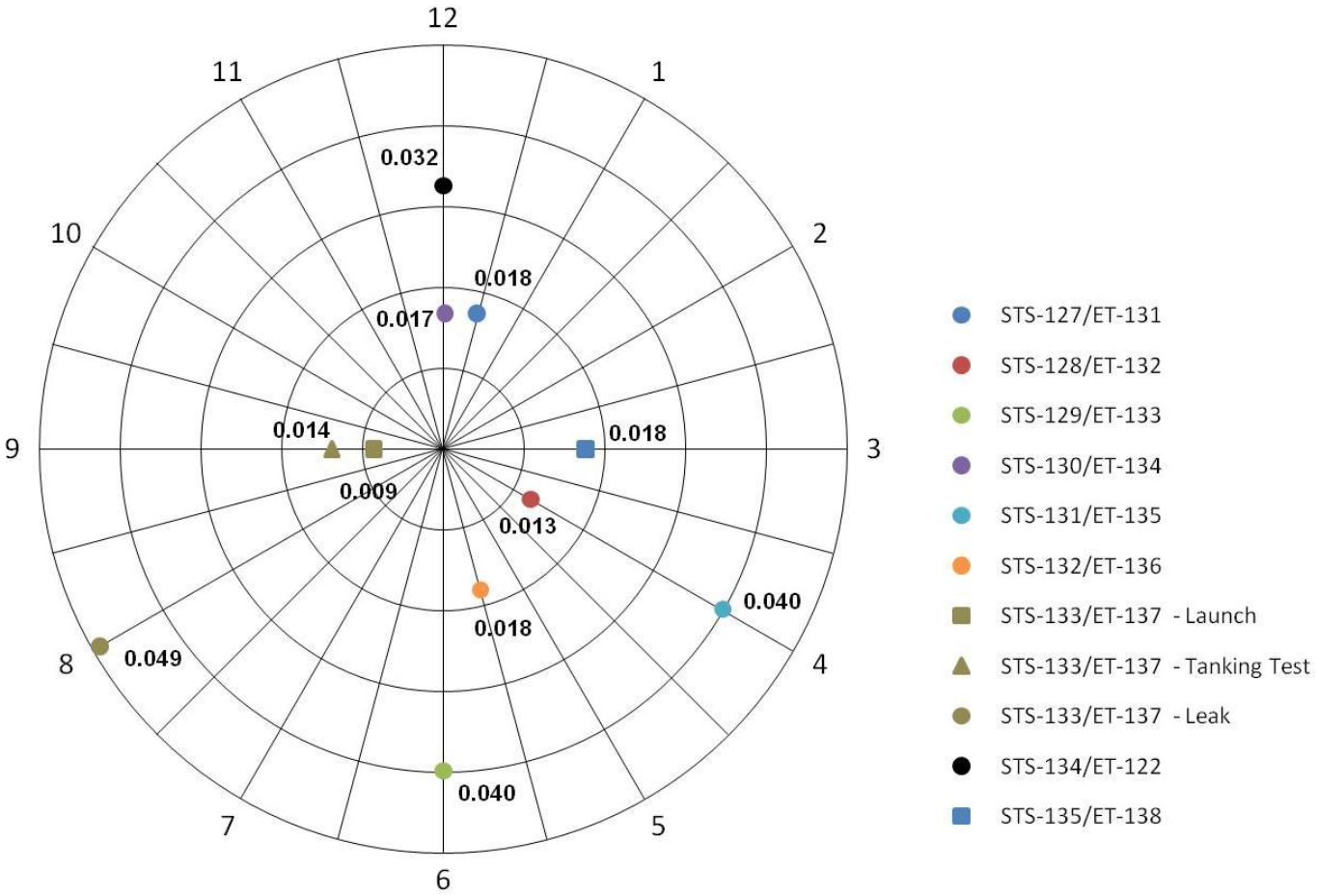
STS	ET	GUCP S/N	GUCA QD S/N	GUCP Concentricity		Installed QD Offset		Resultant Offset		# of No Leak Loadings	Total # of Loadings
				Offset	Clocking	Offset	Clocking	Offset	Clocking		
127	131	8	5	0.018	12:30					4	4
128	132	7	7	0.013	4:00					3	3
129	133	6	10	0.040	6:00					1	1
130	134	5	5	0.017	12:00					2	2
131	135	8	8	0.040	4:00					1	1
132	136	7	7	0.018	5:30					1	1
133 1	137	2	4	0.049	8:00	*0.024*	*6:00*	*0.065*	*7:20*	0	1
133 2	137	3	8	0.014	9:00	0.025	3:00	0.011	3:00	1	1
133 3	137	3	8	0.014	9:00	0.025	3:00	0.011	3:00	NA	NA
133 4	137	3	8	0.009	9:00	0.029	1:30	0.025	1:00	1	1
134 1	122	8	10	0.030	12:00	*0.005*	*1:00*	*0.034*	*12:10*	NA	NA
134 2	122	8	6	0.032	12:00	0.025	6:30	0.010	10:45	2	2
135 1	138	5	5	0.021	4:00	*0.036*	*4:30*	*0.057*	*4:20*	NA	NA
135 2	138	5	8	0.018	3:00	0.015	8:00	0.009	4:45	2	2

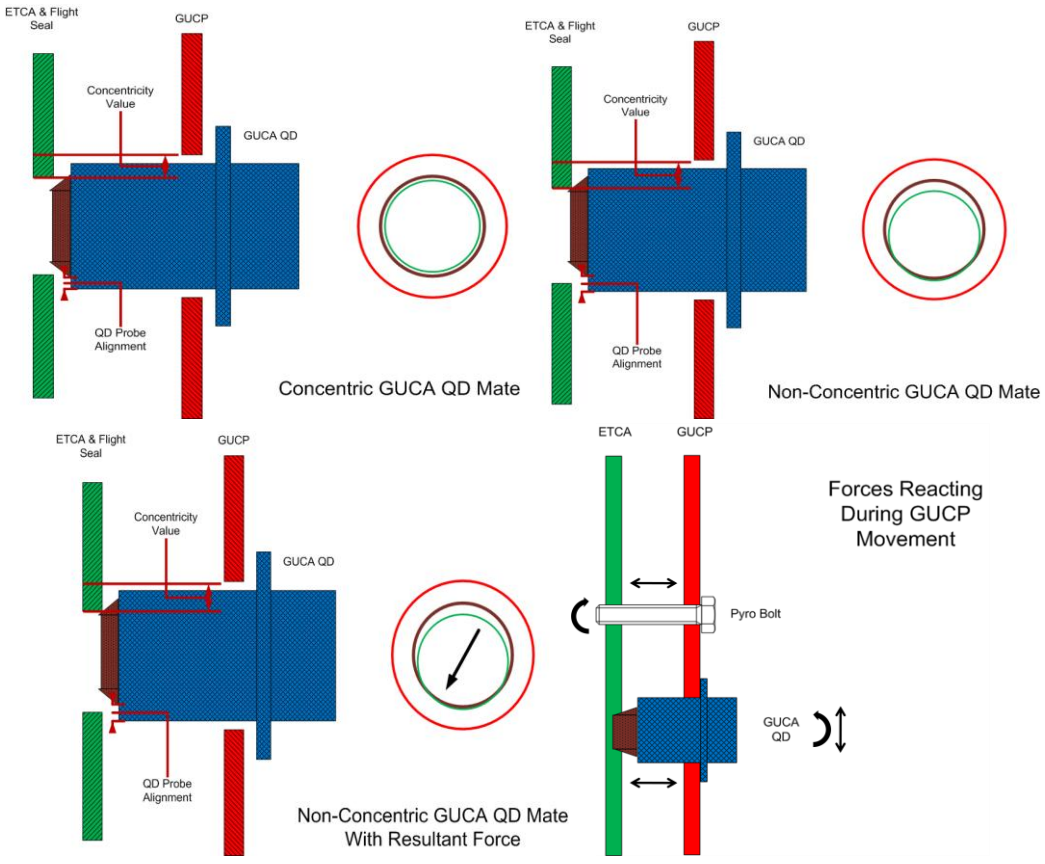
Italicized values are post demate measurements & projections

Resultant Concentricity History – Spider Chart



GUCP Concentricity History – Spider Chart





Appendix C

GUCA Modification History
and
Engineering Changes

(Information provided by Fred Lockhart – Lockheed Martin)

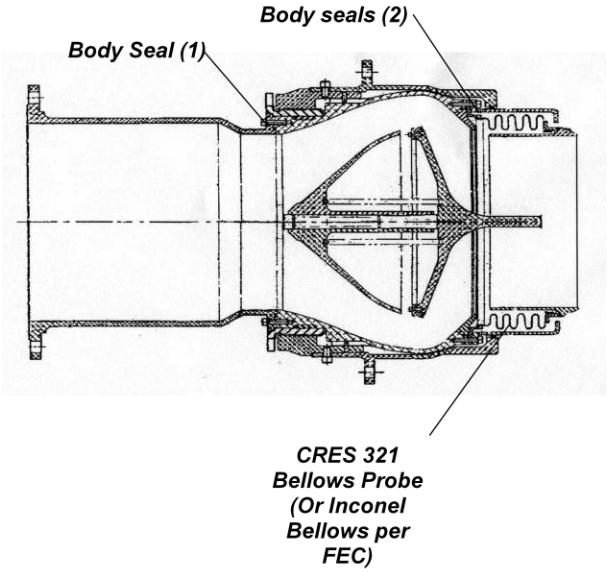
GUCA QD Replacement

(STS 108 and subs)

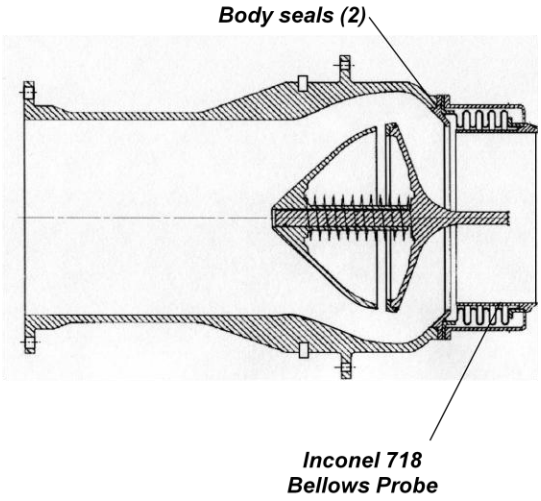
As part of Shuttle Enhancements, the 7 inch GH2 GUCA QD was redesigned to eliminate fatigue of 321 SST bellows and to reduce the number of parts to improve and streamline the assembly and refurbishment time. Additional improvements included using safety cable which saved more than 12 hours per flow in the QD poppet and body flange. The new QD design uses a one piece body with two body seals while the old design had more than 4 major components and 3 body seals.

Implementation of the design was scheduled for ET-122 but due to a poppet mechanical failure on STS-105 (ET-110) the replacement design was implemented early on STS-108 (ET-111) by a Field Engineering Change (FEC). Subsequent uses were via FECs to replace the original SST-321 bellows with Inconel 718 bellows into an original QD body until ET-117 where the use of an entire new designed QD was implemented via a permanent drawing revision.

Current Design (PD4800173-029)



New Design used on STS-108 (80923021020-009)

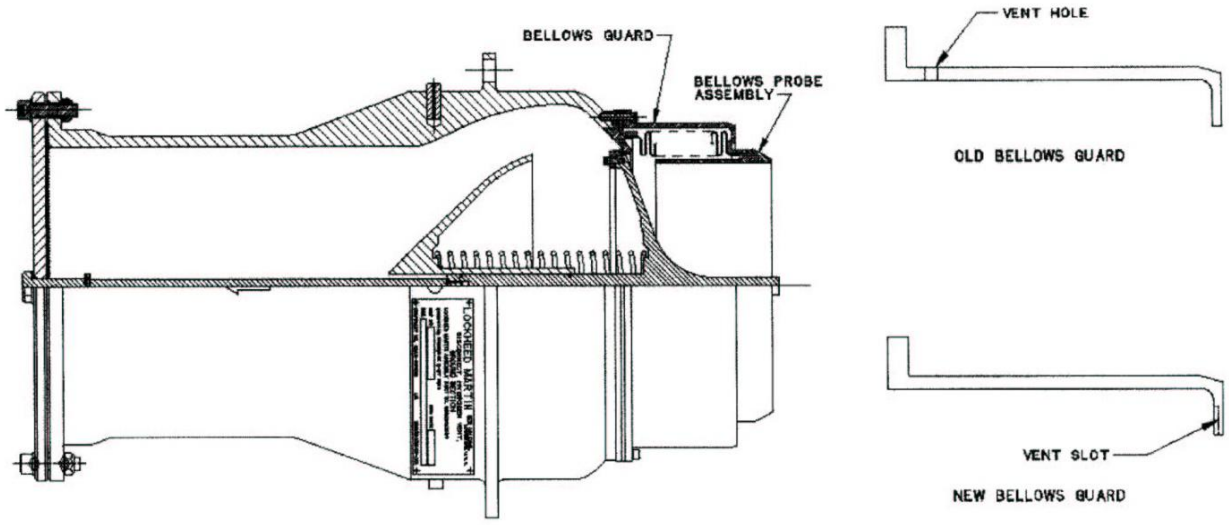


Broken Poppet Stem - STS-105

GUCA QD Bellows Guard Replacement and GUCP/ET Ground Jumper Bolt Replacement

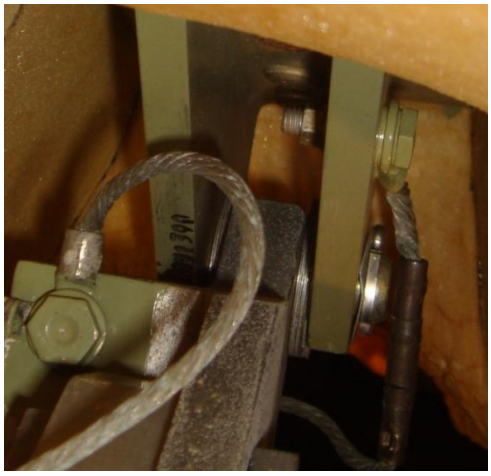
(STS 113 and subs)

The bellows guard of the new Quick Disconnect (QD) was showing signs of corrosion products. During Shuttle launches acid and other contamination entered in through the vent holes. The vent holes were deleted and four machine slots for ventilation on the inside lip of the bellows guard were added.



QUICK DISCONNECT ASSEMBLY

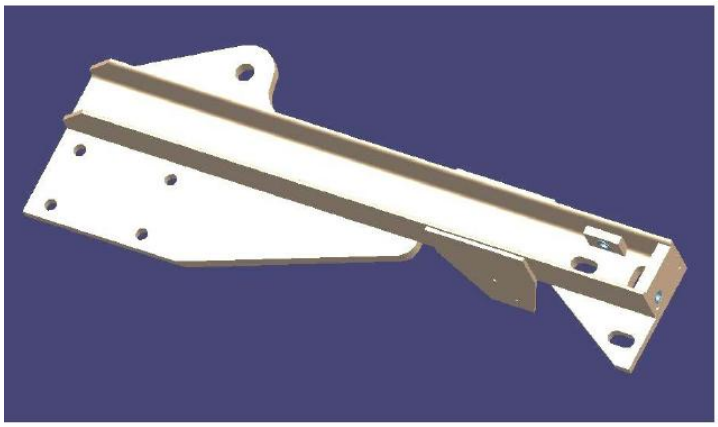
The bond jumper bolts in the umbilical hinge brackets were changed to a shorter length with hex heads. This eliminated the need for a special torque tip and eliminated TPS damage being caused by the torque wrench due to the tight space next to the hinge brackets. This was requested by KSC as an operational improvement and accepted and implemented by MAF design.



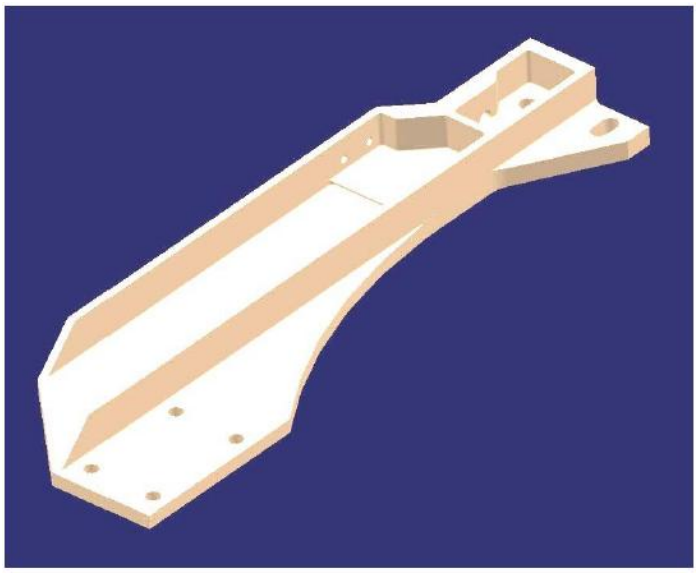
GUCP (Ground Umbilical Carrier Plate) Leg Redesign

(STS 114 and subs)

Was – F.S. < 2.0 (8 Pieces Welded Together)



Now – F.S. ≥ 2.0 (1 Machined Piece)



GUCA Electrical Connector J3 Replacement

(STS 114 and subs)

The ET Bipod Fitting Redesign requires Modification Kits to retrofit the GUCA with new 55 pin connectors to accommodate heater and temperature sensor measurements (was 22-pin connector)

ET-1 Interface Number J-3/P-3 (C) Connector 314W24J03

ET SIDE
Was: NB0E18-32PNS (ET)
Now: NB0E22-55PN(X) (T)

FAC SIDE
Was: NB6WGE18-32SN (ET)
Now: NB6WGE22-55SN(X) (T)

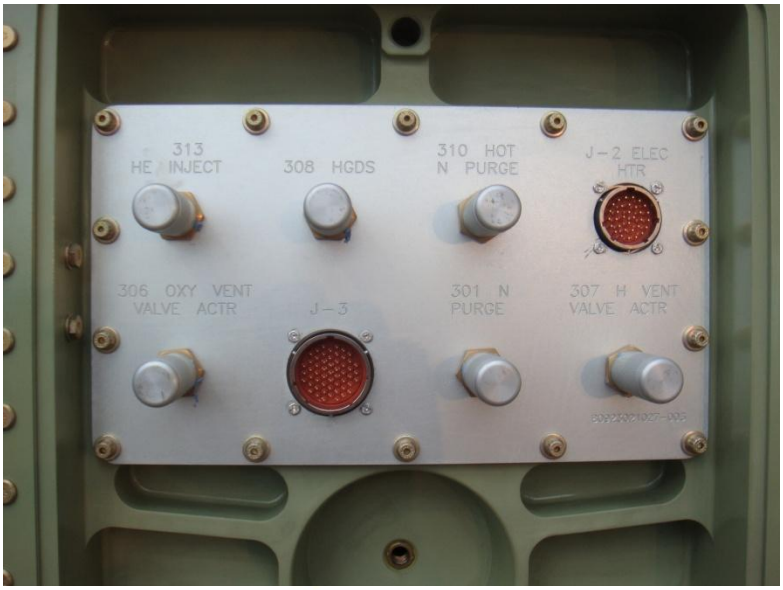
GUCA Electrical Connector J2 Redesign
(STS 121 and subs)

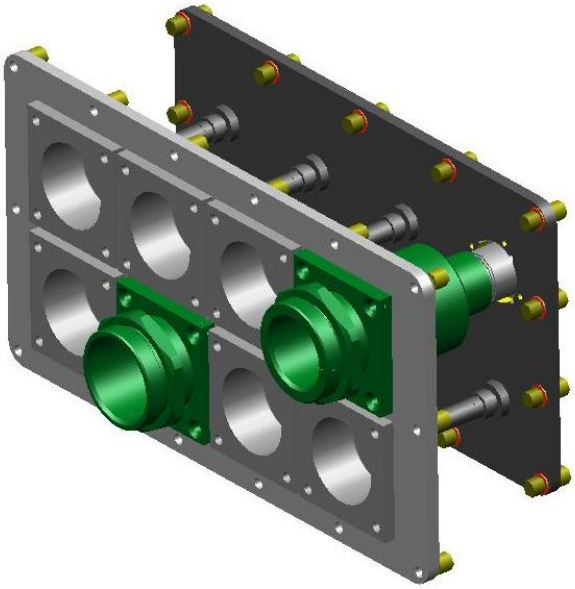
The J2 connector was redesigned to accommodate the LO_2 Feedline Bellows Heater Modification The Space Shuttle Program requested implementation of a LO2 Feedline Bellows Heater at Station 1106 to eliminate critical ice debris. This Modification of the ET Ground Umbilical Assemblies was required to support the implementation of the heater system (CR S062612).

ET-1 Interface Number J-2/P-2 (C) Connector 314W23J02

ET SIDE
Was: NB0E14-18PNS (ET)
Now: NB0E18-32PN(X) (T)

FAC SIDE
Was: NB6WGE14-18SN (ET)
Now: NB6WGE18-32SN(X) (T)

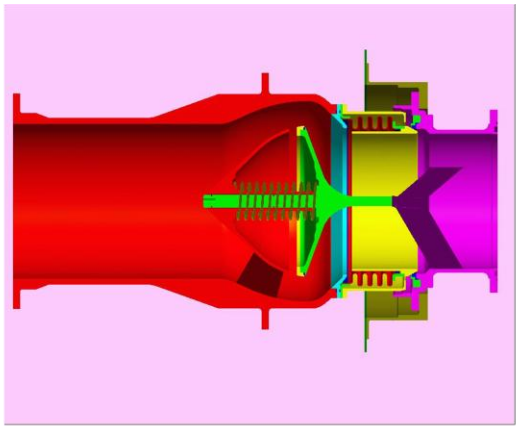




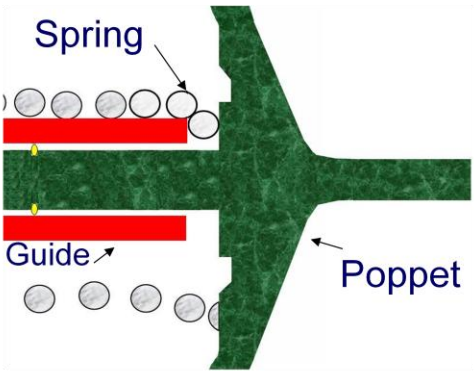
GUCA QD Poppet Guide Chamfer
(STS 118 and subs)

On ET-119(STS-121) and ET-121(STS-114), a defect was discovered in the poppet guide in the H2 Ground Umbilical Disconnect. This defect was caused by the spring dislodging from its groove and becoming sandwiched between the poppet and guide during opening.

In order to stop the spring from being sandwiched between the poppet guide and poppet in the future, it is proposed that a chamfer be added to the cast poppet guide. This would allow the spring to slide off the guide; thus, it would not obstruct the opening of the poppet.



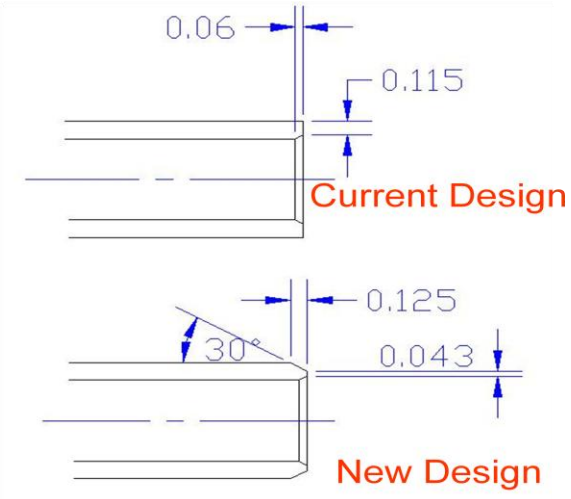
Cross-Section of Quick Disconnect Assembly



Exploded View of Poppet, Guide, and Spring

ET-121

ET-119



ETCA (External Tank Carrier Assembly) Flight Seal Change

(STS 127 and subs)
(Also used on STS 116 (ET123) and 117 (ET124))

During 1st launch attempt of STS-127/ET-131 a launch scrub was called due to a GH2 leakage detected at GUCP which exceeded the LCC limit. Prior to the 2nd launch attempt the 7 inch QD flight seal was removed and replaced. A 2nd launch attempt was also scrubbed due to excessive GH2 leakage. After the second scrub, the one-piece flight seal RG42521 and the seal retainer RG42488 were replaced by two-piece flight seal 80923021043-001 and the seal retainer 80923021046-001 (See figure below).

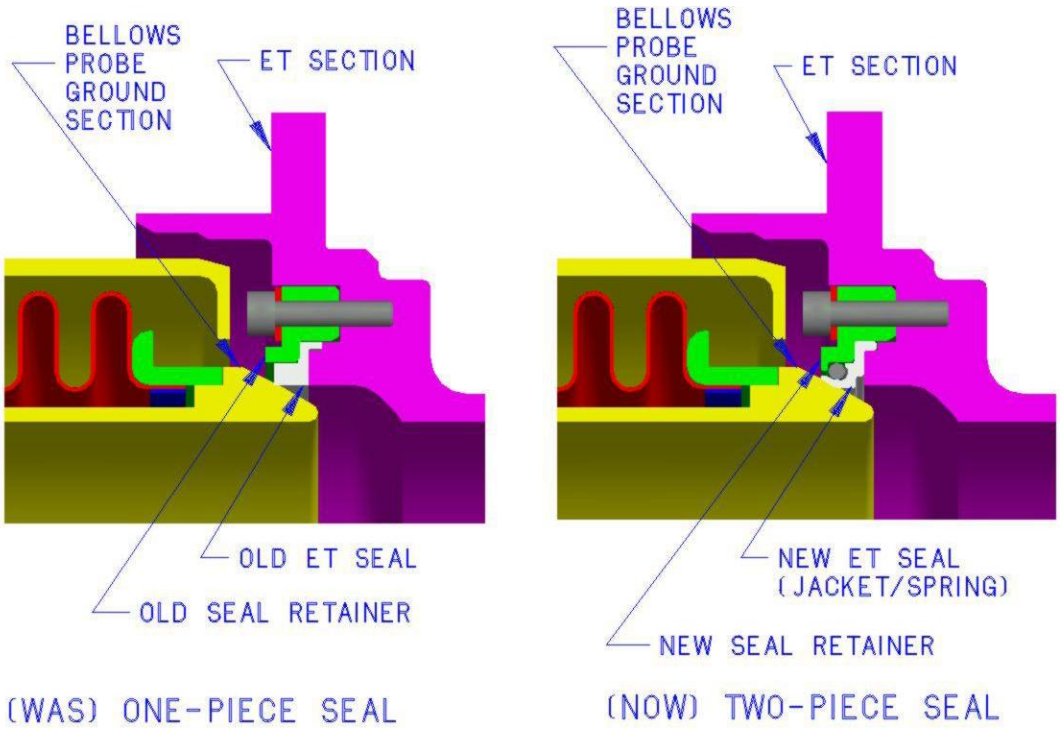
Also, GUCA to ET Pivot Assembly installation was modified by using high fidelity alignment pins, and by adding washers between the pivot assembly feet and the hinge pin bracket support to minimize GUCA relative motion.

The replacement of the flight seal and use of new alignment pin, and the modified pivot assembly with washers on STS-127/ET-131 successfully eliminated the leak on the July 1st '09 Tanking test.

Due to cause and corrective action a decision was made to move back from one-piece seal to two-piece seal. This change enables the sealing surface to be more compliant with the bellows probe interface should a slight misalignment occur. (In the development test the two-piece seal performed better than the one-piece seal when GUCA and ETCA were slightly misaligned).

Also, washers will be used between the GUCP Pivot feet and the hinge pin bracket to prevent the rotation of the GUCP/Leg and minimize the GUCA relative motion/misalignment.

The high definition alignment pins with larger diameter will replace the old alignment pins.



Drawing, Specification, and Process Changes

- ETCA two-piece seal and retainer (80923021043-001 & 80923021046-001, respectively) replaced the one piece seal and retainer (RG42521 & RG42488, respectively)
- Flight Seal Retainer retorque was changed from 12 hours to 3 Hours/3 Hours (FEC KET-0099)
    - Effectivity was STS-128/ET-132 only
    - Released Engineering for ET-133 and subs
- Added 1.130” OD washers (80913000443-014) between the GUCP Pivot assembly feet and the Hinge bracket support (UCN B02168)
- Added new high definition alignment pins (80K54666 which includes the original 82629021003-023/-024 pins)
- Vent Line Flange 30 hour retorque change to a 10 hour re-torque is allowed for *Scrub Turn-around only* per 79K05847 EO 15
    - Not permitted to change the normal processes, unless we are in a situation where we have to torque the flange in a scrub turn-around, in which case it will be handled by deviation to change "30 hr" to "10 hr" in our procedures
- Incorporated the use of the Concentricity Tool (TSA-718)
    - First Generation Tool required the removal of the flight seal and retainer
        - Used the retainer bolt holes as the attach points
        - ET-131 & ET-132
    - Second Generation Tool can be used with the flight seal and retainer installed
        - Uses the ETCA protective cover bolt holes as the attach points
        - ET-133 and subs
    - Concentricity tool requirement incorporated in OMRSD file IV as new requirement T41QAL.150 (RCN MT18321). The requirement called out for less than or equal to 0.050 inches for the GUCP concentricity, 7 inch QD probe concentricity and the net (resultant) concentricity (optimized as close as possible to center). The intent was implemented on STS-133 and STS-134 and officially for STS-135.

Appendix D

Operations Overview

VAB Operations

- Check-Out Cell Processing – GUCP
  - Initial Receiving inspection of the ETCA and Flight Seal
    - High Fidelity Guide Pin fit checks and measurement of the alignment pin hole diameters.
  - GUCP installation
    - GUCP Inspection and Guide Pin Installation prior to GUCP installation
    - Manually lift the GUCP and install the upper guide pin into the ETCA
    - Install the lower guide pins and verify no binding.
  - Pyro Bolt installation
    - Maintain pressure on the GUCP and torque the pyro bolt
    - Obtain axial displacement and parallelism measurements and adjust final torque to meet the requirements
    - Concentricity initial verification and plate position measurements (Operation 500)
  - Pivot Assembly
    - Tightening and verification of no hinge bracket interference
    - (Contingency) Installation of modified pivot assembly to avoid interference
    - Washer installation and Gap verification
    - Pivot Assembly Pre-Load
    - Final Concentricity Verification and plate position measurements (Operation 500)
- Check - Out Cell Processing – 7 inch Ground QD
  - 7 inch QD inspection
    - Detailed bellows probe sealing surface inspection
    - Inspection of the ETCA Flight Seal (visual and tactile)
  - 7 inch QD installation
    - Install the QD alignment pins
    - Install the QD to a ¼ inch separation
      - Insert GSE bolts
    - Remove the alignment pins to allow the QD to float into the seal
    - Install the flange bolts and maintain parallelism of the flanges to final assembly
  - Install the 3/8 inch QDs
  - Final inspection of GUCP and QD position (Operation 500)
- Check – Out Cell processing – Pneumatic processing
  - T1101 Connect vent valve actuation lines
  - T1104 Connect to the blank off plate to leak check the GUCA (6 psi)
  - T1160 Vent the LO2 tank and electrical connections
  - T1108 Venting for angle and tip load of the umbilicals
  - T1004 and T1005 Disconnect flex hoses
- Integration Cell Processing – Pneumatic Operations
  - V1149
    - T1203 Connection of the vent valve actuation lines
    - T1201 LH2 and LO2 Tank venting
    - T1203 Disconnection of the vent valve actuation lines

- Integration Cell Processing – GUCA
  - Final inspection of GUCP pre-rollout (Operation 500)
    - Contingency: Pivot Assembly Adjustment

PAD Operations

- Prior to Shuttle Roll-out
  - Validation - all major subsystems inspected and verified, satisfying 29 File VI OMRS requirements
  - Monthly, Quarterly, Annual and Bi-annual maintenance
    - Satisfies File VI OMRS requirements for wire rope and hoist integrity
    - Lubricates and refurbishes all major subsystems
- Shuttle Roll-out – S0009
  - Vent Line to GUCP Mate
    - Vent Line is raised to GUCP level and all connections are made to the GUCP
      - Flexhose and Vent Line weight are fully supported during mate to QD by the Line Handling Post
      - After Flanges are connected and torqued, the Vent Line weight is transferred to the GUCP by lowering it
      - Withdrawal Weight is lowered, transferring the additional 1500 lb weight onto the GUCP
    - Vent Line service lines are connected
    - GUCP feet are checked for contact and pads are adjusted onto ET
  - Interface Leak Checks
    - GUCP interface is leak checked at ambient using Helium. Integrity is checked using mass spectrometer through the same Haz Gas lines/system used for launch.
- Ordnance
  - Pyro Cables are connected to GUCP pyro bolt
  - Pyro bolt and cables are installed into T-0 Lock
- Prior to S0007
  - Close-out of the system occurs prior to S0007 Launch Countdown
  - Static Lanyard weight is lowered after retracting GUCP Access Platform
  - Final GUCP and system inspections are performed
  - ET / IT Arm is retracted
    - No further access to GUCP or Vent Line after this point
    - Access to subsystems on the FSS are restricted until after Post-launch activities
- S0007
  - ET Vent Line supports LH2 loading and GUCP interface connections
  - T-0 – Vent Line retracts in less than 2 seconds to clear path for the vehicle
- Post-launch
  - Ordnance is safed and removed
  - GUCP is retrieved and returned to VAB for refurbishment

Appendix E

GUCA Summary Matrices

ET GUCA Flow Summaries

ET and QD History Final.xls

Pivot Assembly History

Pivot Assembly History.xlsx

Operations 500 Analysis

Op 500 Analysis.xlsx

GUCA QD Body Seal Gaps & Torque Summaries

QD Gap and Torque checks Rev B.xlsx

GUCA Loading Performance Summaries

GUCP Leak Overview Final.ppt

Appendix F

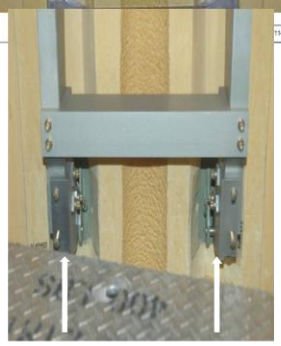
Operation 500 Measurements

Sample Recordings

Ground Umbilical Carrier Assy (GUCA) Plate Periphery Measurements

4.629 +0.002 -0.006	4.862 +0.003 +0.009
4.724 +0.009 +0.009	4.826 -0.003 -0.009
4.720 +0.007 +0.009	4.773 -0.086 +0.008
4.668 +0.004 +0.007	4.666 +0.004 -0.014

OB	IB	IB	OB
0.043 +0.001 +0.002	0.197 +0.002 +0.004	0.078 +0.000 +0.013	0.163 +0.006 -0.004
Between Washers		Between Washers	
0.008 -0.001 -0.001	0.002 +0.000 +0.000	0.013 -0.001 -0.001	0.020 +0.010 +0.010
Washers		Washers	
3 On Pin Yes	13 At Apex Yes	4 On Pin Yes	11 At Apex Yes



Pivot Assembly Gap Check Measurements

Run 4 – After QD Installation

Current Run's readings
Change from previous state
Change from initial state (Run 1 for all except for Pivot Gap which is Run 3)
Guide Pin Size

0 0 0 — 0 0 0

0 0 0 — 0 0 0

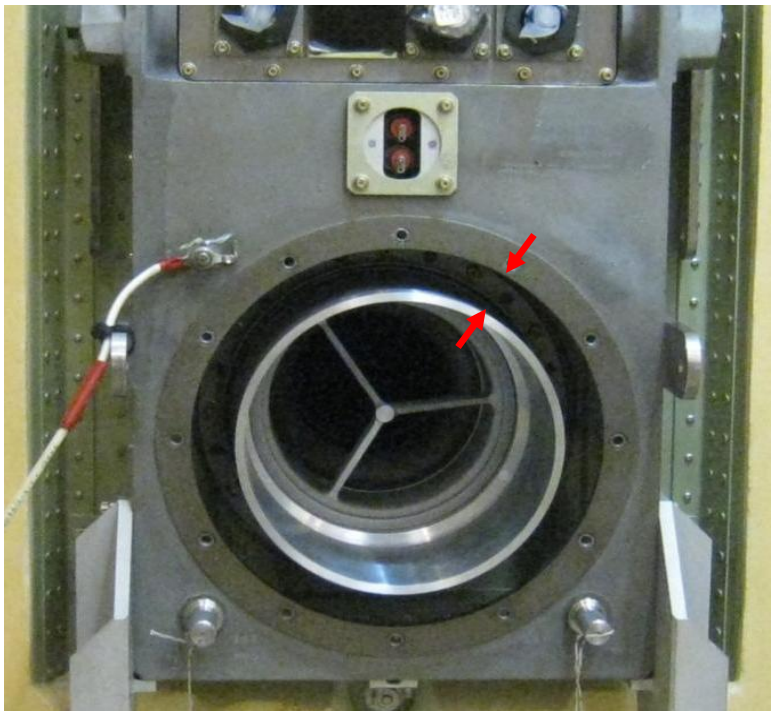
GUCP Swivel Pad Gap Check Measurements

ET-132-ST-0009 Operation 500

Axial Displacement and Parallelism

STS-135 Displacement and Parallelism	
12 o'clock	7.018 in.
3 o'clock	7.022 in.
6 o'clock (shown)	7.011 in.
9 o'clock	7.006 in.
Average	7.014 in.
Min. = 7.000	Max. = 7.060
Values must be within .035 in. of each other. Values from T1147 Step 50-23	

Concentricity Measurements



Measurements taken at 12 positions
(1 o’clock to 12 o’clock)