

Measuring the On-Orbit Clearance between ISS Hardware using Imagery



**The Image Science and Analysis Group
NASA - Johnson Space Center**

Presentation at the 2017 CMSC Conference

Rev 1.2 July 18, 2017



Viewing Note



- Stereo images will be presented for viewing in the last half of this presentation.
- In order to view these images in 3-D you must look at the imagery through the Red/Cyan glasses, provided **with the left eye looking through the red lens.**

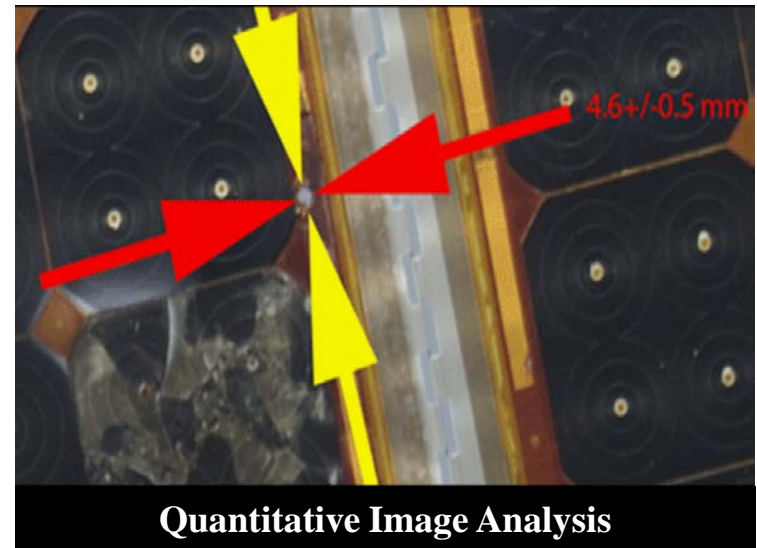




What is The Image Science and Analysis Group (IS&AG)



- IS&AG was created after the Challenger Shuttle Accident to provide NASA with a dedicated image analysis team.
- IS&AG is a 17 member team of engineers and imaging scientists which perform image based engineering analysis in support of any NASA programs, including:
 - Space Shuttle
 - International Space Station (ISS),
 - the Space Launch System (SLS),
 - the Orion Multi-Purpose Crew Vehicle (MPCV)
 - Commercial Space Program (Orbital and SpaceX)
- Which includes:
 - Turn-key measurement task planning, image acquisition and analysis
 - Quantitative Image Measurement
 - Image Enhancements and Data Visualization
 - Periodic Inspections of On-orbit hardware
 - 3-D Modeling and CAD Generation





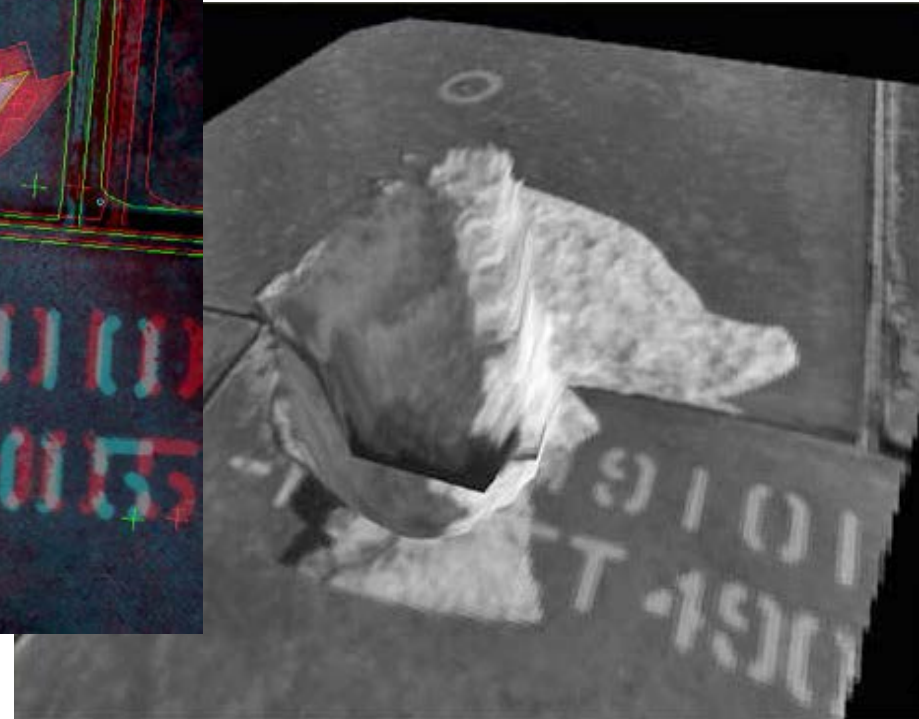
Common Analysis Tasks



Damage Assessment and CAD Modeling

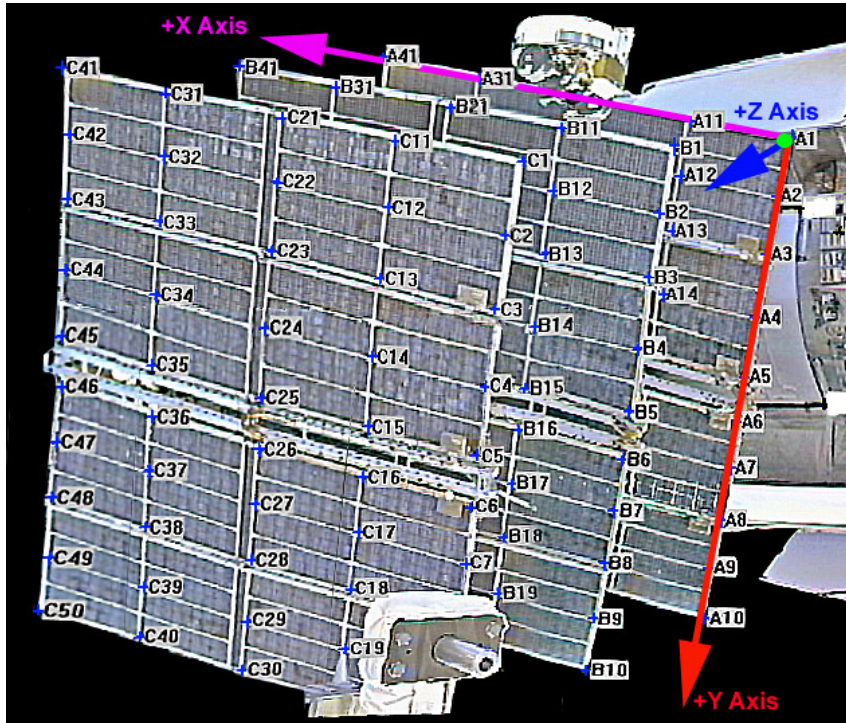


Damage to Thermal
Protection Tile during
Shuttle Mission
STS-118

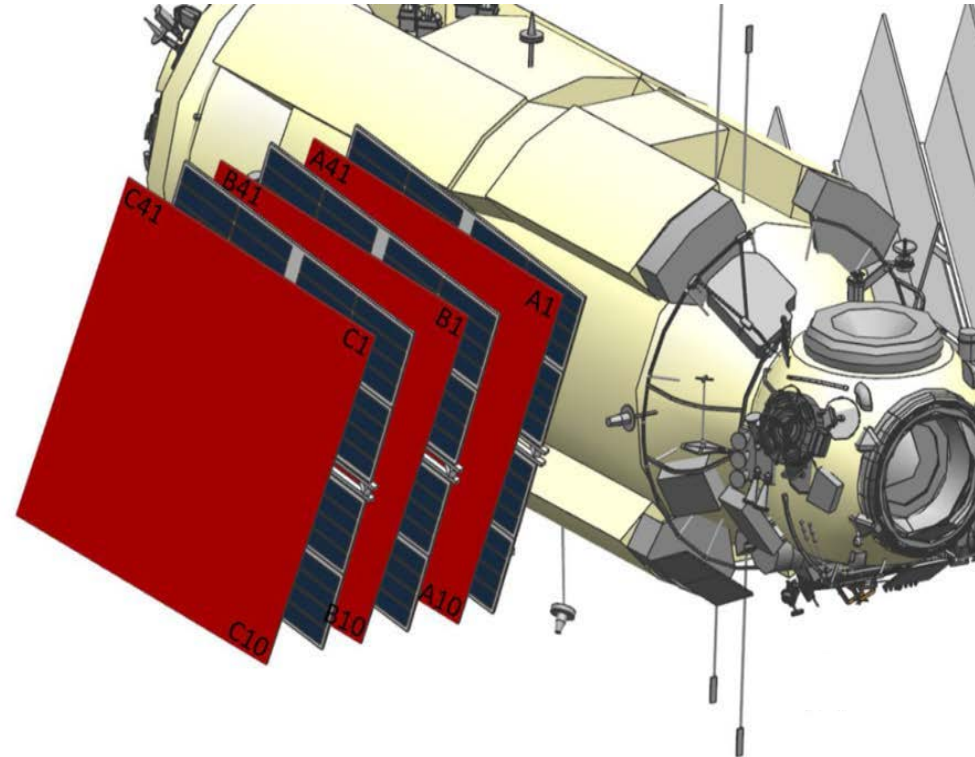


Common Analysis Tasks

3D Photogrammetry for Absolute and Relative Measurements



Photogrammetric Measurement of Solar Array using standard definition imagery (640x480 pixels) from the television cameras on the end of the robotic arm



Comparison of Photogrammetric Measurements (in red) to Retracted Design State of the Solar Array (shown in blue)

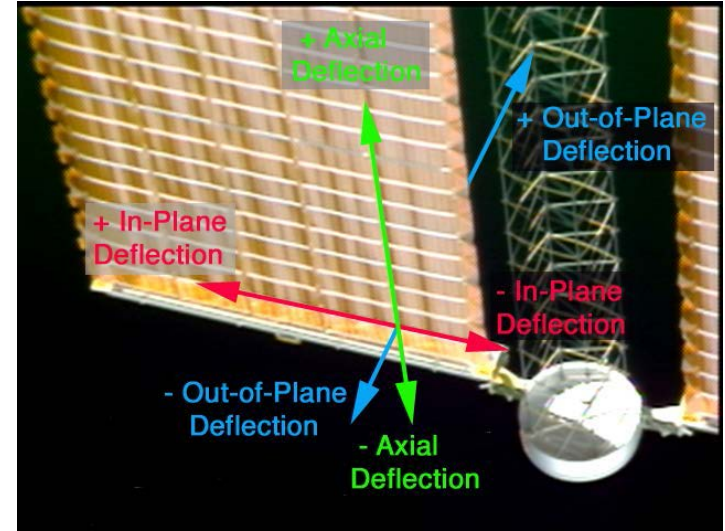
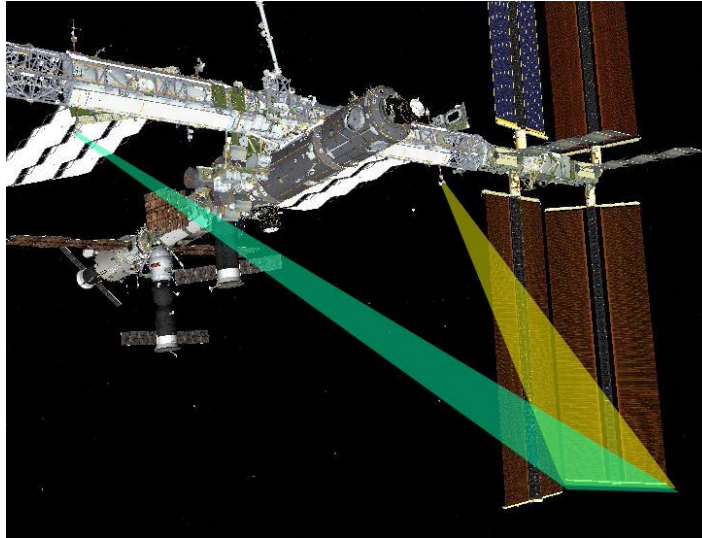


Common Analysis Tasks

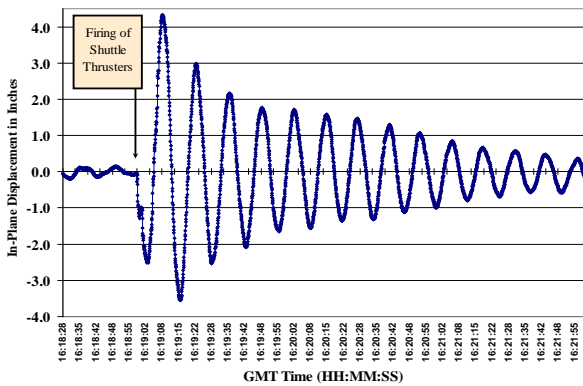
4D Photogrammetry



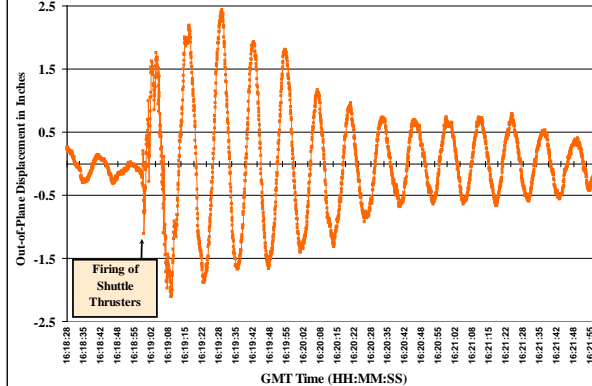
4D (Video)
Photogrammetry
used to quantify
the natural
frequency of the
solar array wings
on the ISS
beginning in
Nov. 2000



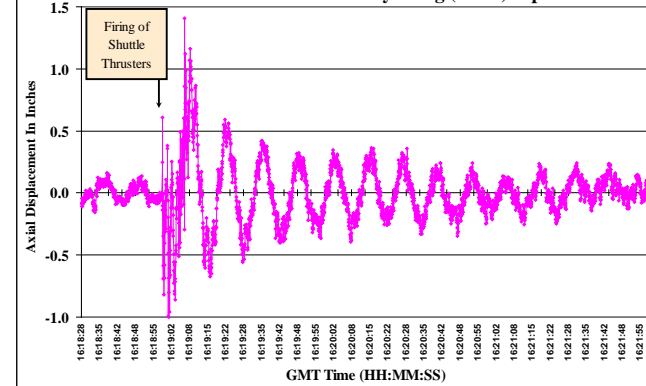
Example of In-Plane Displacement of Solar Array Wing (SAW) Tip



Example of Out-of-plane Displacement of Solar Array Wing (SAW) Tip

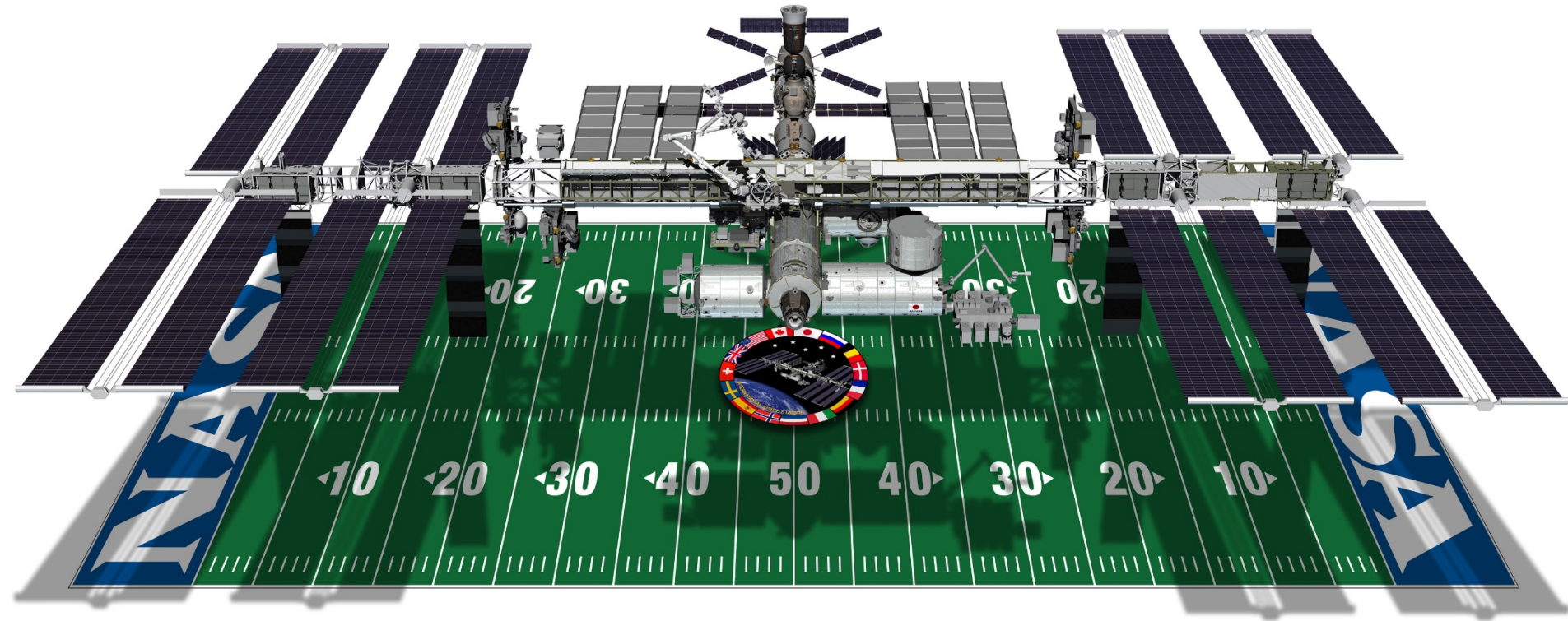


Example of Axial Displacement of Solar Array Wing (SAW) Tip





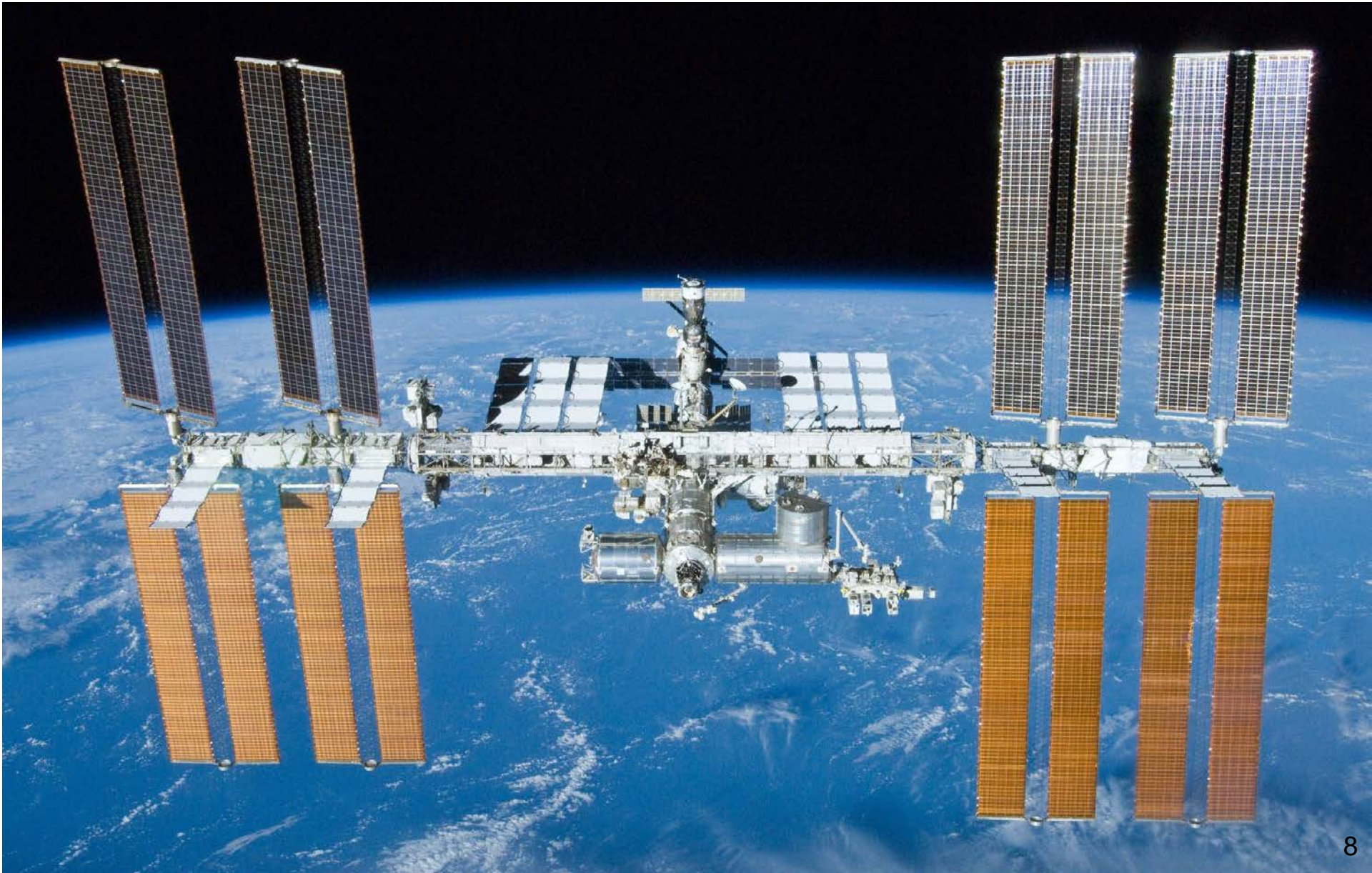
International Space Station (ISS)



- On-orbit assembly began in Nov 1998, Completed March 9, 2011
- Continuously occupied by 52 Expedition crews, since Nov. 2, 2000
- The size of an NFL football field, including the end zones.
- Pressurized Volume of 32,898 sq ft – equivalent to interior of a 747
- Solar powered by 8 solar arrays (120 x 39 feet each) generating 84 Kw
- Equipped with a 55 foot robotic arm capable of moving a 220,000 lb mass.
- Orbits Earth once every 90 minutes (4.7 miles/sec) at an altitude of ~250 miles
- Current Lifespan 2024, with work on going to extend life to 2028.

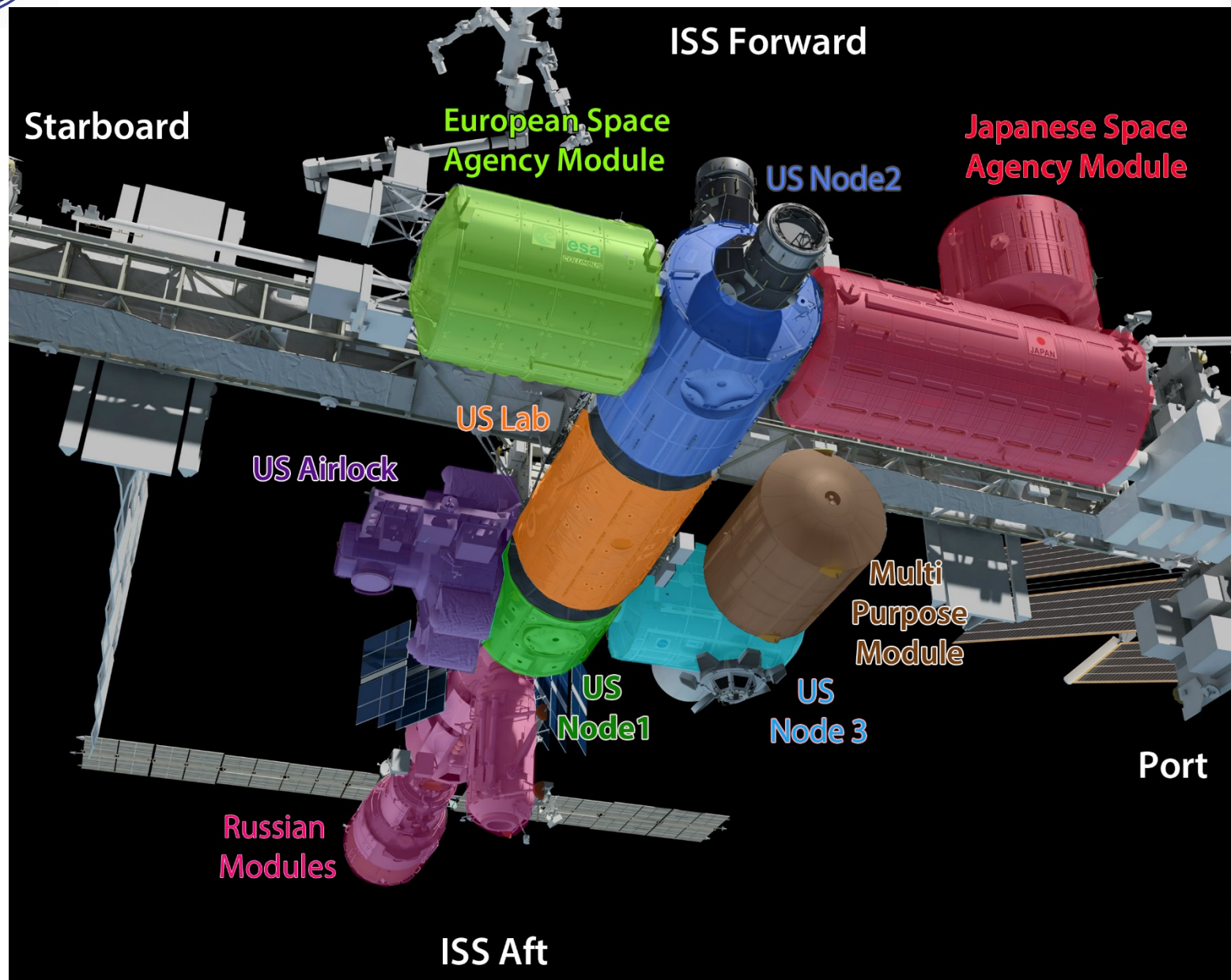


ISS as Seen from Space Shuttle Mission STS-132



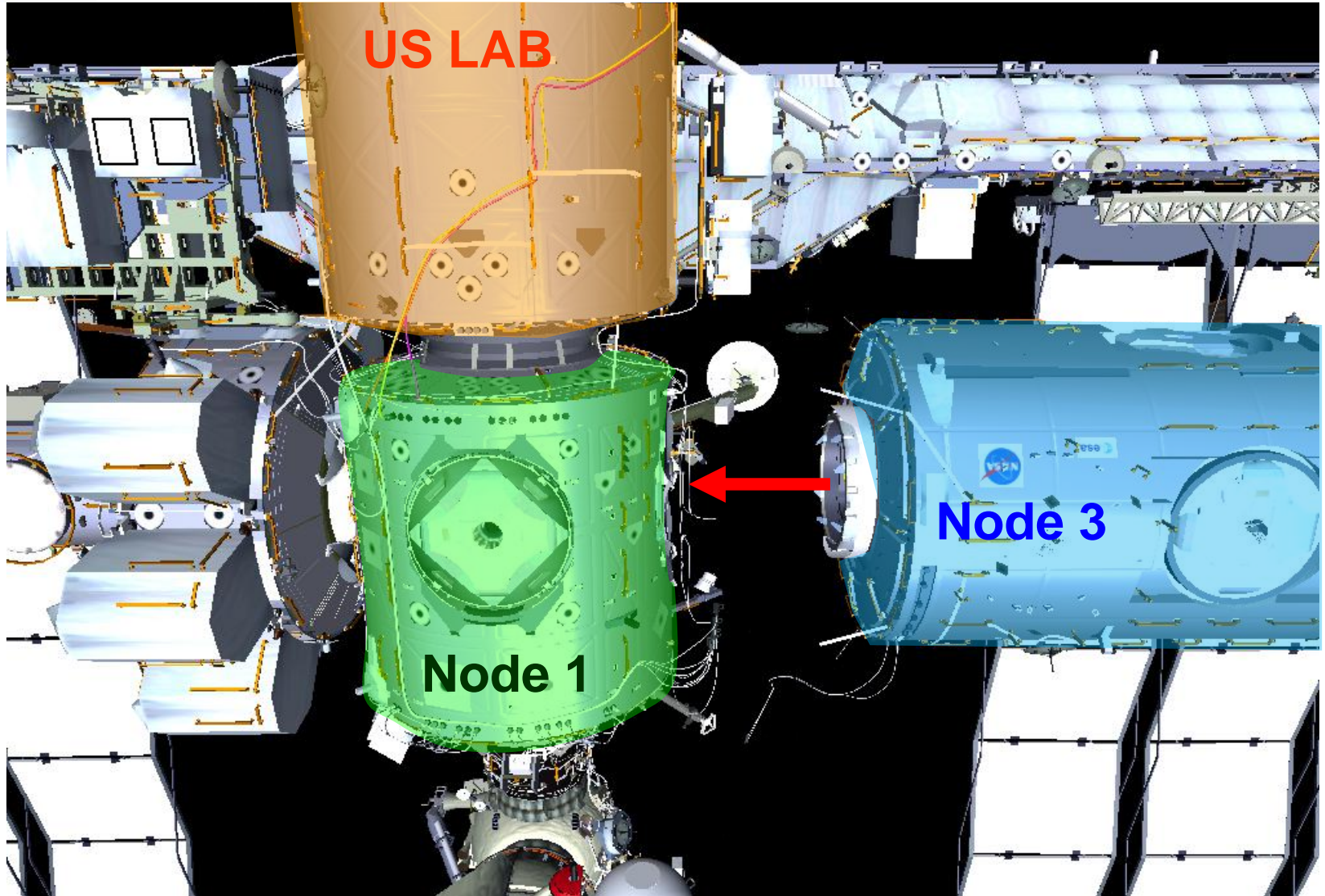


Pressurized Portion of ISS





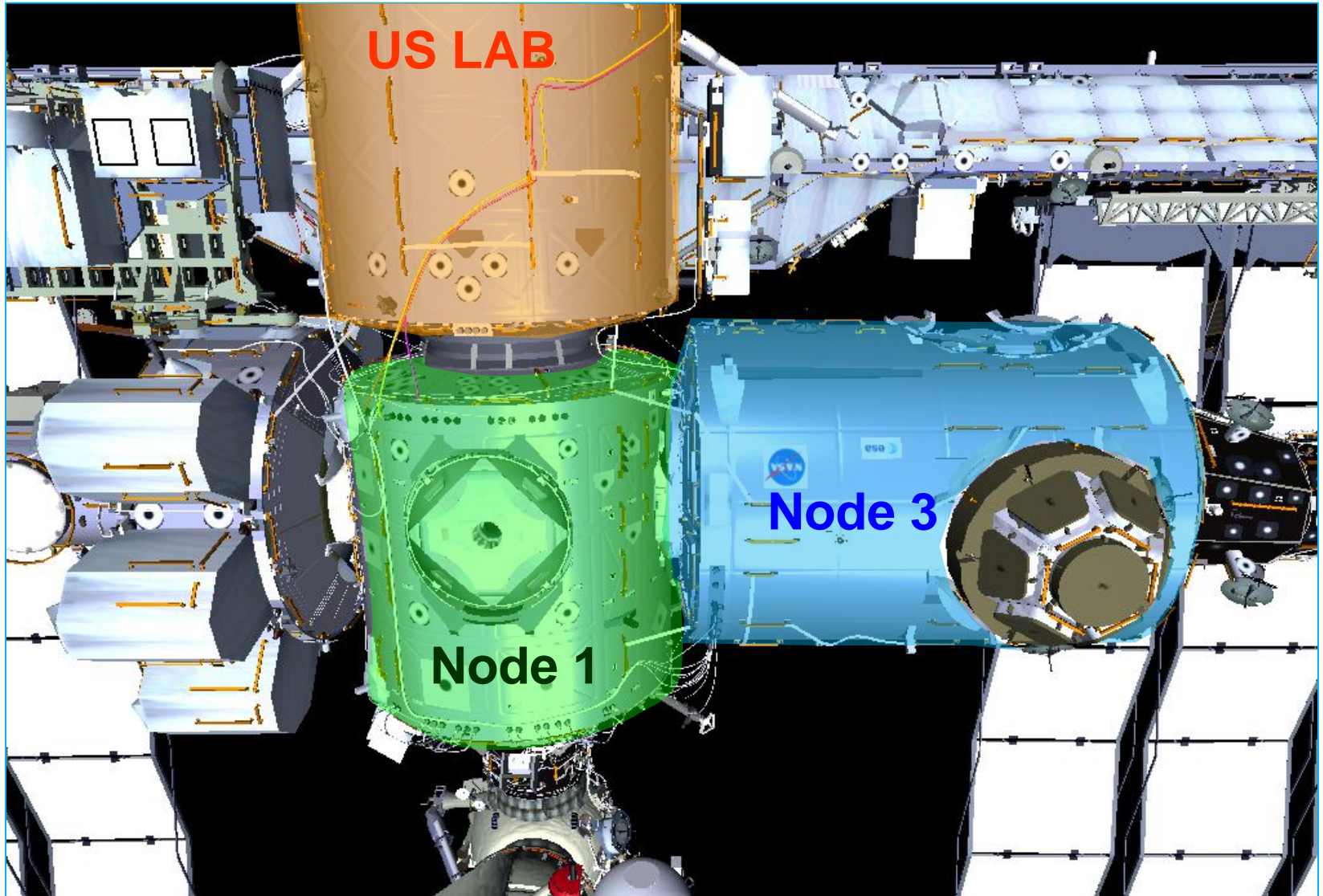
Task Background



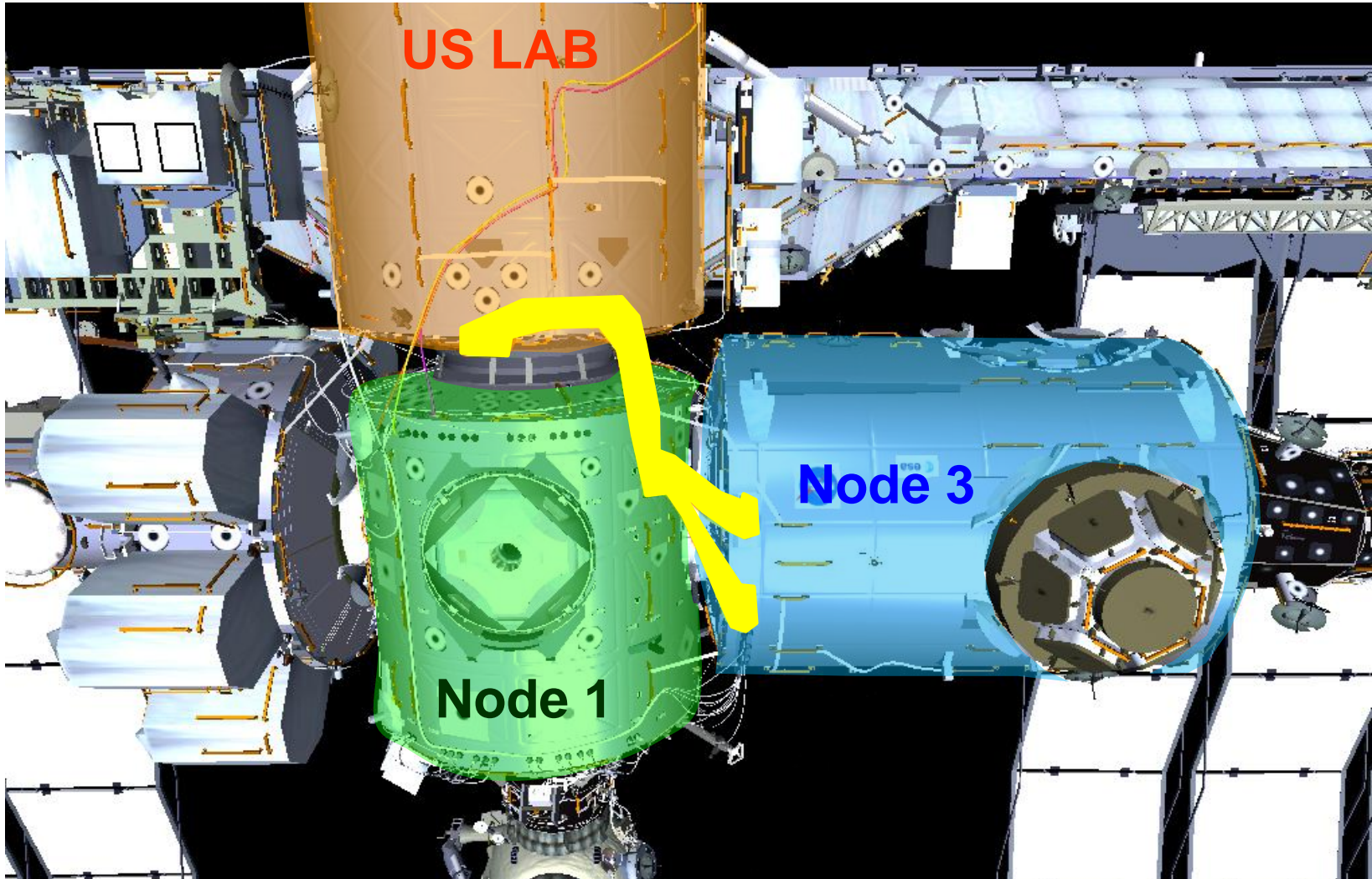
In February 2010, the Node 3 module was berthed to the Node 1, Port CBM.



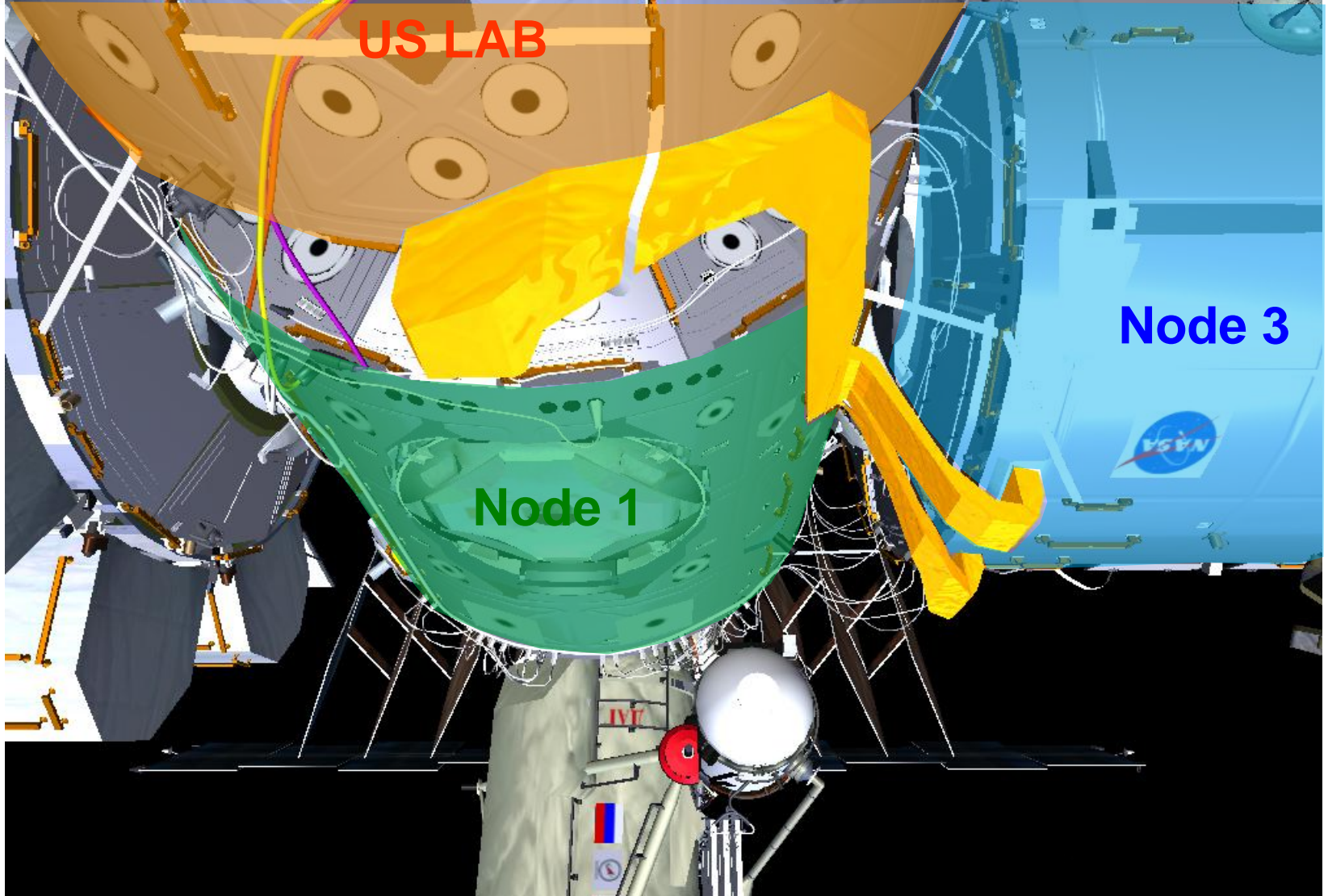
Node 3 Connected to Node 1



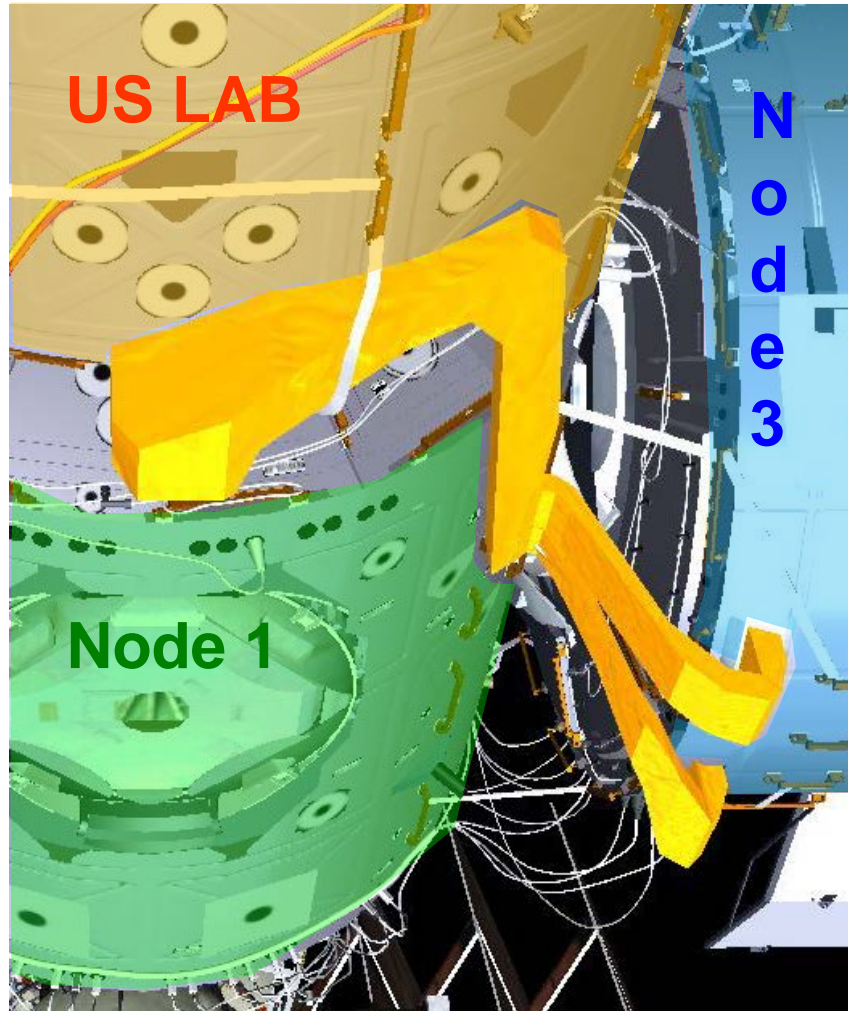
“Nodes” are a module containing 6 berthing ports, called Common Berthing Mechanisms (CBM) where other modules can be connected.



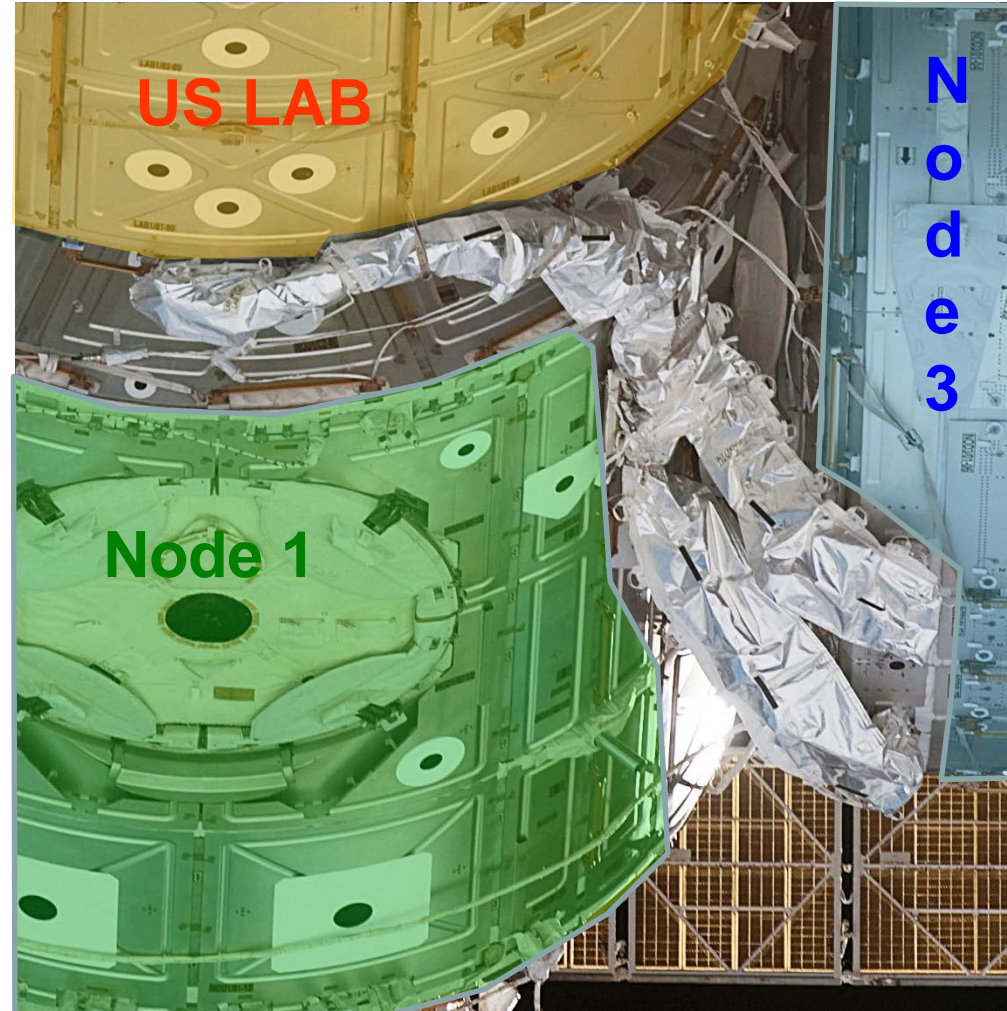
Since this was not the originally designed location for this module, external Ammonia coolant lines were installed between the US Lab module and Node 3.



A “generalized” CAD model was developed to represent the shape and position the ammonia lines wrapped in Multi-layer Insulation (MLI). 13



Generalized CAD of Ammonia Line

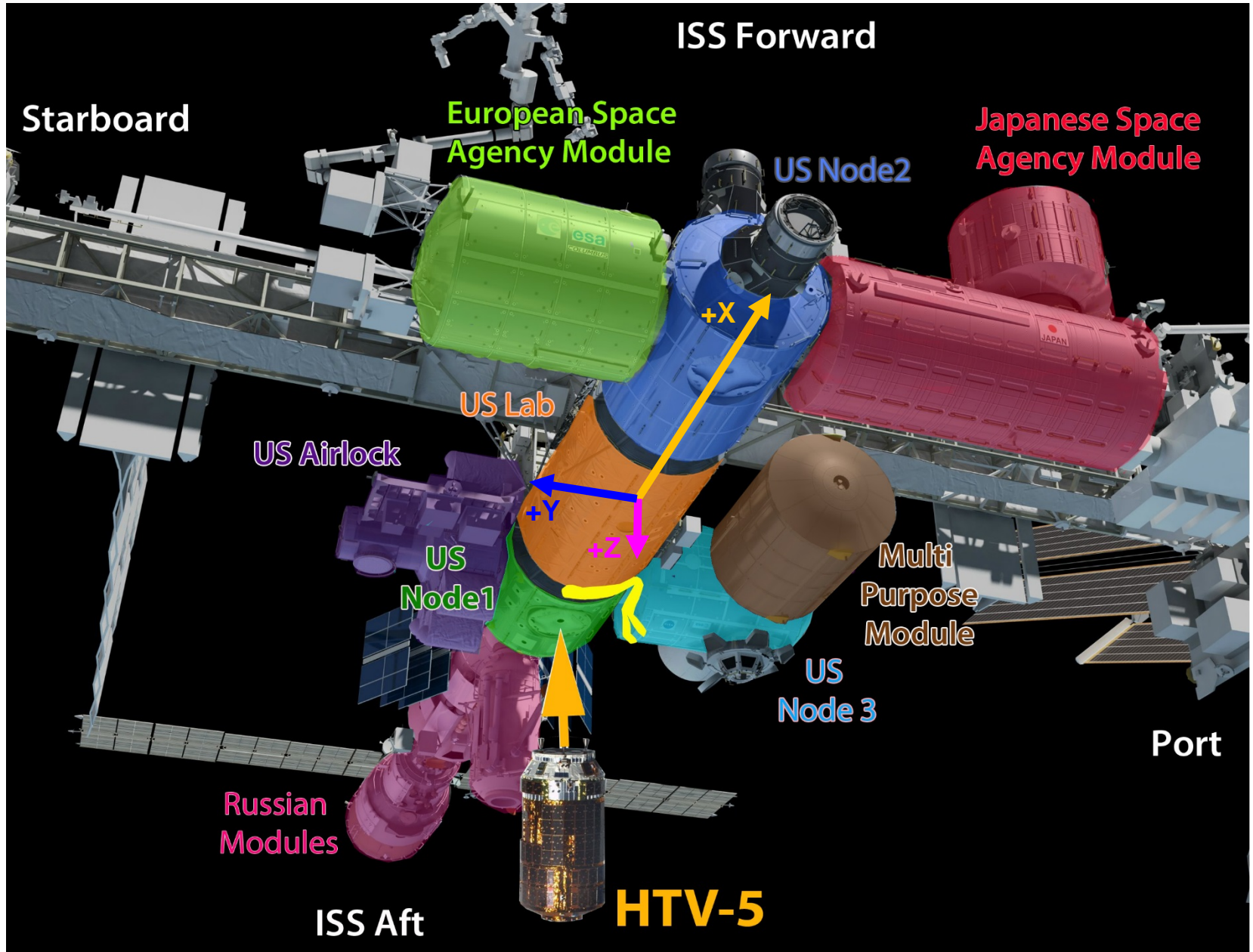


On-Orbit Installed Ammonia Line

The generalized CAD bore a modest resemblance to the actual lines installed on-orbit, but the accuracy of its location was not verified.

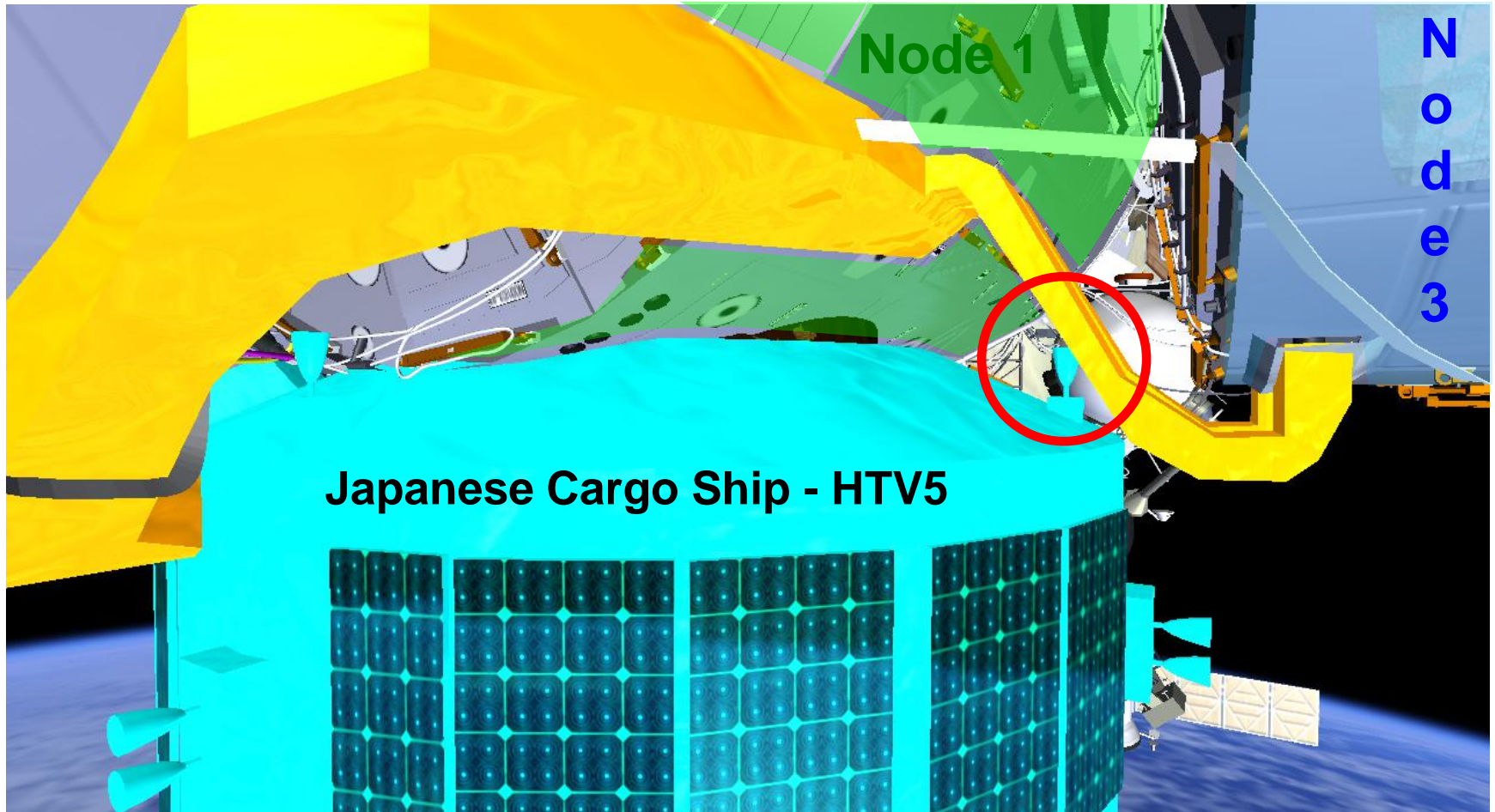


HTV-5 Berthed to Node 1, Nadir, Common Berthing Mechanism (CBM)

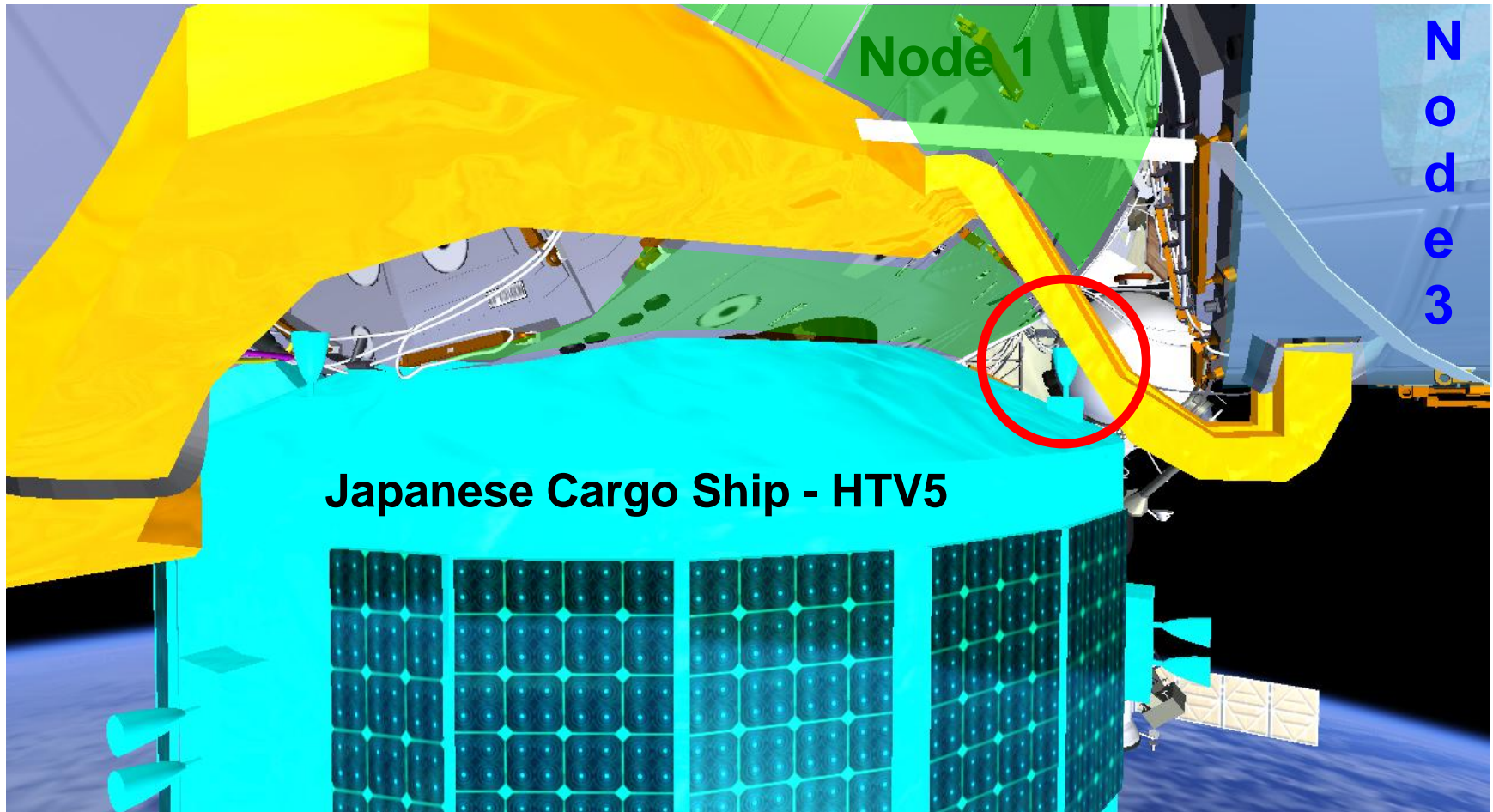




Problem



In April 2015 a CAD based analysis showed a four inch negative clearance between the generalized CAD model of the ammonia line and the port thruster nozzle on Japanese HTV Cargo Transfer Vehicle #5, (shown in blue) when berthed to the Node 1, Nadir CBM.



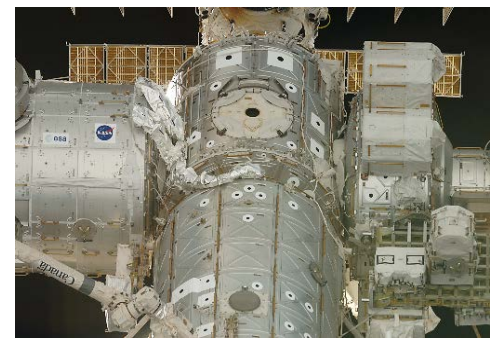
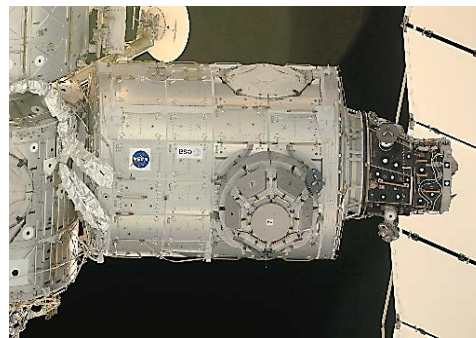
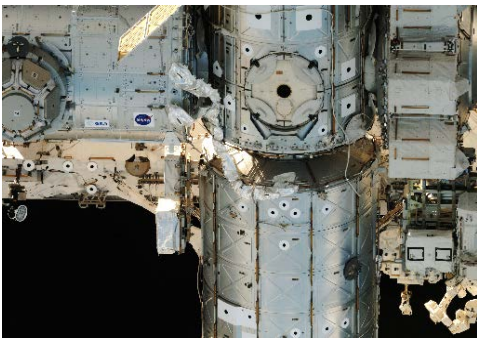
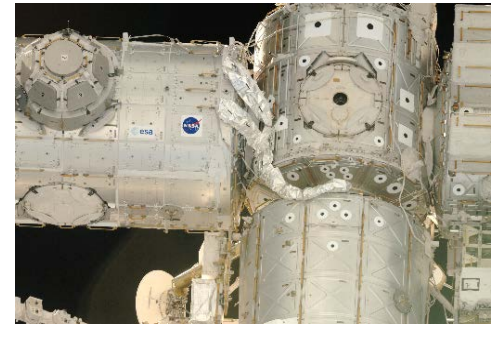
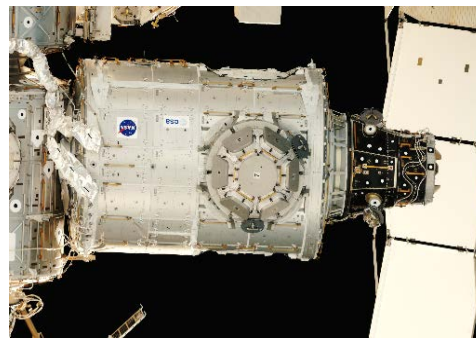
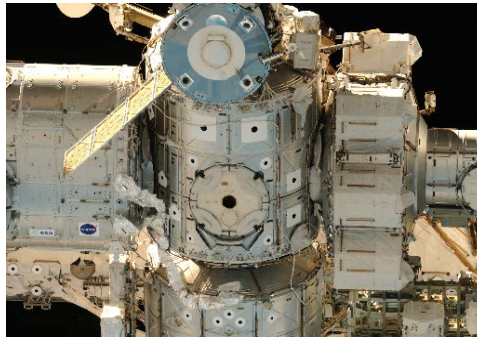
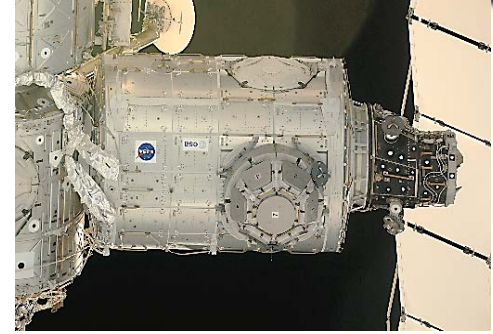
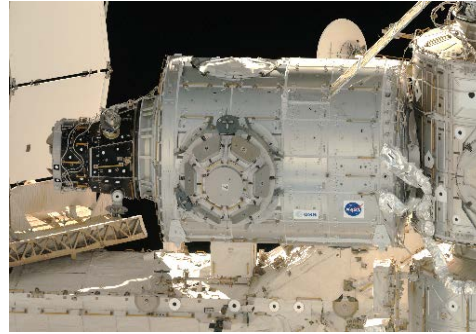
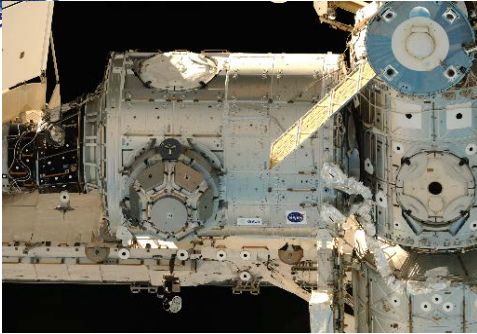
Recognizing that the CAD model was inaccurate, the ISS program requested that IS&AG measure the location of the on-orbit ammonia lines and compute the clearance between them and the berthed HTV5 thruster nozzle.



Task Setup



- **Objective:** Determine the on-orbit clearance between the as-installed position of the Nadir surface of the external ammonia line MLI cover and lip of the HTV-5 thruster nozzle when the vehicle is berthed to the Node 3, Nadir, Common Berthing Mechanism (CBM).
- **Accuracy:** +/- 1.0”
- **Imagery Resources:** Existing imagery from previous EVAs and Shuttle fly arounds of the ISS (new image acquisition not time feasible)
- **Analysis Coordinate System:** ISS Analytical Coordinate System (ISSACS)
- **Data Resources:**
 - Location (in ISSACS) of the position of the HTV thruster nozzle lip when the vehicle is berthed at the Node 3, Nadir, CBM, based on “pre-launch” DPA measurement of HTV-5.
 - DPA measurements of hardware visible on surface of Node 1 and Node 3 (Control)
 - IS&AG intrinsic camera data for several hundred camera / lens combinations.
- **Date Needed:** Yesterday (as usual) !



- A review of existing imagery showed that there was no imagery suitable for analysis after Expedition 23, in July 2011.
- The best available imagery was taken from a Space Shuttle fly-around in Feb 2010 (acquired with a Nikon D2Xs camera with a 400mm lens, from 600 feet).

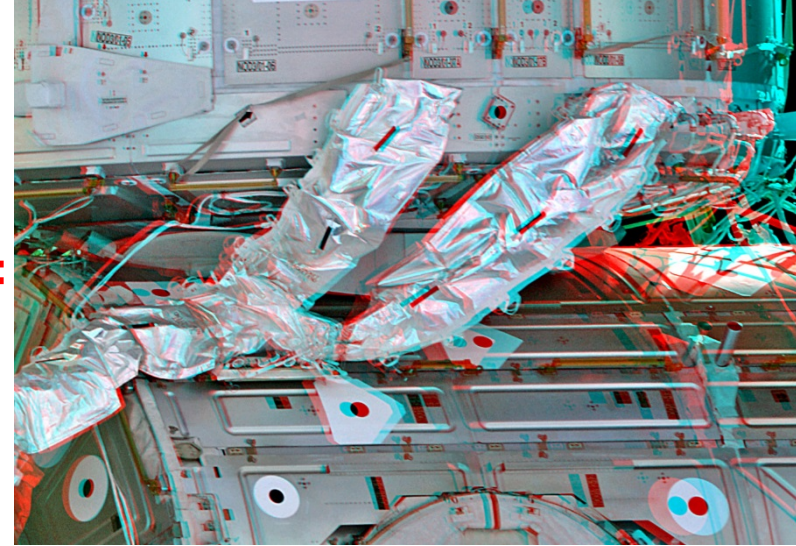
Creating Stereo Images



+

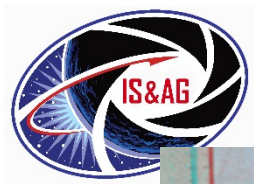


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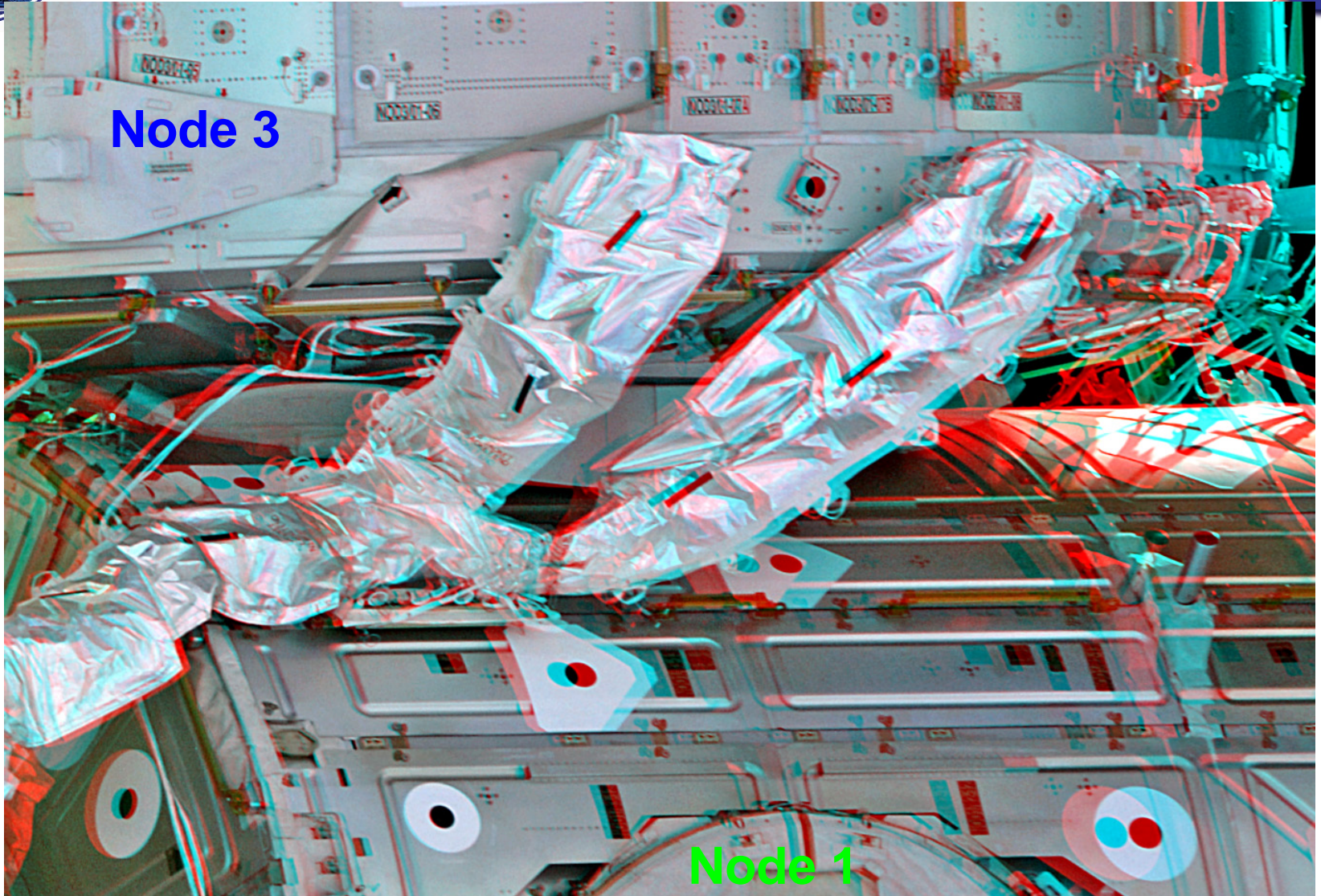


To view this image you must use Red/Cyan anaglyph glasses with the red lens over the left eye.

- Using the principles and mathematics of Photogrammetry, a 2D picture added to a second 2D picture, taken from a slightly different perspective, yields a 3D picture.
- The stereo image can not only be viewed in 3-D, but relative measurements of the objects can be made in the 3-D image.



Stereo Imagery of Ammonia Lines



Using control points on the exterior of the Space Station (SVS targets and hand rails stanchions), the analysis was transformed into ISSACS.



Stereo Imagery of Ammonia Lines



To view in 3-D you must use Red/Cyan anaglyph glasses with the red lens over the left eye.



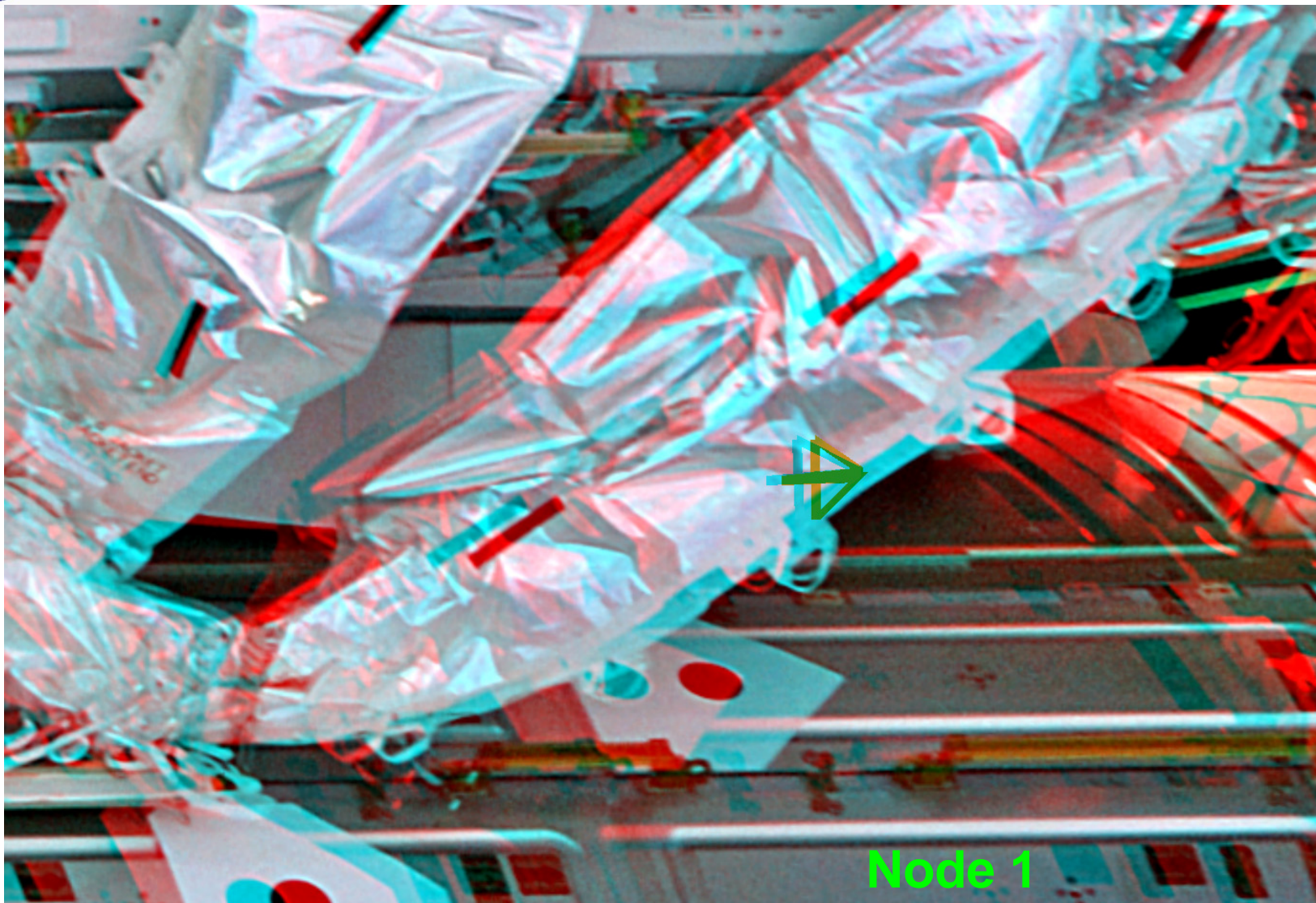
A closer view of the MLI wrapped ammonia lines.



Stereo Imagery with HTV5 Thruster Location Indicated



To view in 3-D you must use Red/Cyan anaglyph glasses with the red lens over the left eye.



The nominal berthed position of the HTV5 Thruster Nozzle in ISSACS was displayed in the stereo image above (as indicated by the green triangles).



Stereo Imagery with HTV5 Thruster Location Indicated



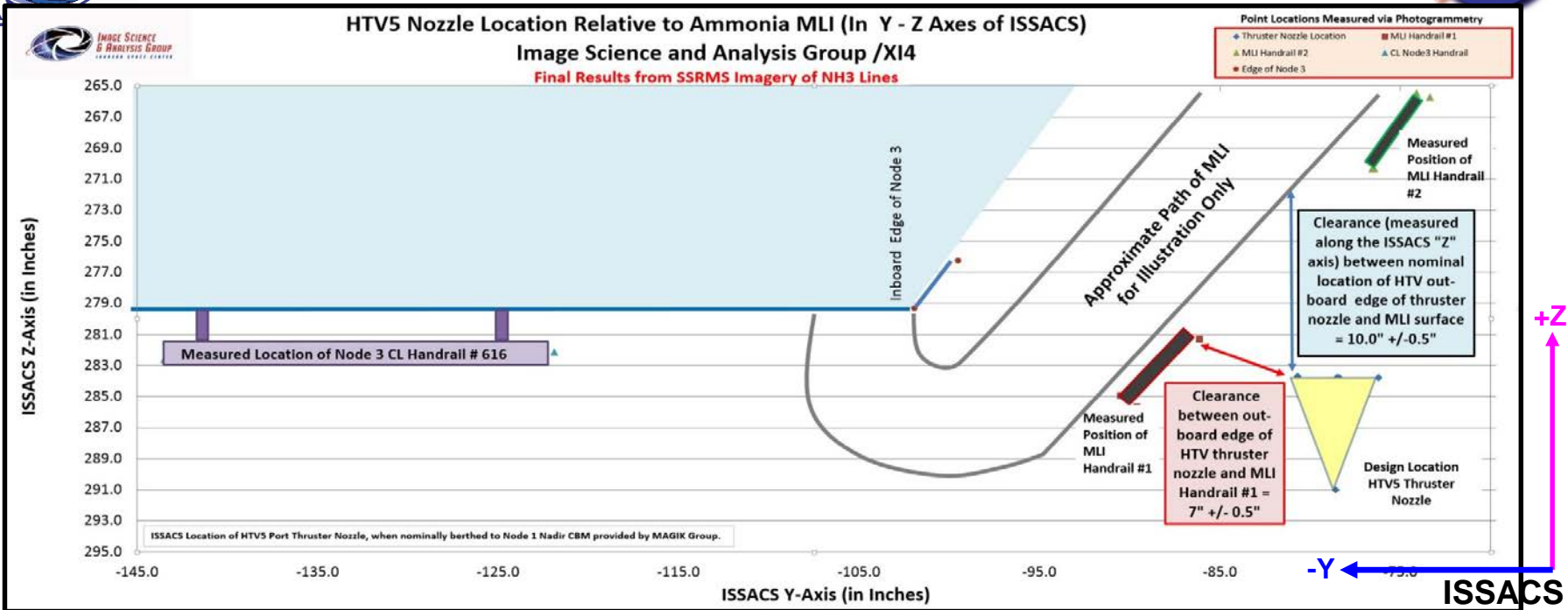
To view in 3-D you must use Red/Cyan anaglyph glasses with the red lens over the left eye.



The visible clearance between the thruster nozzle location and the surface of the MLI wrapped ammonia lines indicates positive clearance.



Numerical Measurement of Clearance



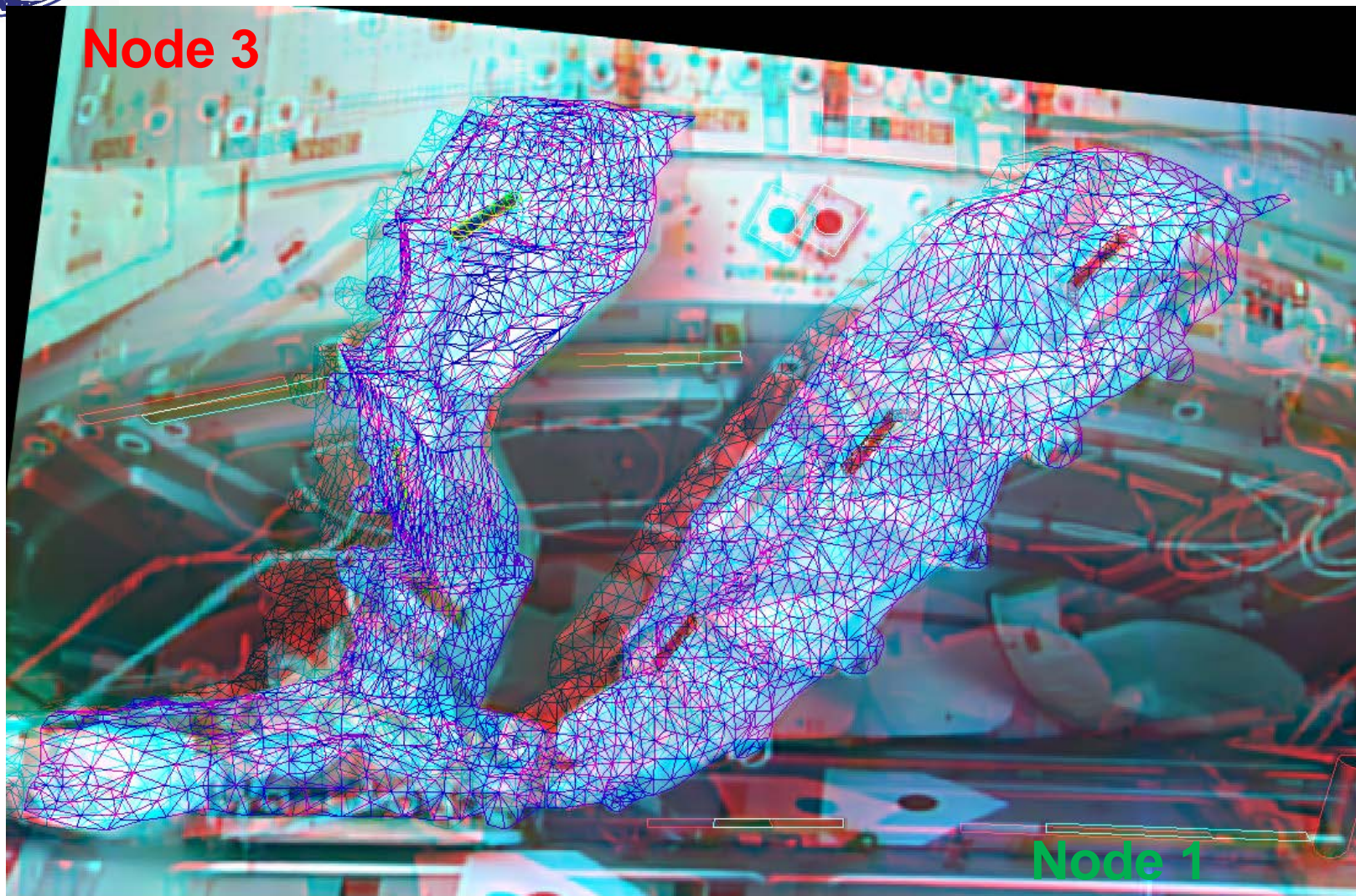
Numerical analysis confirmed a minimum 10" positive clearance between the HTV5 Port Thruster Nozzle and the "as-installed" MLI surrounding the Ammonia Lines.



Full CAD Model of On-Orbit Configuration



To view in 3-D you must use Red/Cyan anaglyph glasses with the red lens over the left eye.



As this analysis only accounted for a nominal HTV5 berthing configuration, IS&AG then produced a CAD model of the full MLI surface which was used to conduct a clearance analysis for off-nominal berthing configurations.



Summary of Image Analysis Task



- The initial analysis to prove positive clearance was completed over a 2 day weekend, by a single analyst.
- As the initial analysis used imagery from 2010, the ISS program approved a resurvey to acquire new imagery in the summer of 2015.
- Final results using the 2015 imagery confirmed a minimum 10" +/- 0.5" positive clearance between the HTV5 Port Thruster Nozzle and the "as-installed" MLI wrapped ammonia lines.
- IS&AG used photogrammetry to generate a CAD model of the current MLI wrapped surface of the ammonia lines.
- The IS&AG CAD proved that there was positive clearance between the thruster nozzle and the MLI wrapped lines regardless of the berthing configuration.
- The IS&AG produced CAD model of the MLI wrapped ammonia lines will replace the "generalized" model in the master ISS CAD database.

Most Importantly: The results of this analysis relieved the ISS program of the need to conduct an EVA (space walk) to relocate the ammonia lines, along with the time and cost of planning the activity.