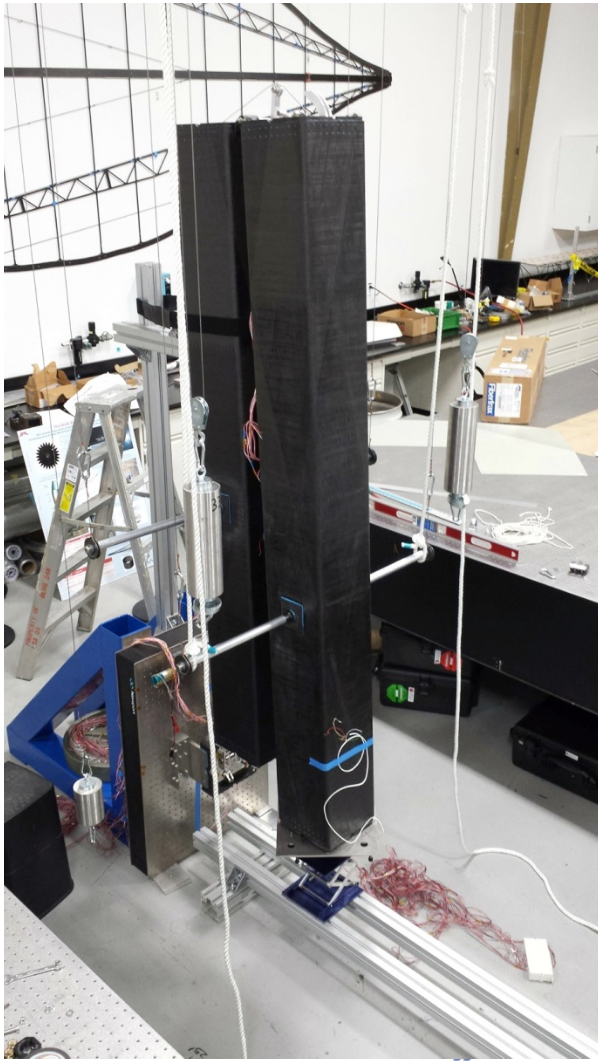
National Aeronautics and Space Administration

ACT-10-0043 PRECISION DEPLOYABLE MAST FOR THE SWOT* KARIN INSTRUMENT:



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Jet Propulsion Laboratory
California Institute of Technology

October 29th, 2014

*Mission Concept – Pre-decisional – for Planning and Discussion Purposes Only

Team

- Greg Agnes – PI
- Mark Thomson – Co-I
- Lee Peterson – Co-I
- Ernesto Rodriguez – Co-I
- Richard Hughes – Collaborator, SWOT* MSE
- Jeff Waldman – CogE / Analyst
- Dan Kahn – Design / Test
- Mickey Hui - Designer

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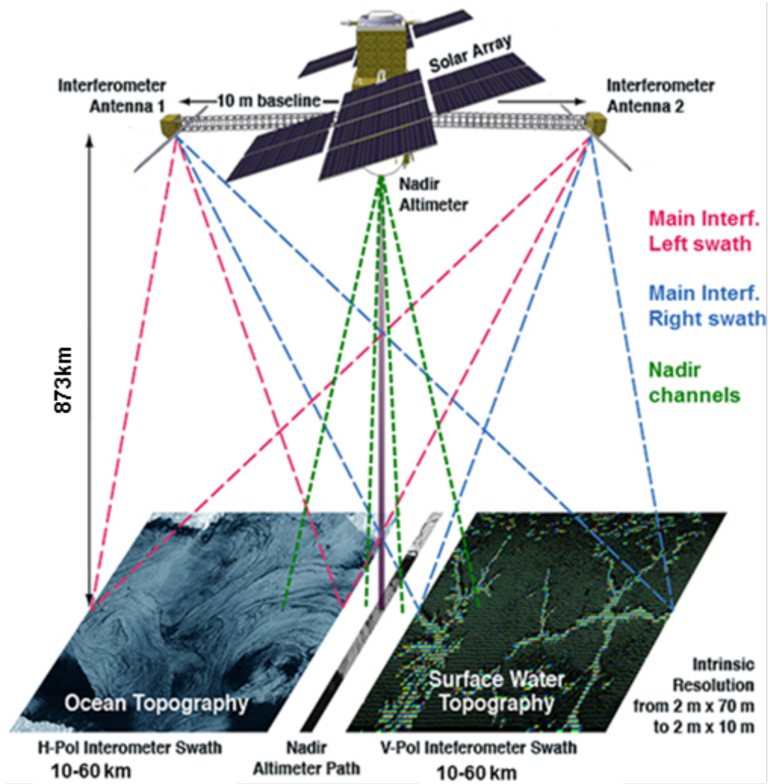
SWOT* Mission Concept

Mission Science

Oceanography: Characterize the ocean mesoscale and sub-mesoscale circulation at spatial resolutions of 15 km and greater.

Hydrology: To provide a global inventory of all terrestrial water bodies whose surface area exceeds $(250m)^2$ (lakes, reservoirs, wetlands) and rivers whose width exceeds 100 m (requirement) (50 m goal) (rivers).

- To measure the global storage change in fresh water bodies at sub-monthly, seasonal, and annual time scales.
- To estimate the global change in river discharge at sub-monthly, seasonal, and annual time scales.



Mission Architecture

- Ka-band SAR interferometric (KaRIn) system with 2 swaths, 50 km each
- Produces heights and co-registered all-weather imagery
- Use conventional Jason-class altimeter for nadir coverage, radiometer for wet-tropospheric delay, and GPS/Doris/LRA for POD.
- On-board data compression over the ocean (1 km^2 resolution). No land data compression onboard.

- Partnered mission with CNES & CSA
- Science mission duration of 3 years
- 873 km Orbit, 78º Inclination, 22 day repeat
- Flight System: ~1700Kg, ~1900W
- Launch Vehicle: NASA Medium class
- Cat 2 Project, Risk Class: C (TBC)
- Target Launch Readiness: Oct 2020

Task objectives

- Objective Reduce the SWOT* mission's performance margin and cost risk by designing and prototyping a lightweight, precision-deployable mast for the SWOT* KaRIn antenna.
- Specifically, we :
  - Built a full-scale, deployable prototype of the SWOT* KaRIn Mast
  - Performed deployment testing on the prototype and access its repeatability.
  - Developed a lightweight pointing adjustment mechanism.
  - Initiated a nonlinear, multiphysics model of the deployment precision and post-deployment thermal soak stability.

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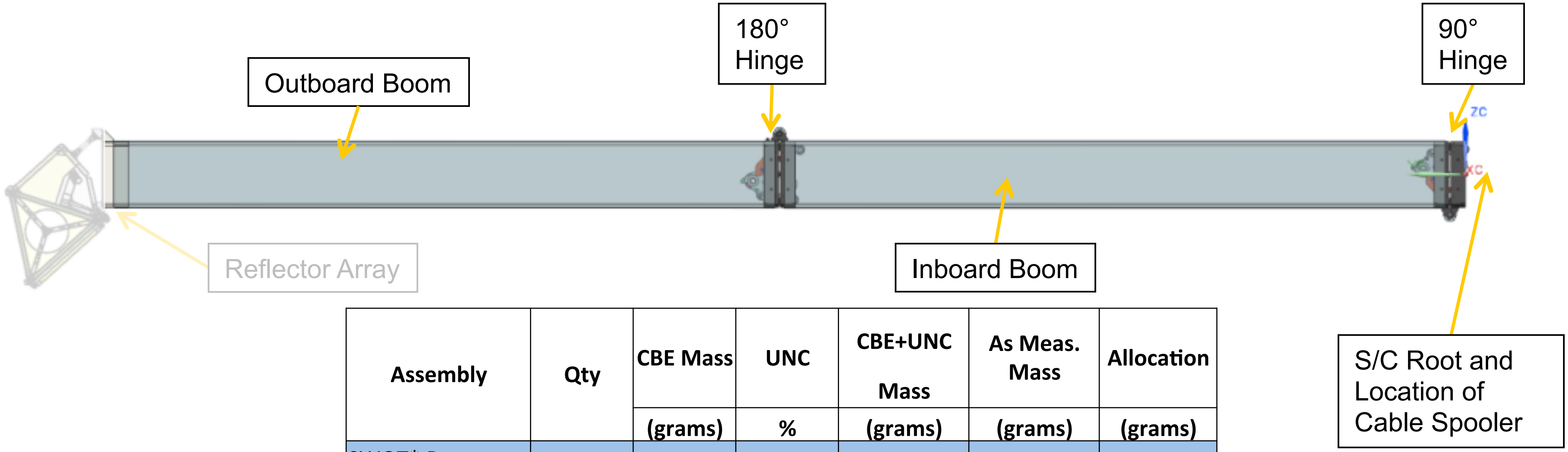
Mass Summary



Assembly	Qty	CBE Mass (grams)	UNC %	CBE+UNC Mass (grams)	As Meas. Mass (grams)	Allocation (grams)
SWOT* Boom Assy	1	19519	30%	25375	19685	41200
Hinge Assy	2	3529	30%	4588	3583	
Cable	1	65	30%	85	65	
Cable Spooler	1	0	30%	0	0	
Inboard Boom	1	6930	30%	9009	6824	
Outboard Boom	1	4654	30%	6050	4643	
Center Pulley	1	140	30%	182	132	
Outboard Boom Close Out	1	672	30%	874	700	

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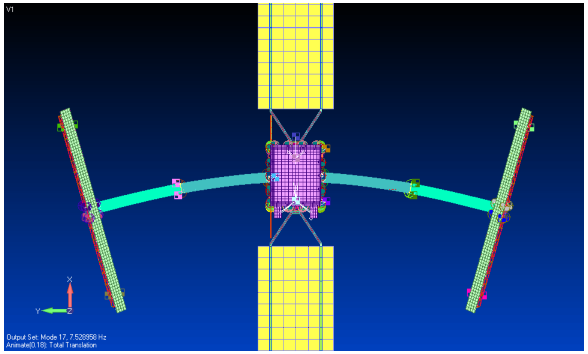
Earth Science Technology Office

Frequency

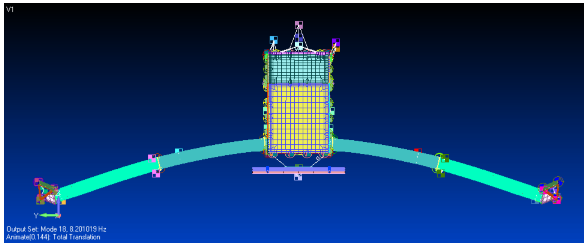
- Model assumes a reflector array mass of 24.0 kg.
  - This is the same for both the model with the adjustment mechanism and without the adjustment mechanism
- The first mode of the system meets the 7Hz frequency requirement.
  - **<u>Requirement:</u>** The deployed modal frequencies of a 2 mast antenna attached to the metering structure in a complete S/C configuration in a free-free environment shall be greater than 7Hz.

Mode	Frequency (Hz)					
	No Array Adjustment Mech.			With Array Adjustment Mech.		
	CBE	CBE+UNC	Alloc.	CBE	CBE+UNC	Alloc.
7	7.53	7.44	7.28	7.43	7.35	7.20
8	8.20	8.08	7.87	8.18	8.06	7.85
9	8.97	8.96	8.95	8.70	8.69	8.69

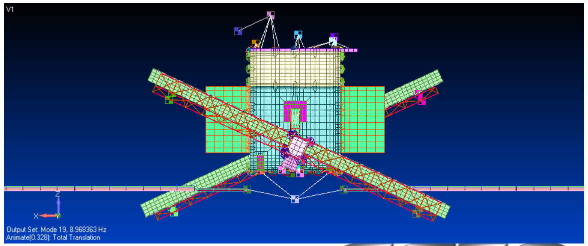
<u>Mode 7:</u>
Z Axis Bend Mode



<u>Mode 8:</u>
X Axis Bend Mode



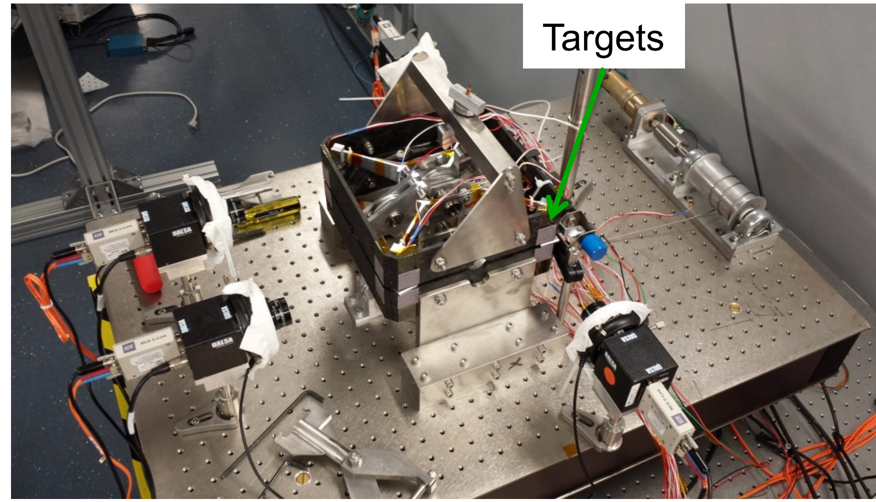
<u>Mode 9:</u>
Y Axis Torsion Mode

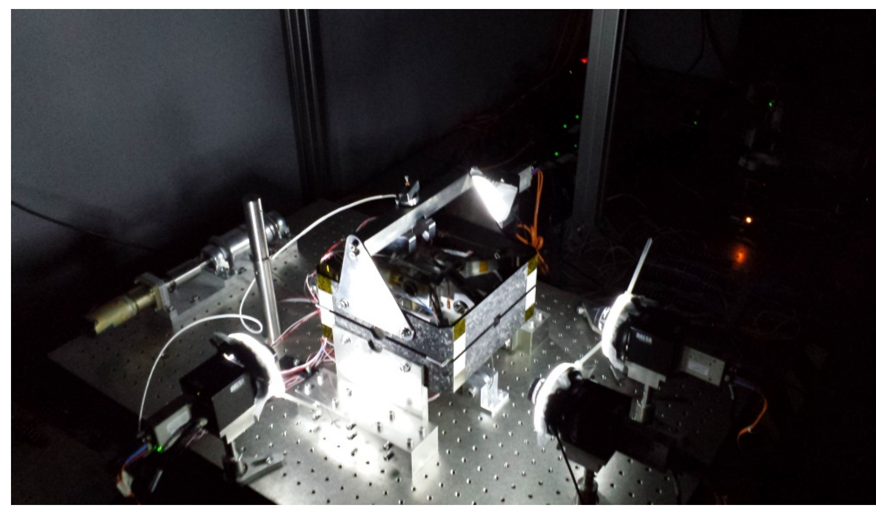


Hinge Testing

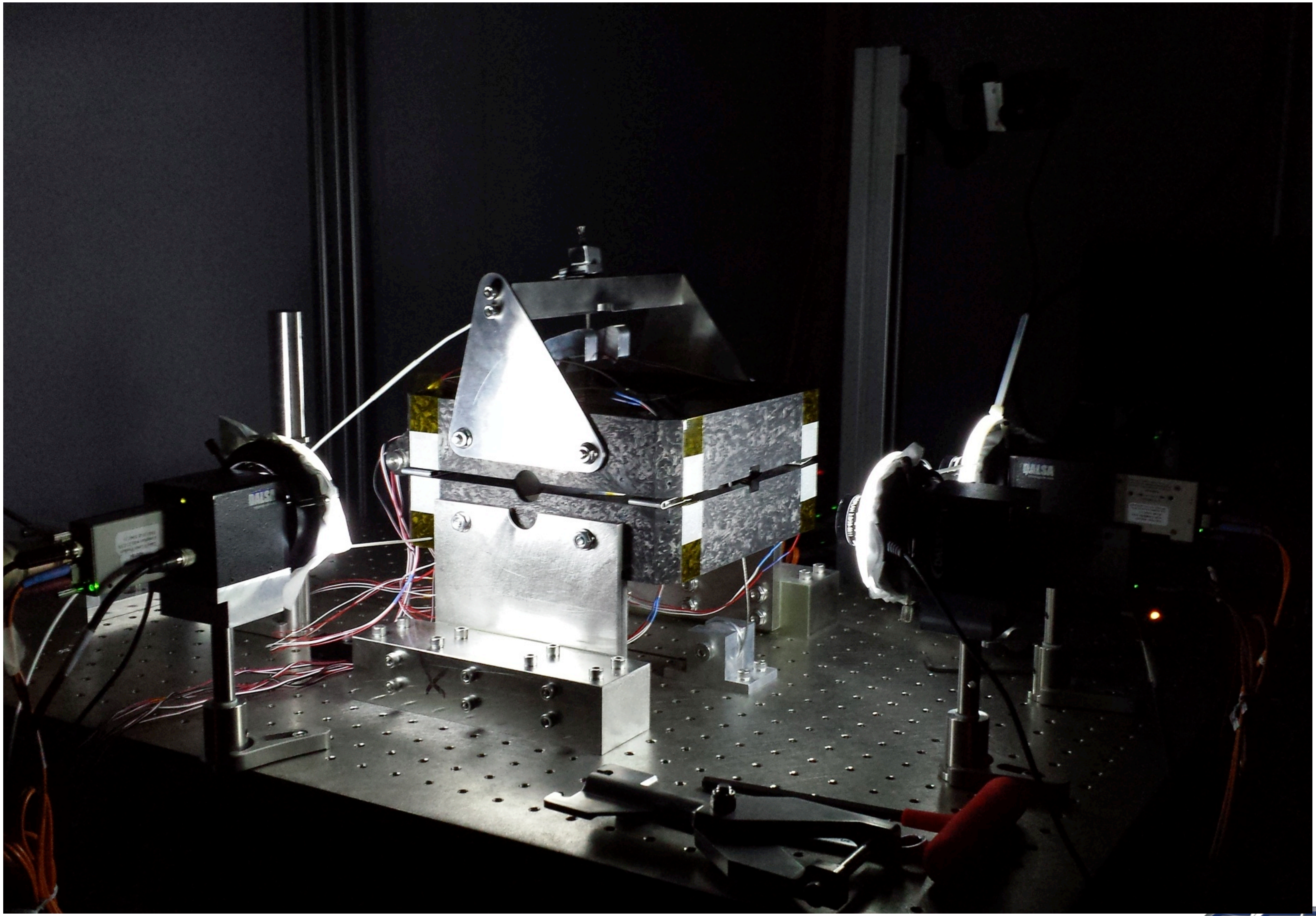
Hinge Testing
Test Set-up

- Test set-up is similar for both the 90 degree root hinge and 180 degree mid-hinge.
- 4 cameras set up around the hinge to image targets affixed to the hinge bodies.
  - Each camera sees 2 targets, one on the upper hinge body and one on the lower hinge body.
- Each camera uses NAMS (nano meter accurate measuring system) to measure the relative motion between the hinge bodies.
- These recorded motions are used to calculate the rigid body translation and rotation of the upper hinge body relative to the lower hinge body.





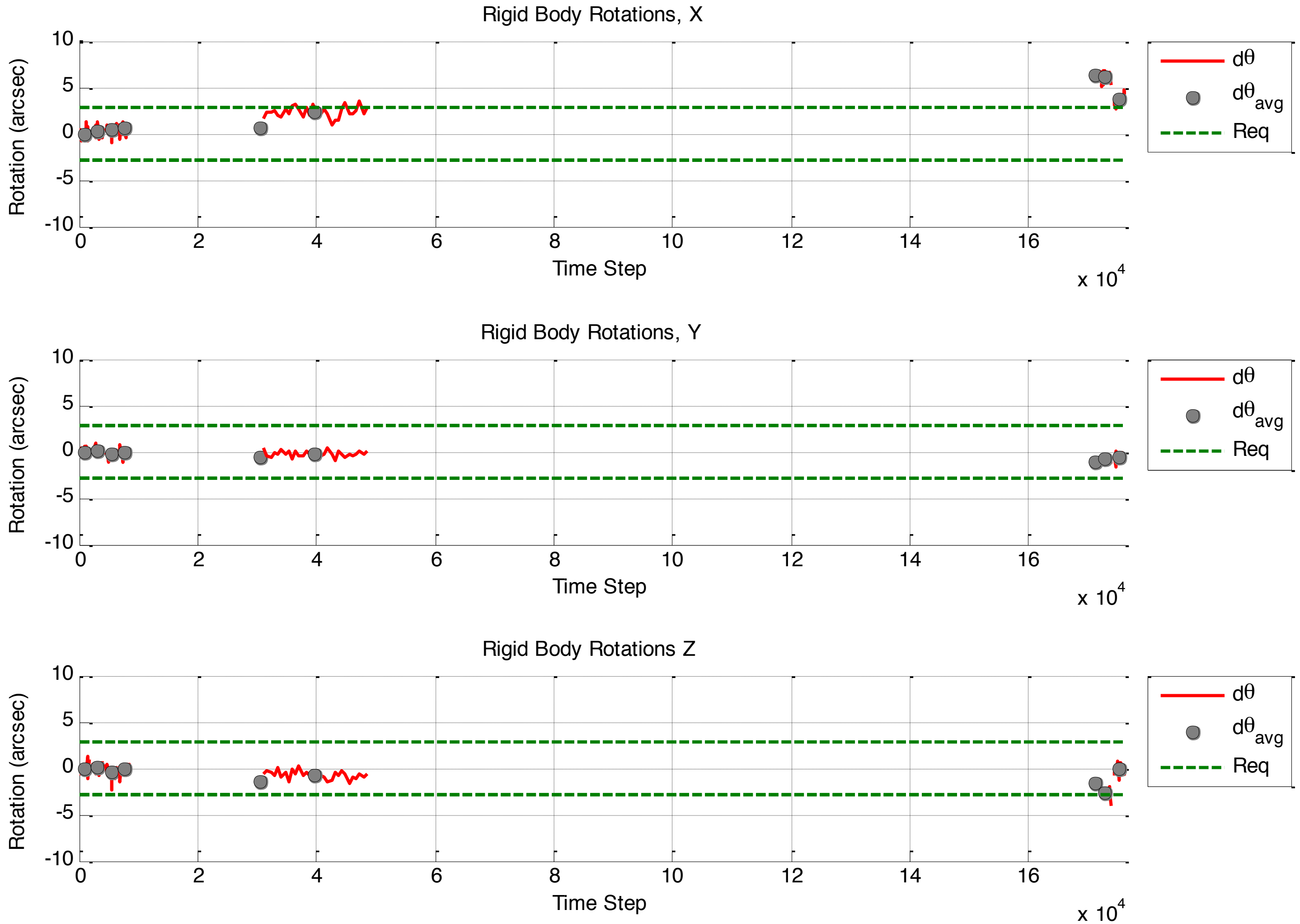
Results – Both Hinge Bodies have completed lab testing



Earth Science Technology Office

Root Hinge 90 degrees
No lubrication on balls

Hinge Testing
Test Results



- Grey circles show the average pointing error for each deployment.
  - Some excursions from the requirement are shown due to not using any lubricant on the balls.

ESTO
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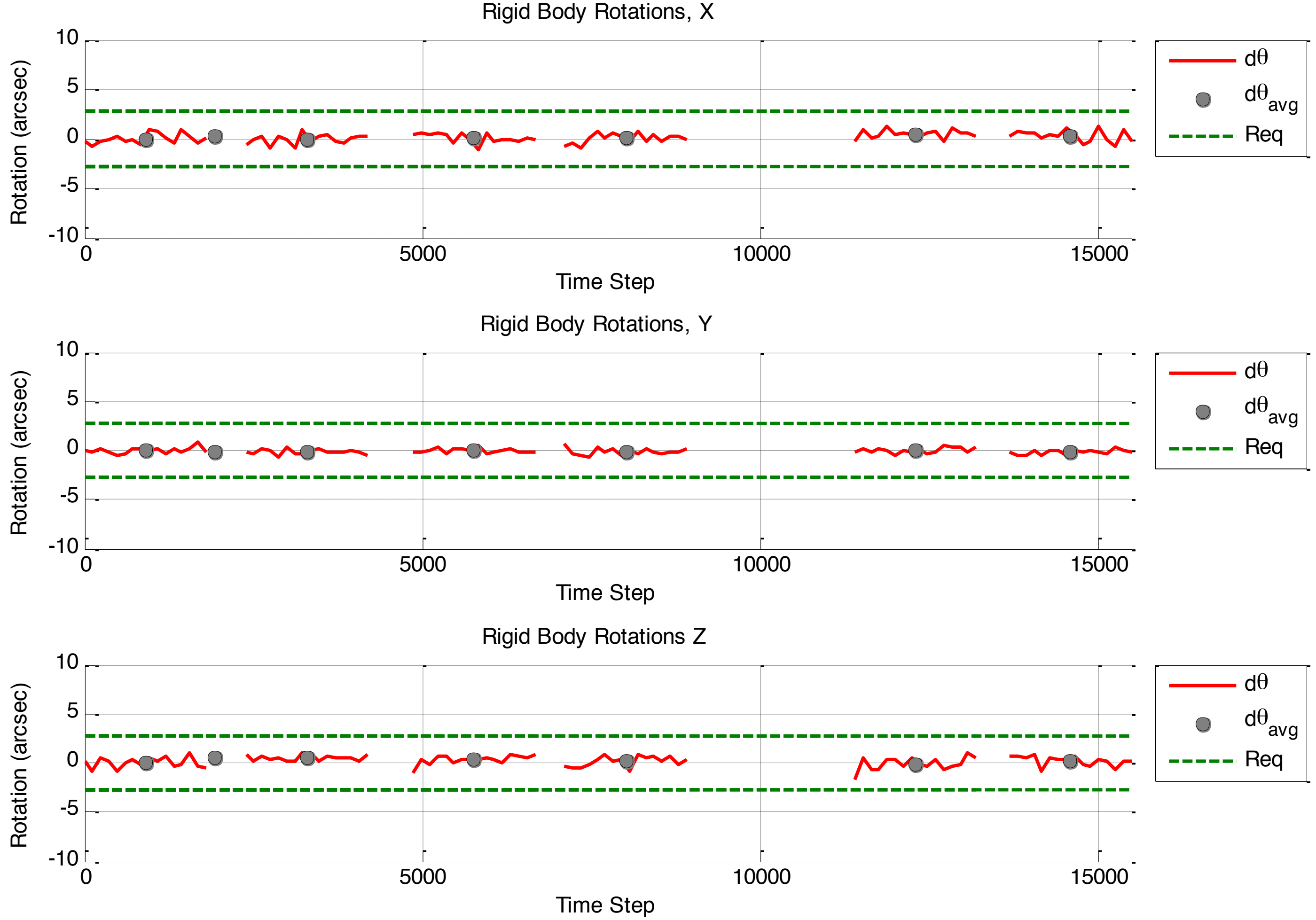
Root Hinge 90 degrees
With Moly lube on balls

Hinge Testing
Test Results

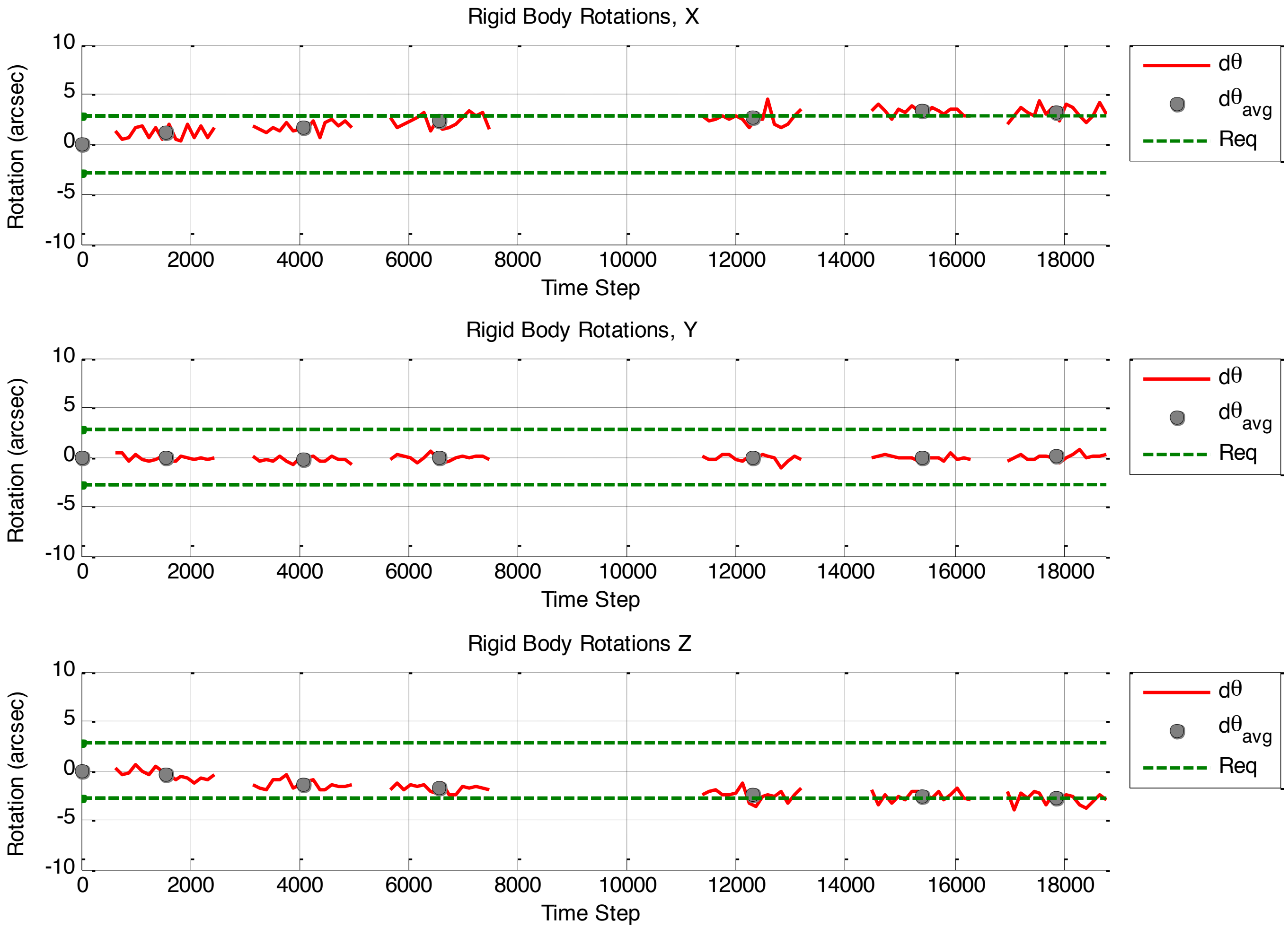


- Grey circles show the average pointing error for each deployment.
- Moly disulfide coated balls greatly improves the repeatability. Now all cases are well within the requirement.

Earth Science Technology Office

Mid Hinge 180 degrees
No lubricant on balls

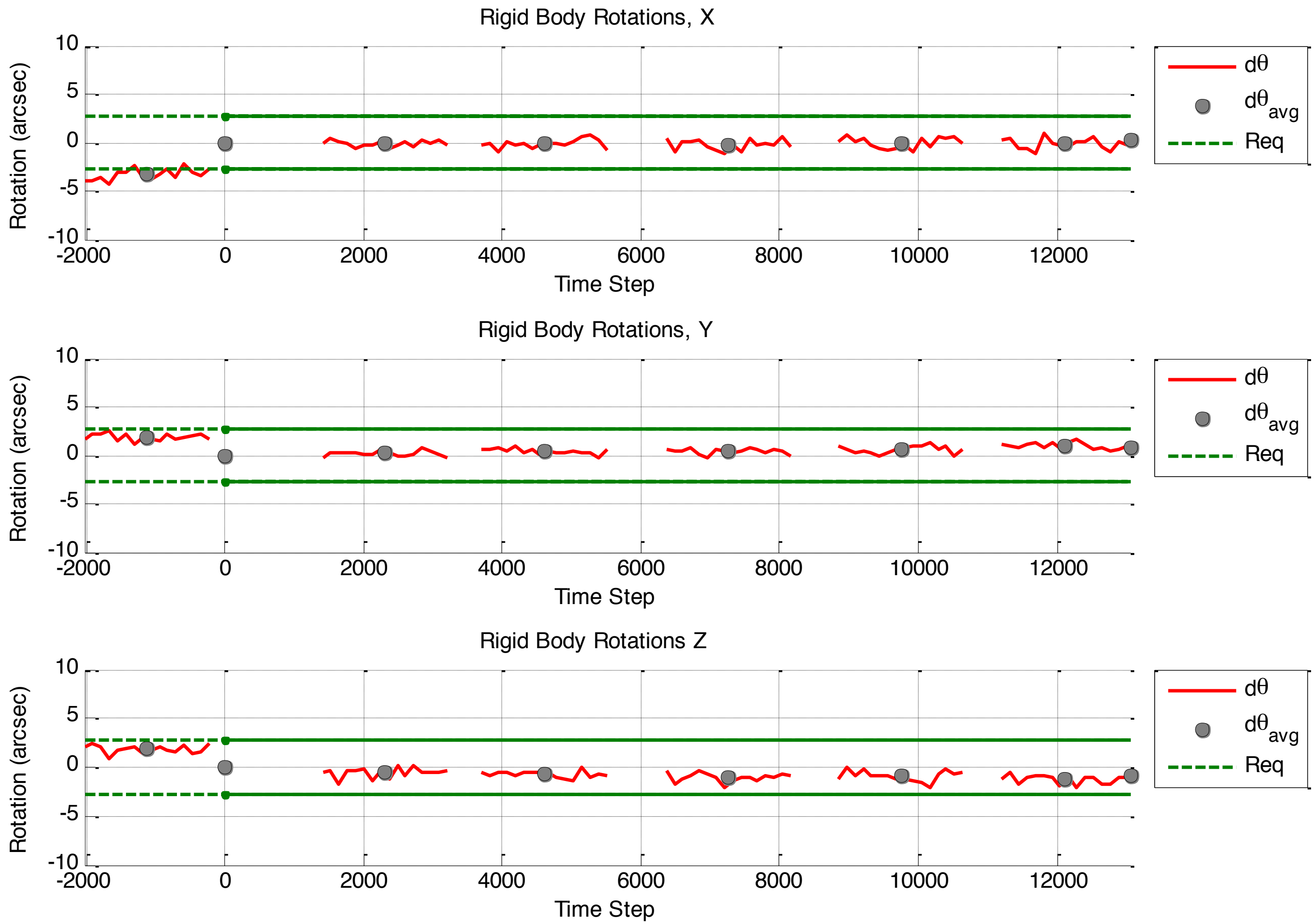
Hinge Testing Test Results



- Grey circles show the average pointing error for each deployment.
  - Some excursions from the requirement are shown due to not using any lubricant on the balls.

Mid Hinge 180 degree
With Moly lube on balls

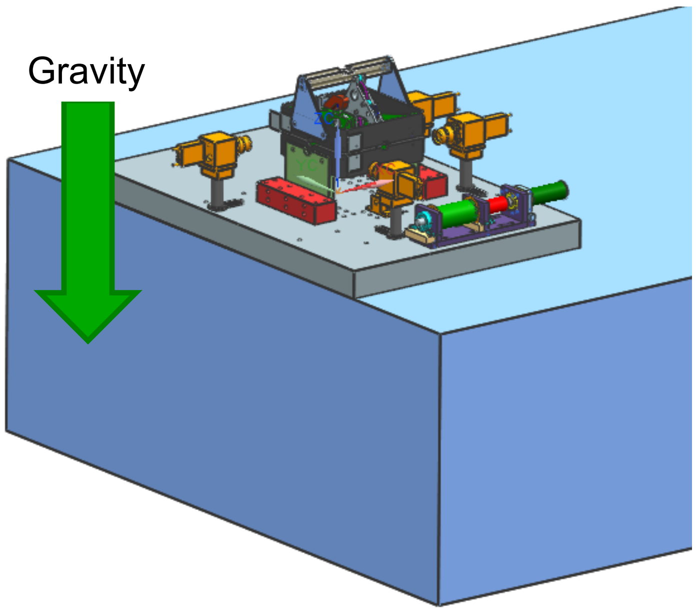
Hinge Testing
Test Results



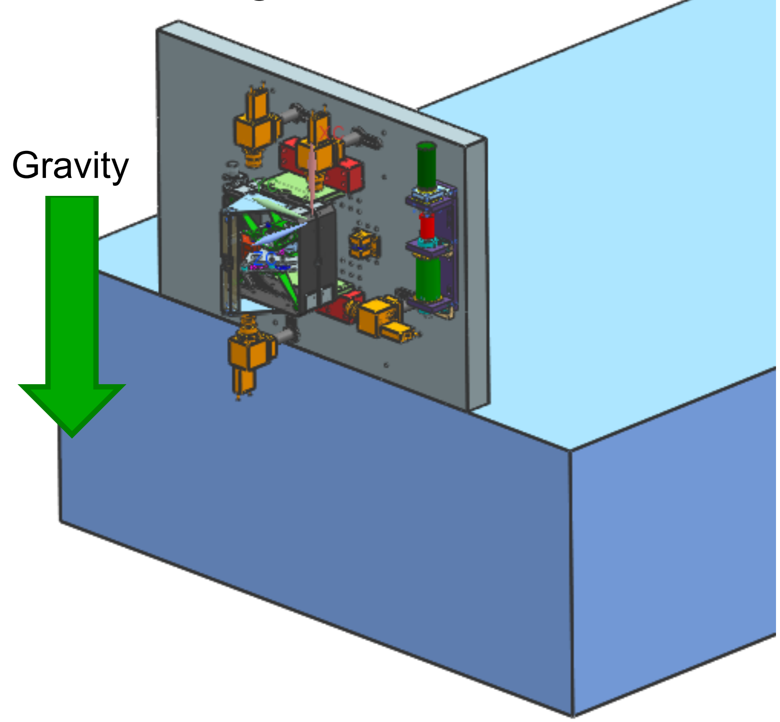
- Grey circles show the average pointing error for each deployment.
- Moly disulfide coated balls greatly improves the repeatability. Now all cases are well within the requirement.

Hinge Testing
90 degree rotation of set up

Hinge Standard Orientation



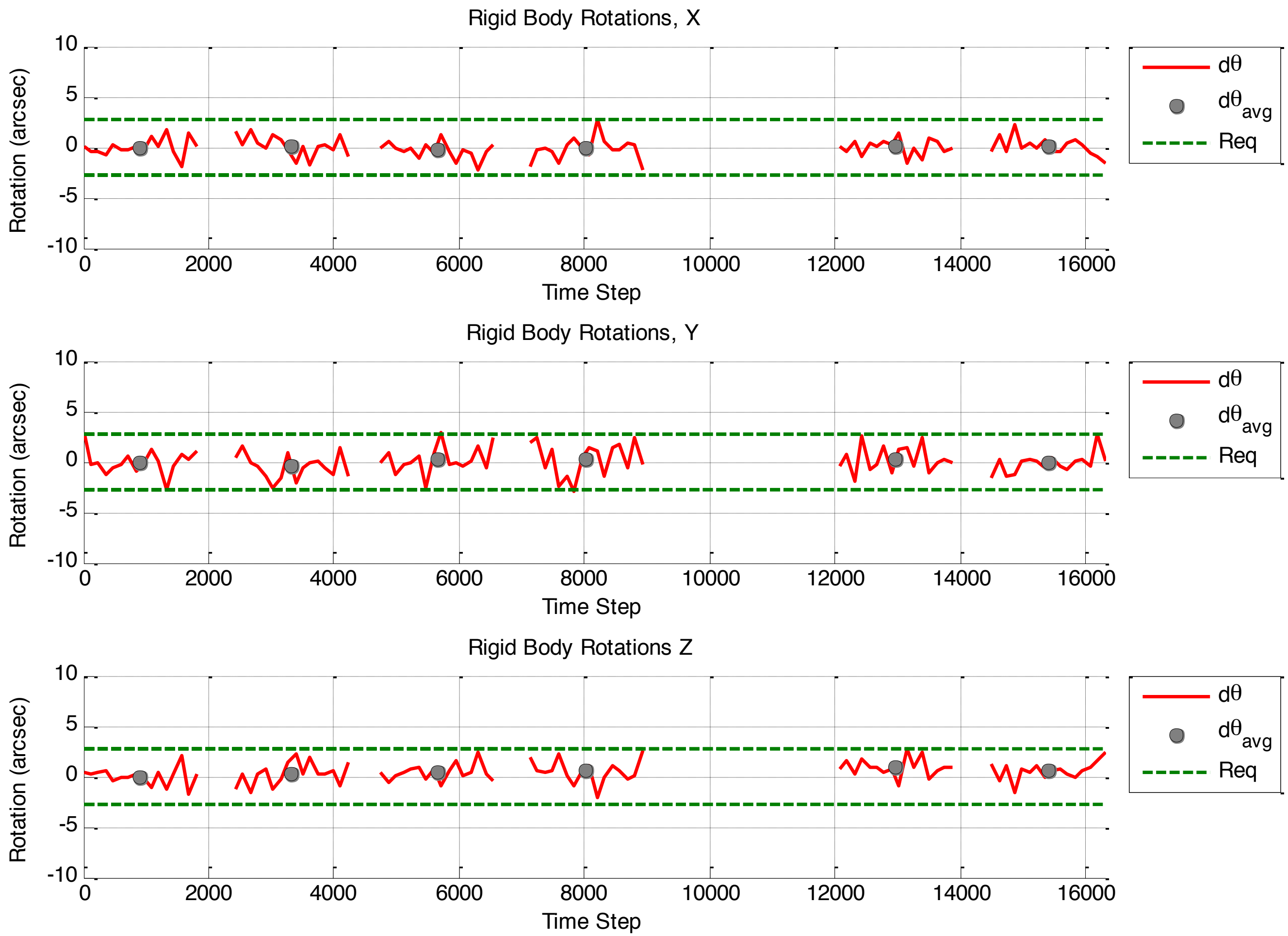
Hinge Rotated Orientation



- The orientation of the hinge was rotated by 90 degrees to observe the effect (if any) that gravity has on the hinge deployment repeatability.

Mid Hinge 180 degree Rot90
With Moly lube on balls

Hinge Testing
Test Results



- Grey circles show the average pointing error for a deployment.
- For this case, the hinge was rotated vertically to see if gravity had an affect on point repeatability.
- All cases well within requirements. Gravity has no discernible impact on performance.

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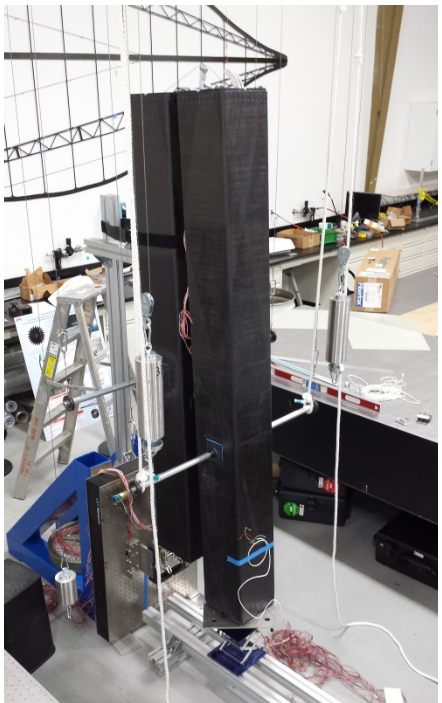
Hinge Testing
Performance Summary

- Hand burnishing molybdenum disulfide onto the balls greatly improved repeatability by reducing friction as the balls slide into their cones.
- All cases using the moly lube met the hinge repeatability sub-allocation.
- This was in agreement with the nonlinear modeling results presented last summer.
- Changing the direction of gravity in relation to the hinge had no impact on the deployment repeatability.

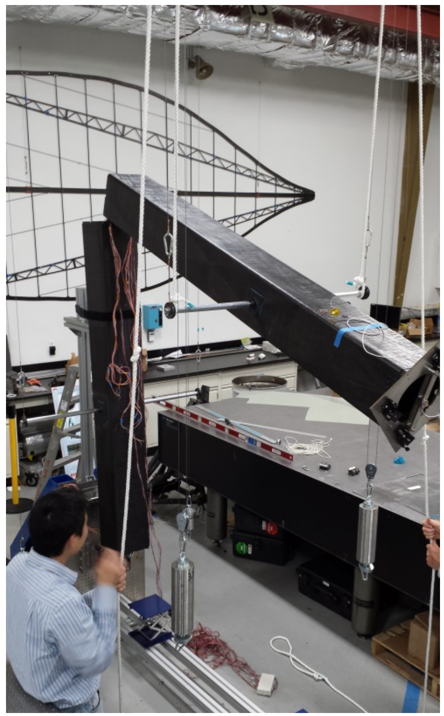
Mast Kinematic Testing

Mast Testing
Kinematic Testing

- The deployable mast is tested through its full range of motion while supported by its gravity offloading fixture in the high bay of building 299 to verify the kinematic working of the mechanism.
  – Mid-hinge moves through 180 degrees of motion.
  – Root hinge moves through 90 degrees of motion.
  – No performance data taken during this testing.

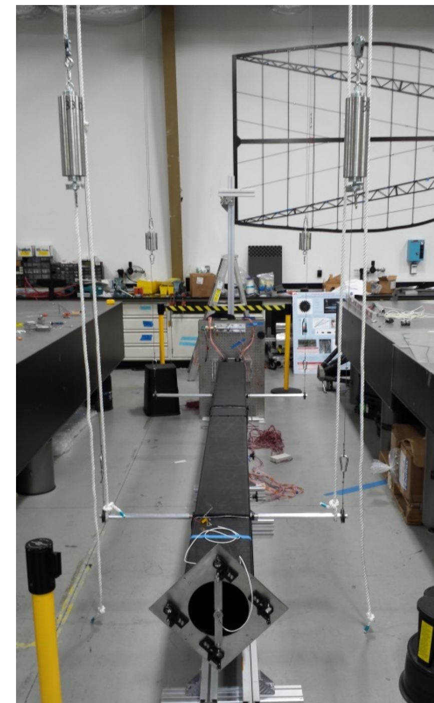


Fully Stowed



Mid Hinge Deployment

Mid Hinge Deployed

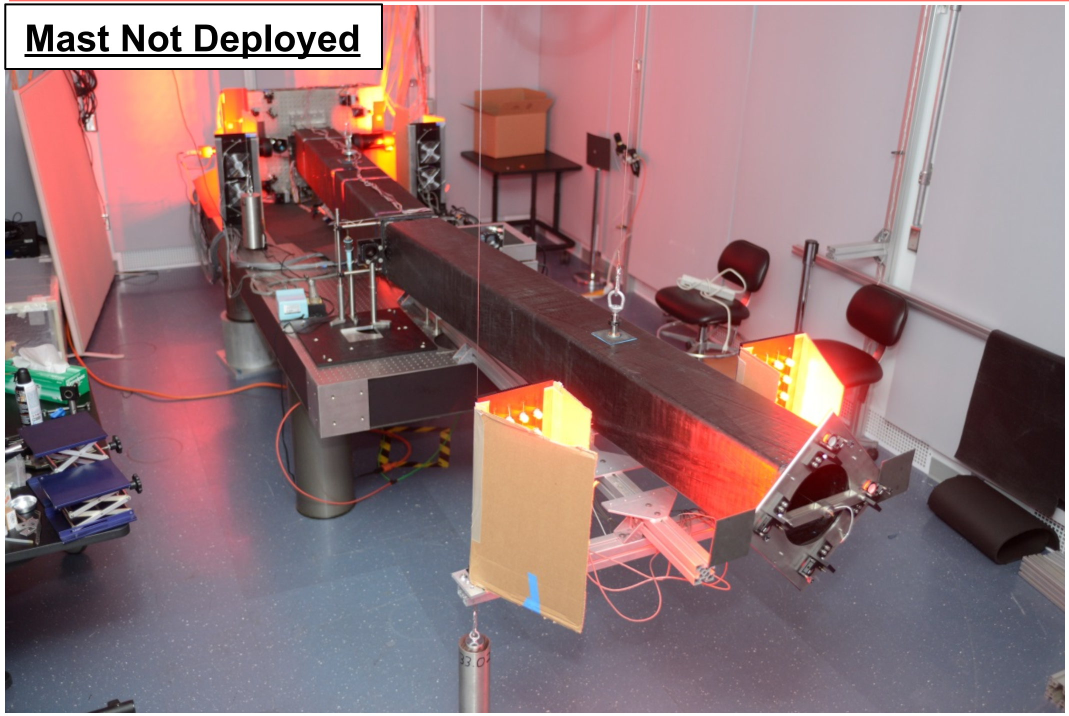


Fully Deployed

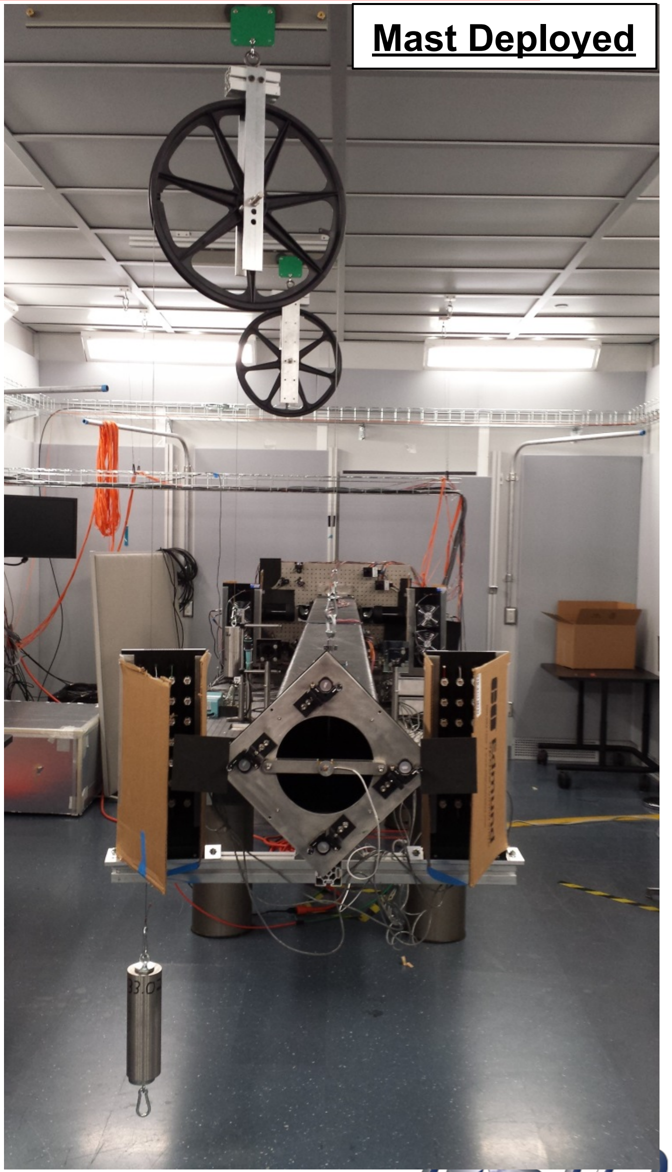

Mast Performance Testing

Mast Testing
Performance Testing Setup

Mast Not Deployed

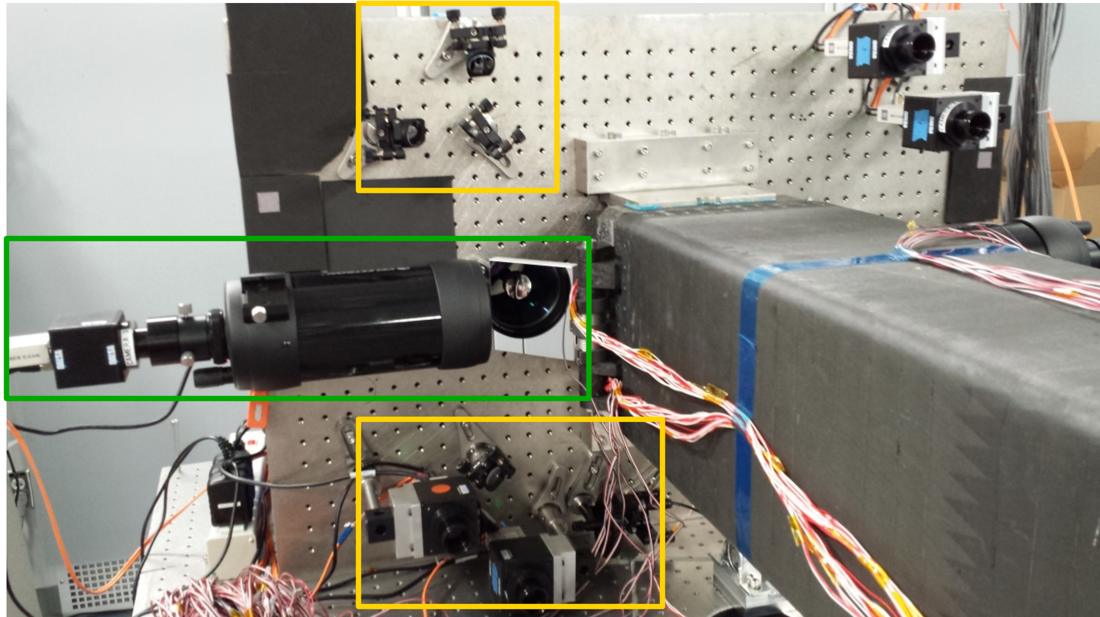


Mast Deployed



- These two pictures show the mast in its not deployed and deployed states.
- Not deployed picture shows the red lights used for the optical path.
  - Use of the telescope dimmed the image considerably. These lights brighten it back to useable levels.
- Deployed picture shows offload GSE attached to ceiling (large wheels on tracks).

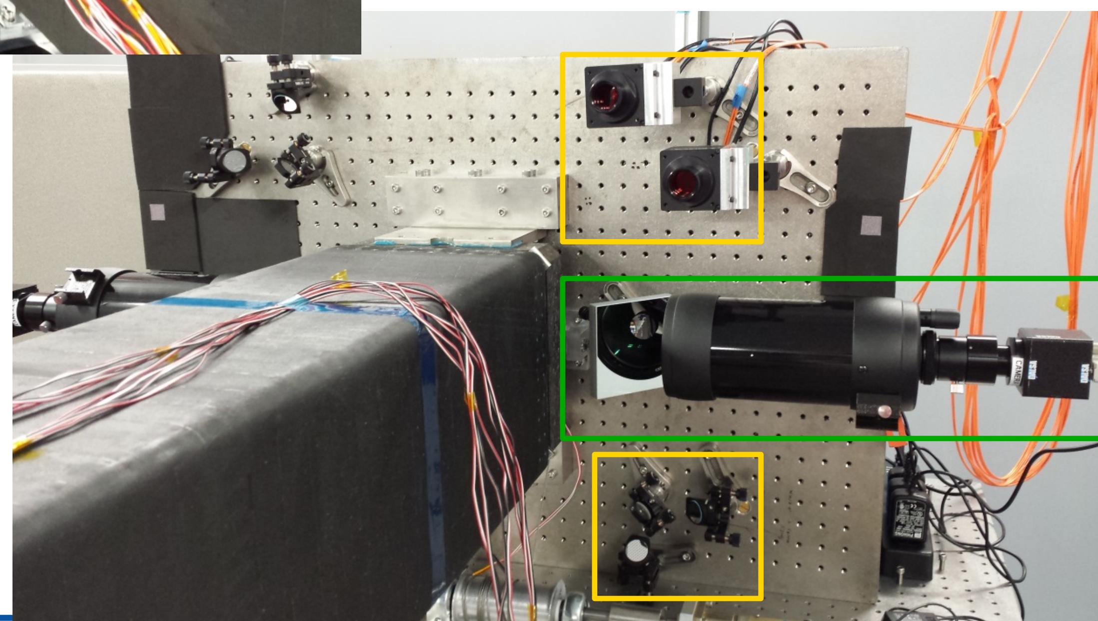
Mast Testing
Performance Testing Setup
Invar Breadboard Closeup



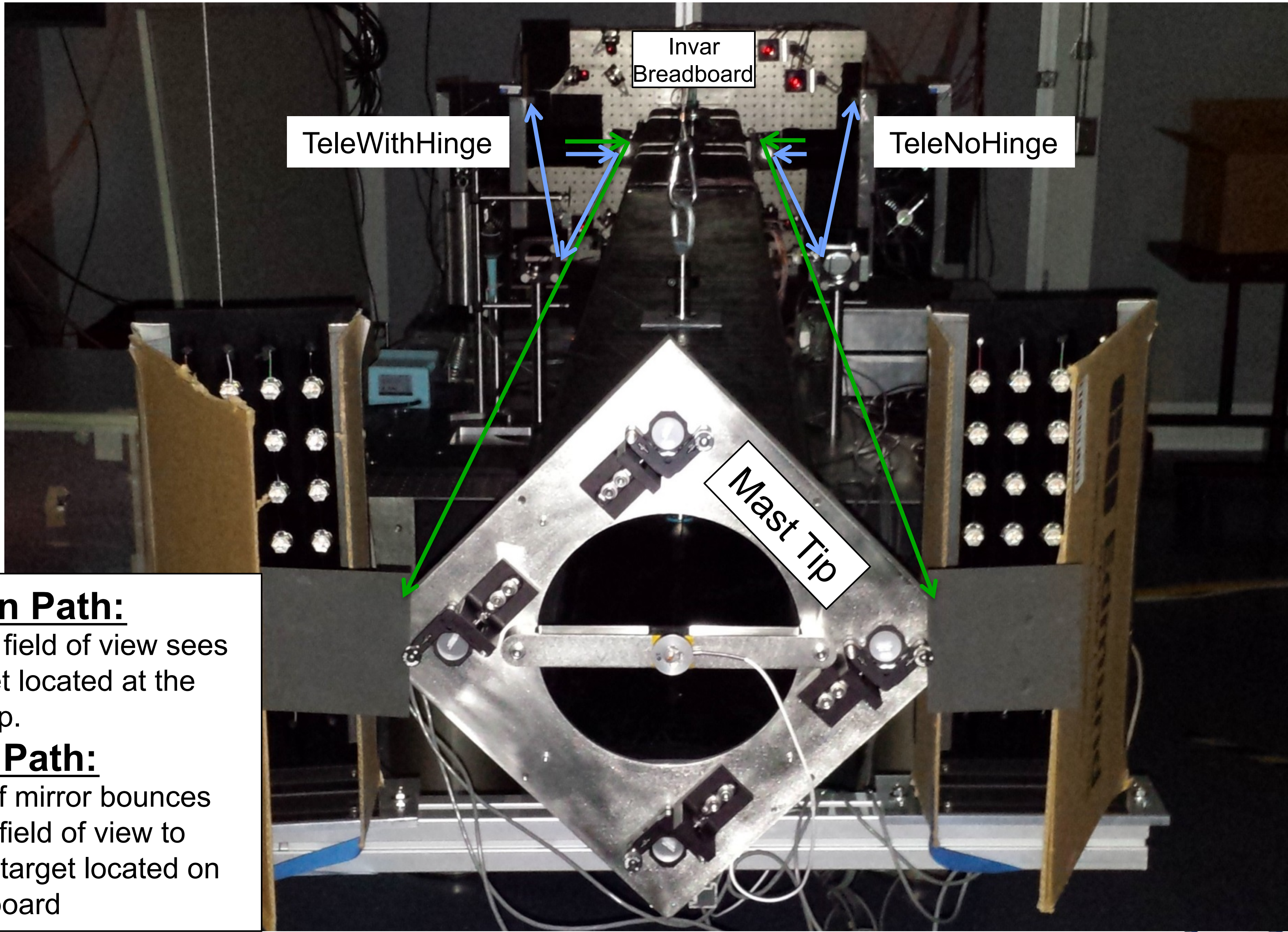
NAMS Optical Path Components

Laser Path Components

- NAMS Optical Path used to measure twist (rotation in Y) of the mast tip.
- Laser Path used to measure tip/tilt (rotation in X and Z) of the mast tip.



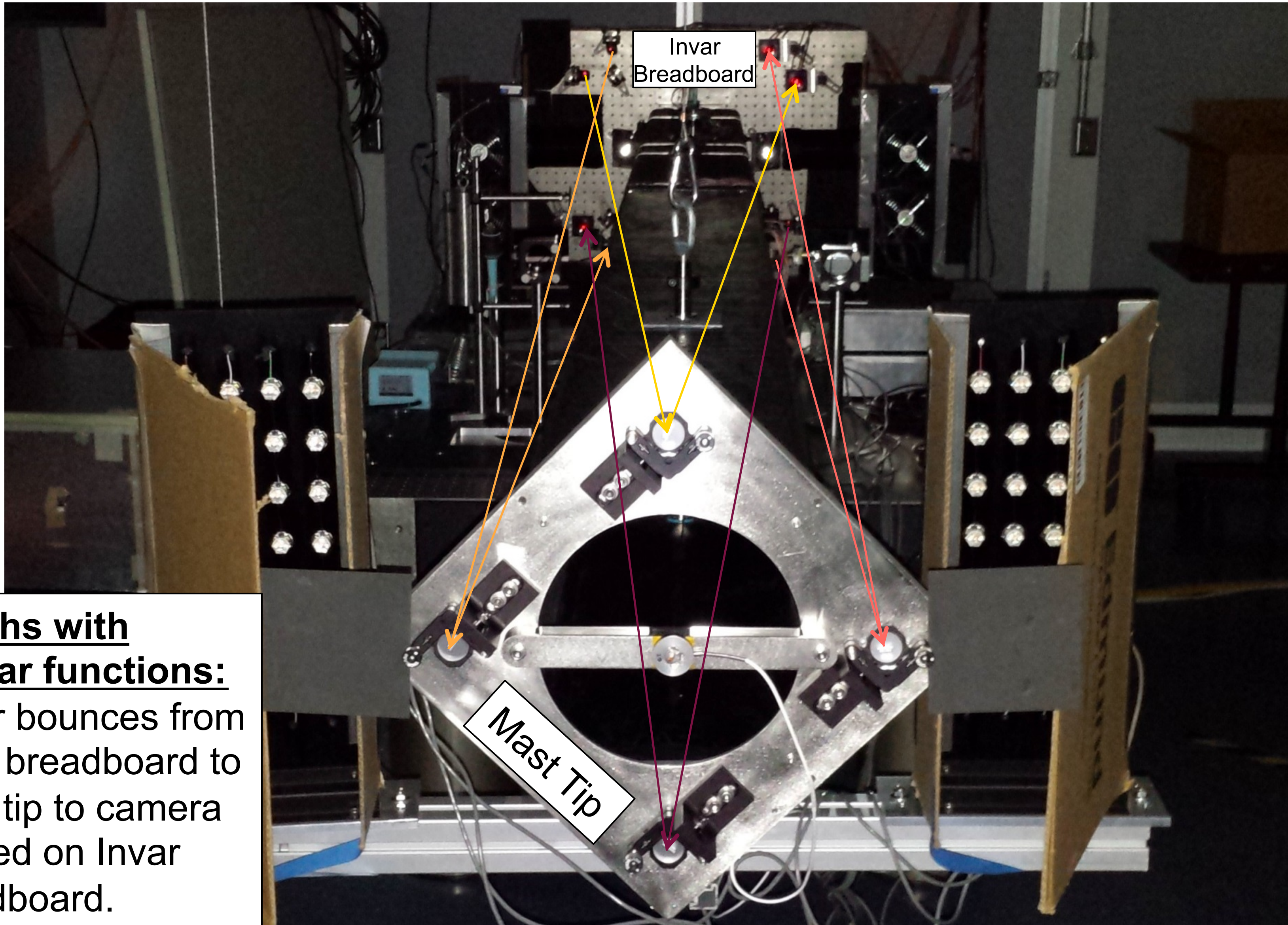
Mast Testing
Performance Testing Setup
Optical Paths



Green Path:
Half of field of view sees a target located at the mast tip.

Blue Path:
Pick off mirror bounces half of field of view to "fixed" target located on breadboard

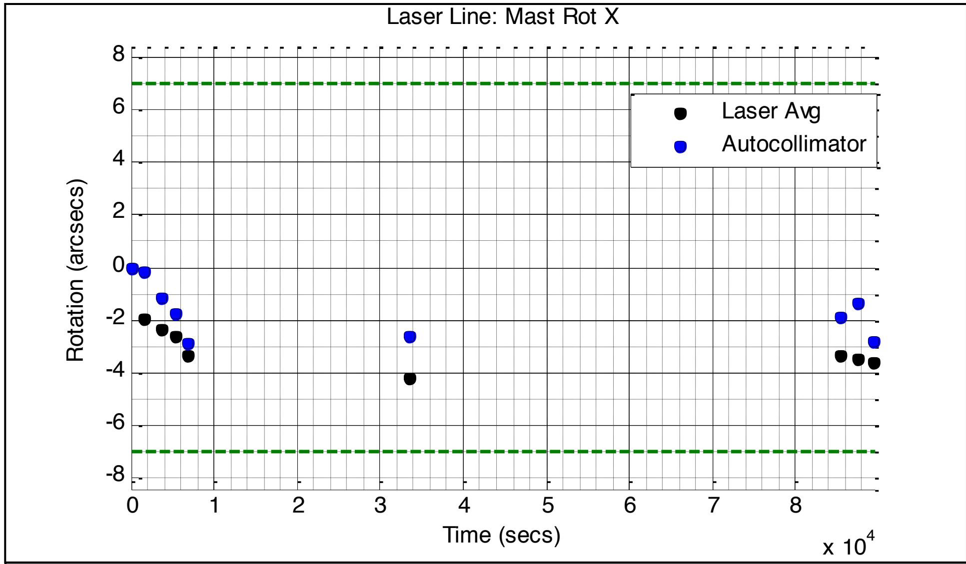
Mast Testing
Performance Testing Setup - Laser Paths

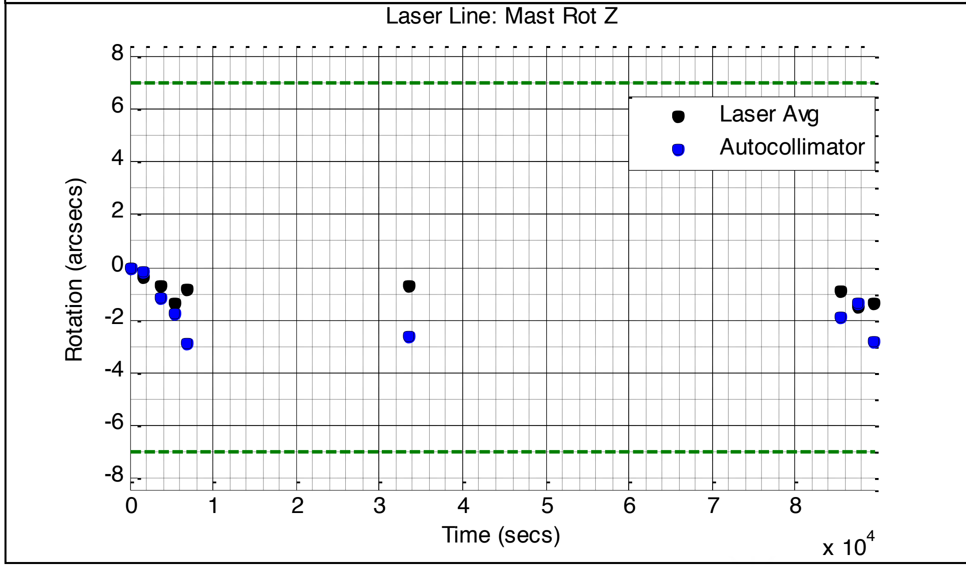


4 paths with similar functions:
Laser bounces from Invar breadboard to mast tip to camera located on Invar breadboard.

Mast Testing
Performance Testing Results - Laser Line

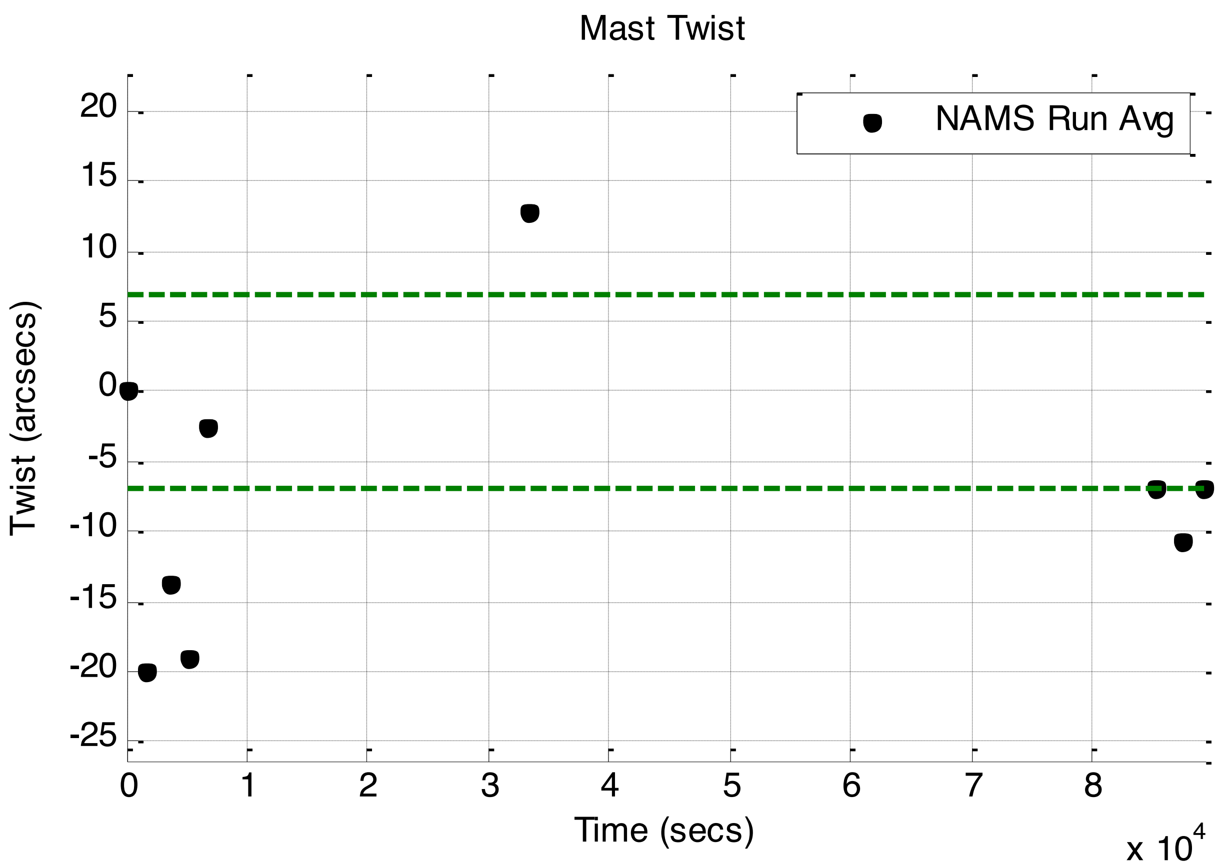
- Green dashed line is the requirement.
- Reasonable agreement between the autocollimator and the laser line results.
  - Both methods indicate that the deployable mast is well within its requirements.





Mast Testing
Performance Testing- Optical Line

- Each black circle represents the average repeatability for each run.
- Mast twist used NAMS with a telescope to calculate the angular motion.
  - Mast twist requirements are not shown to have been met, but it seems likely that this is an issue with the test set up and not with the hardware.



Mast Testing
Performance Testing – Optical Line

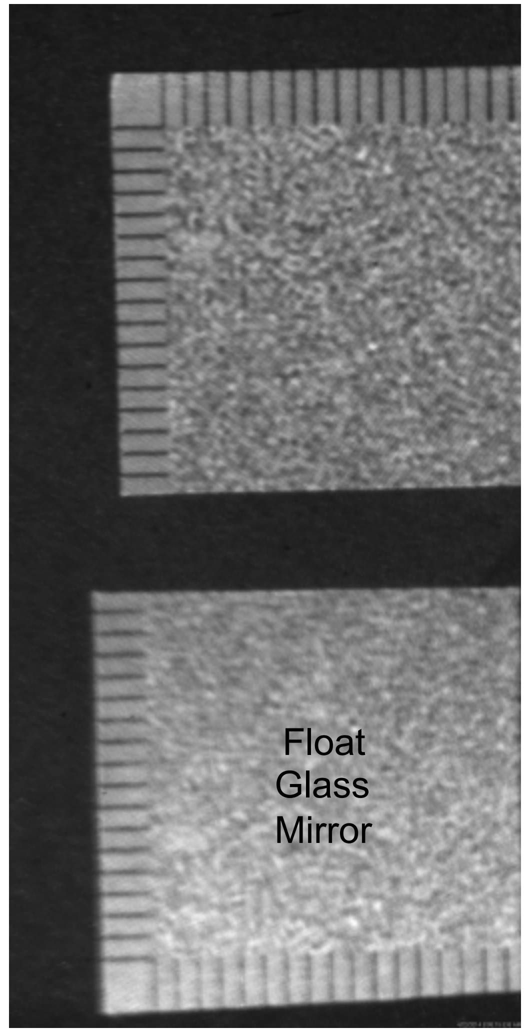
- The gifs to the right show the noise in the measuring system. 18 frames of data are taken at 16fps of a motionless system. Ideally nothing should be moving.

- The float glass mirror seems to either be vibrating or its optical surface is not flat enough, causing an apparent motion as well as an inability to focus perfectly.
  - It appears to be moving when the entire system should be stationary.

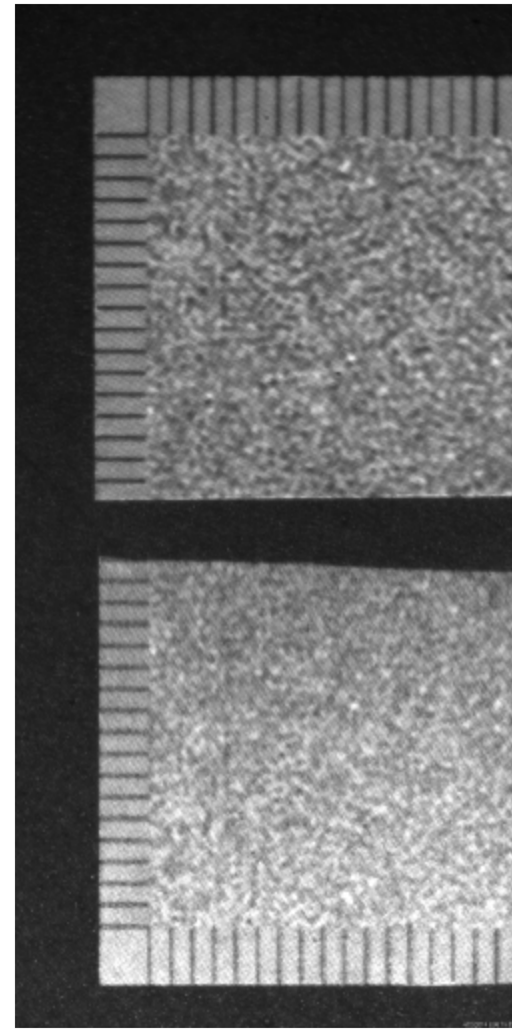
Mast Target

“Fixed” Target

TeleNoHinge

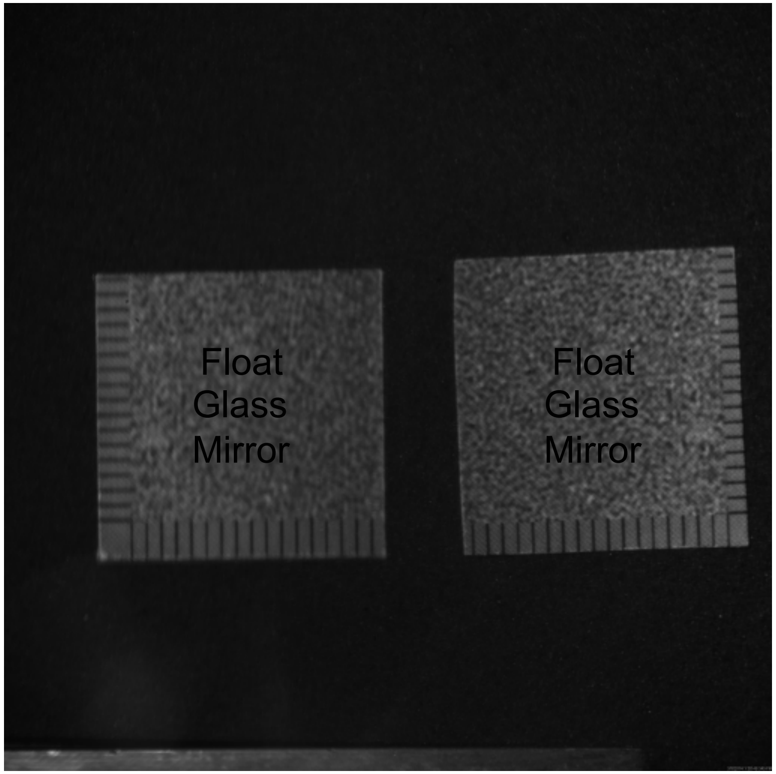


TeleWithHinge

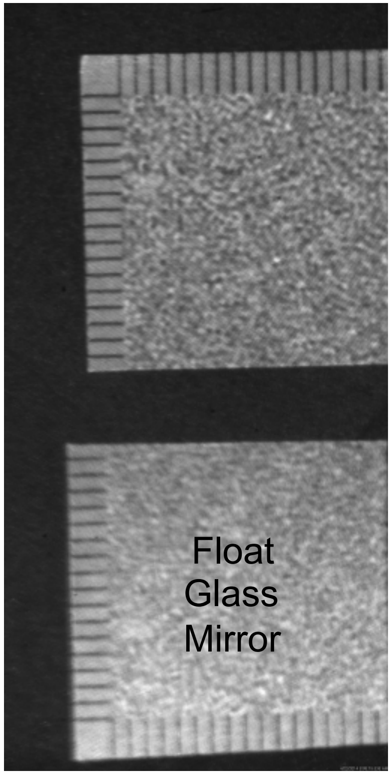


Mast Testing
Performance Testing
Optical Line

Telescope Calibration



TeleNoHinge



- The image on the left is from our calibration testing which also used float glass mirrors.
  - In the calibration testing, none of this "shimmering" was seen and much better focus was able to be achieved using the same mirrors as in the mast twist performance testing.
- It is unclear why this phenomenon occurred only in the mast testing and not in the calibration and verification stages.

Lessons Learned

- NAMS (nano meter accurate measuring system) can be very accurate, but needs to be very carefully set up.
  - Need optically flat mirrors of ¼ wave or better. Float glass, while cheaper, unacceptably affects results.
  - Cameras need very bright, very flat lighting to produce accurate results.
    - Light intensity gradients across the image can affect accuracy.
  - Precise temperature control of the cameras is needed for accurate results. This makes it difficult to use for thermal testing.
  - Best when used to make relative measurements between two targets within the same camera field of view. Otherwise camera mount stability becomes the dominating motion.
- Laser path shows random jitter.
  - A more stable mount for the laser would be used in the future.
  - Jitter motion was able to be averaged out so did not affect performance results significantly.
- Offload GSE was hung from the ceiling while rest of the hardware was supported from the optical table.
  - Even if the optical table was floated, vibrations could enter the system through the ceiling, to the offload GSE, and to the hardware, introducing noise into the results.
  - Need to have fully self contained system that can be floated, i.e. support GSE from the optical table instead of the ceiling.

Summary

- A full scale boom was designed fabricated and tested for the SWOT* KaRIn Instrument.
- Boom kinematics were demonstrated:
  - Hinge bodies were tested both at ambient and at temperature
  - Full Scale Deployment
- Test results indicate deployment repeatability of +/- 2.5 arcsecs – well within the SWOT* requirements (+/- 7.5 arcsecs)
- Analysis shows deployed frequency and stability requirements are met
  - SWOT* to test this winter
- Technology has successfully been transferred to the SWOT* project.

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