Model Predictions and Observed Performance of JWST's Cryogenic Position Metrology System

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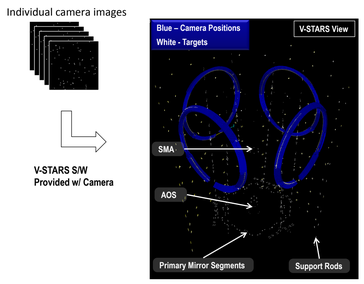
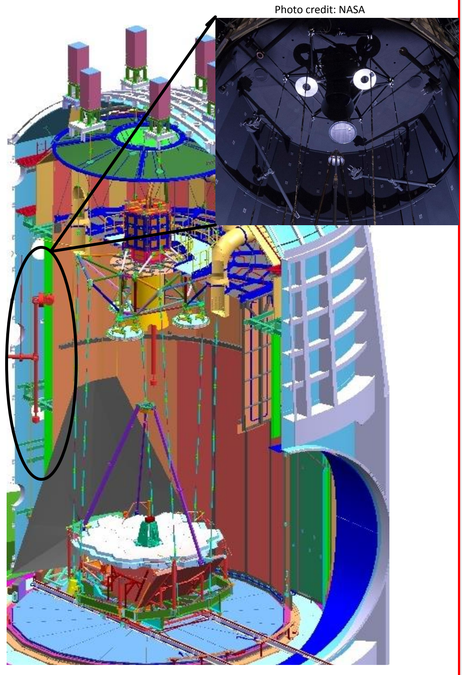
INTRODUCTION



Photogrammetry Overview

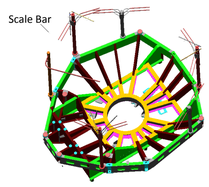
- PG cameras collect hundreds of images
- V-STARS software process images ("bundles") identifying individual targets and determines target locations & uncertainties
  – Locations defined for a specified coordinate system
- Data is exported
  – Each target provided a unique repeatable identifier
- Process data to Cardinal Data Report returns locations and uncertainties for optical assemblies

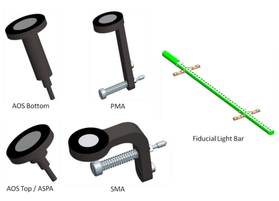
Photo credit: NASA

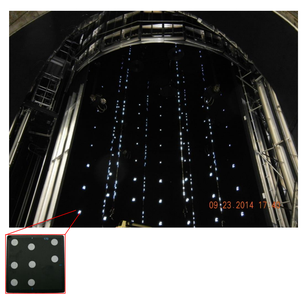


CPM Overview

For Thermal/Vacuum (T/V) tests of the JWST observatory, a set of four cameras on rotating windmill booms are used inside the helium shroud. The camera system records images of special targets placed on and about the OTE. The OTIS photogrammetric survey will be done primarily during conditions of a 30K vacuum environment.





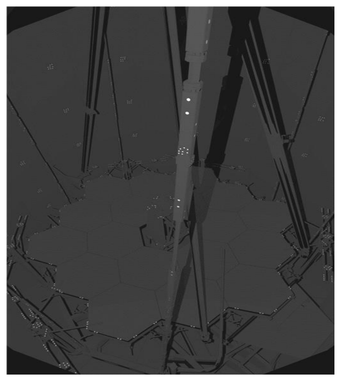


PG target components

Several types of targets are used in the chamber to ensure good photogrammetric results.

- **Scale bars** – To scale a photogrammetric measurement, at least one known distance must be present in the imagery.
- **Target Assemblies** – Individual reflective targets attached to hardware of interest.
- **Code Targets** – Code targets are a special type of target that the V-STARS software can recognize to automatically calculate the position and orientation of the camera to aid bundle adjustment. Code targets are present on:
  - Chamber walls
  - Telescope rod sleeves

COMPUTER MODEL CONSTRUCTION



Possible QR code for video (pending approval)

The computer model was constructed using the **D**igital **I**mage and **R**emote **S**ensing **I**mage **G**eneration (DIRSIG) version 4.5 software developed by Rochester Institute of Technology Digital Image and Remote Sensing Laboratory. DIRSIG performs end-to-end radiometric calculations from source to detector.

Model construction process:

- Extensive testing of actual targets at various sizes, angles, and distances was done with the INCA3 camera to determine distance and angle fall-off of target reflective material.
- CAD model of the OTIS configuration as well as the material properties of 3M retro reflective material used for the target material used to construct realistic model of the structures.
- Camera positioning and movement was incorporated into the definition of each modeled image.
- Image processing after the computer model generation was used to simulate sensor response and an adequate point spread function of the INCA camera system, and then converted to 8-bit.

The images were then imported into V-STARS for processing to determine the predicted PG measures of each point.

CHAMBER PERFORMANCE VERIFICATION

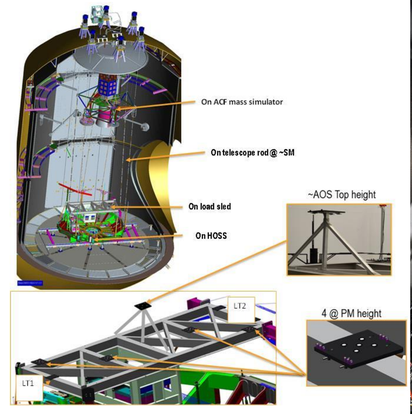
The performance of the CPM was evaluated during the initial Chamber Commissioning Testing (CCT) T/V tests and follow-on work was performed during Optical Ground Support Equipment (OGSE) 1 & 2 chamber T/V tests.

CCT Configuration:

The hardware configuration used for CCT had 8 calibration fixtures at various heights appropriate to the key components of OTIS and spread across the PM footprint. Two laser trackers were used during testing of the PG system to measure the absolute position of the calibration plates targets with respect to each other.

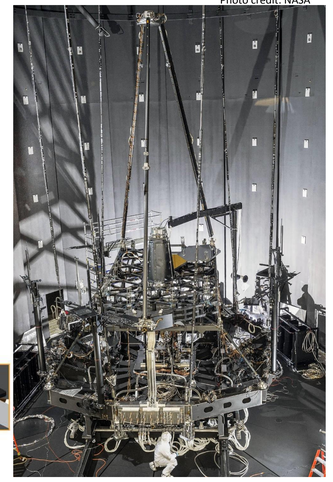
OGSE1 Configurataion:

Measurements for CPM performance assessment were done on individual PG targets attached by mounting assemblies to various hardware points to support OGSE 1 testing. The specific targets measured were determined by both height in the chamber to match heights of interest and visibility to the laser radar (LR) system that was used as the reference for absolute accuracy comparisons.



CCT Configuration

Photo credit: NASA



OGSE2 Configuration

RESULTS AND CONCLUSIONS

The overall image residuals of the system were higher for the modeled imagery than actual imagery (1/13 of a pixel vs. 1/40 of a pixel). The bundle adjustment and measurement uncertainty scale similarly to the image residuals between the modeled and actual results. The absolute accuracy was predicted well by the model.

Absolute Accuracy. Averages are across all targets on the indicated object. Modeled numbers are in ().

	Avg ΔV1 (mm)	Avg ΔV2 (mm)	Avg ΔV3 (mm)	Magnitude
ACF	-0.575 (-1.056)	0.08 (0.016)	0.013 (0.047)	0.581 (1.057)
SM	0.086 (0.187)	--- (-0.01)	--- (0.018)	0.086 (0.187)
AOS	-0.075 (0.022)	0.054 (-0.006)	0.019 (-0.075)	0.094 (0.078)
PM	-0.045 (0.129)	-0.104 (-0.0004)	-0.023 (-0.0035)	0.116 (0.129)

PG Measurement Uncertainty. RMSE across all targets on the indicated object. Modeled numbers are in ().

	σ ΔV1 (mm)	σ ΔV2 (mm)	σ ΔV3 (mm)	Magnitude
ACF	0.15 (0.055)	0.52 (0.255)	0.475 (0.268)	0.72 (0.374)
SM	0.043 (0.146)	--- (0.11)	--- (0.117)	N/A (0.217)
AOS	0.045 (0.231)	0.101 (0.064)	0.151 (0.096)	0.187 (0.258)
PM	0.102 (0.136)	0.085 (0.251)	0.112 (0.23)	0.174 (0.367)

Conclusions

- The close range photogrammetry system that is used in T/V testing of JWST hardware was modelled extensively prior to construction in order to verify performance, define camera pointing schemes, and assess effects of various proposed target configuration.
- A computer generated DIRSIG model predicted a higher level of image residuals and measurement uncertainty then observed in the actual system, but correctly predicted the error in absolute measurement. When the difference between model and actual image residuals are accounted for, the measurement uncertainty from the DIRSIG model is similar to that found in chamber T/V verification testing.
- The CPM system was predicted by the DIRSIG model to meet the requirements of the error budget and in-chamber testing confirmed those predictions. The measurement uncertainty of the CPM is < 0.1 mm, the absolute positional accuracy at the AOS and PM level is <0.1mm, and the absolute positional accuracy is <0.15mm at the SM level.
- The CPM has been successfully used in 3 chamber tests and will be used in the final OTIS testing phase.

Acknowledgements
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