James Webb Space Telescope
Optical Telescope
Element/Integrated Science
Instrument Module (OTIS) Status

Lee Feinberg
GSFC JWST OTE Manager
& OTIS Technical Lead

Co-authors:
Mark Voyton, Julie Lander, Ritva Keski-Kuha, GSFC
Gary Matthews, Harris Corporation
What is OTIS

- Optical Telescope Element (OTE) + Integrated Science Instrument Module (ISIM) = OTIS
- Accept delivery of the OTE, ISIM and related components
- Responsible for the integration of ISIM to OTE to create OTIS
- Responsible for the environmental testing of OTIS and necessary Ground Support Equipment (GSE) required to accomplish this
  - Acoustic Testing at GSFC
  - Vibration Testing at GSFC
  - Cryogenic thermal vacuum testing at JSC Chamber A
- Deliver OTIS to observatory for integration and observatory level testing
Where Are We In OTIS Flow

GSE & Test Preparations
- Facility Functional
- Clean Room
- GSE Install
- Takeout
- Commissioning Phase I
- Commissioning Phase II

Completed Aug 12

Fall 14

JWST OTIS Integration and Test

Risk Reduction Activities

Flight OTIS I&T
- Install Flight ISIM to OTE
- Pre Environmental Test
- Acoustic & Vibe Tests
- Post Environmental Test
- Ship OTIS to JSC
- OTIS Cryo Preps
- OTIS Cryo Test
- OTIS Cryo Post-Test
- Ship OTIS to NGAS

Legend
- Prep & Transport
- Functional / Test
- Assembly / Integration
- Delivery

Acronyms
- AOS: Aft-Optics Subsystem
- GSE: Ground Support Equipment
- MGSE: Mechanical Ground Support Equipment
- NGAS: Northrop Grumman Aerospace Systems
- OGSE: Optical Ground Support Equipment
- PF: Pathfinder
OTIS Test GSE Architecture

**Center of Curvature Optical Assembly (COCOA)**
- Multiwavelength interferometer (MWIF), null, calibration equipment, coarse/fine PM phasing tools, Displacement Measuring Interferometer – Installed in Chamber

**3 Auto collimating Flat Mirrors (ACFs)**
- 1.5 M Plano for Pass and Half Testing
- ACF 1 installed in Chamber A, ACF 4 and ACF 5 are complete,

**AOS Source Plate Assembly (ASPA)**
- Testing complete at Ball
- Delivered to JSC

**Space Vehicle Thermal Simulator (SVTS)**
- and Sunshield Simulator
- Procurements and fabrication

**ADM**
- Testing complete at JHU
- Delivered to JSC

**HOSS – Hardpoint Offloader Support Structure**
- In integration in Clean Room

**Deep Space Edge Radiation Sink (DSERS)**
- Frame integrated

**Mag Damper Cryo Test Article**
- Delivered

**USF Structural Frame**
- supports Metrology
- Installed in Chamber

**Cryo Position Metrology (CPM)**
- Photogrammetry System
- Integration Complete

**Chamber Isolator Units**
- Dynamically isolates OTIS Optical Test – Integration of 6 units complete
Pathfinder mounted to the HOSS as seen from inside the chamber
Pathfinder in the chamber for OGSE1
OGSE1 Results

- OGSE1 was extremely successful and met test objectives
  - Achieved the mandatory objective of performing a cryogenic proof load test of the Aft Optics System (AOS) interface to assure OGSE2 can proceed safely
  - Demonstrated Multi-wavelength High Speed Interferometry of the primary mirror including successfully phasing two primary mirror segments
  - Performed detailed dynamics characterization of the isolation system
  - Performed functional testing and characterized the Beam Image Analyzer, showed that it is aligned well enough for OGSE2
  - Trained the team on optical test operations
  - Mirror vertical gravity sag data qualitatively matched models (first time mirrors were tested vertically)
  - Photogrammetry worked extremely well including implementing lessons learned from Cryo Commissioning Test

- OGSE1 did it’s job and generated very important lessons learned
  - Identified a mechanical short to ground that happened during cooldown between the DSERS frame and the HOSS magnetic damper bracket that can easily be fixed for future tests
  - Learned a lot about isolator tuning and developed an improved tuning process for OGSE2
  - Got a better understanding of what optically drives the segment optical testing (phase calibration of the interferometer) and the metrics to use to evaluate dynamics performance (velocity) which can be applied to flight OTIS testing
Pathfinder in Chamber for OGSE2
OGSE2 Summary

- OGSE2 completed in approximately 35.5 days (allocated 35)
- Overall, OGSE2 was a tremendous success optically
  - All Primary, Secondary, Tertiary Test Objectives were all met
    - Demonstrated every optical test used during OTIS at some level
    - GSE checked out (only exception was only 1 ACF used)
    - Training and practice of test execution and data analysis
  - Only 2 Problem Failure Reports (PFR’s):
    - Center of Curvature Object Assembly (COCOA) Hexapod worked intermittently but the issue has since been addressed with electrical improvements in the GSE.
    - Dynamics/vibration levels higher than expected
- Despite vibration, optical testing was very robust
  - Photogrammetry, COCOA primary mirror testing and half pass testing not impacted by the vibration thanks to the test design
  - Only 2 Pass and a Half tests were impacted, optical workaround developed that is insensitive to vibration but vibration will also be addressed (belt and suspenders)
Interferometric segment phasing demonstrated with 2 flight like segments for OTIS test.

During cryo testing in OGSE 2 the 2 segment primary mirror was phased from mm and mrad tolerances to step heights < 30 nm.

- Several independent teams analyzed data and results are matching well.

All results reviewed with independent Product Integrity Team chaired by Prof. Duncan Moore/University of Rochester, positive feedback.

Team will repeat COCOA testing during the Thermal Pathfinder test.

---

**Center of Curvature Optical Test Demonstrated End to End Phasing**

- **Coarse Alignment**
- **Fine Alignment**
- **Multi-Wavefront Phasing Using Synthetic Wavelengths**

**Measured (165 nm-rms) Model Predict (161 nm-rms) Difference (31 nm-rms)**

Difference of 31 nm-rms consistent with estimated uncertainty of 30 nm-rms,
All Optical Tests were Demonstrated

- **1.5m Diameter Autocollimating Flat Mirrors (3)**
- **Photogrammetry Cameras on windmill arms (1 of 4)**
- **Inward and Outward facing sources at Intermediate Image**
- **Fiducial lights above PM edge**

- **Half pass Prediction vs. Data**
- **Pass and a Half Prediction Vs Data (“Stacked”)**

- **HP OGSE2 Pupil Image**
- **PAAH OGSE2 Pupil Image**
- **LED’s used at edge of PM to align pupil to FSM and NIRCAM**

- **Shadowgram tests Indicated No Vignetting Issues**
# Optical Test Status (Summary)

**Priority 1:** Verification measurements and critical crosschecks – minimum needed for test success/verification

**Priority 2:** Important crosschecks – prioritized but can relax requirements for test success

**Priority 3:** Risk mitigation and secondary crosschecks, high ROI but not required for test success

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test</th>
<th>Test Configuration</th>
<th>Status</th>
<th>OGSE 2 Impacted by Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM to AOS alignment</td>
<td>Photogrammetry</td>
<td>Demonstrated capability during OGSE2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>PM to AOS alignment (multifield)</td>
<td>Pass and a Half</td>
<td>Demonstrated capability during OGSE 2</td>
<td>mitigated by Hartmann test</td>
<td></td>
</tr>
<tr>
<td>SM to AOS alignment</td>
<td>Photogrammetry</td>
<td>Demonstrated capability during OGSE2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>SM to PM optical axis</td>
<td>Photogrammetry</td>
<td>Demonstrated capability during OGSE1 &amp; 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>SM 5 dof (multifield)</td>
<td>Pass and a Half</td>
<td>Demonstrated capability during OGSE 2</td>
<td>mitigated by Hartmann test</td>
<td></td>
</tr>
<tr>
<td>ISIM to AOS alignment</td>
<td>Half Pass imaging &amp; Pupil Alignment</td>
<td>Combines OTRD 360, 361, 362, &amp; 363 results</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>AOS to ISIM object surface despace</td>
<td>Half Pass imaging</td>
<td>Demonstrated capability during OGSE2, in evaluation</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>AOS to ISIM object surface decenter</td>
<td>Half Pass imaging</td>
<td>Demonstrated capability during OGSE2, in evaluation</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Decenter of NIRCam ap stop to FSM mask</td>
<td>Half Pass, Pupil Alignment</td>
<td>Demonstrated capability during OGSE2, in evaluation</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>ISIM tilt via entrance pupil &amp; object surface</td>
<td>Half Pass imaging</td>
<td>Demonstrated capability during OGSE2, in evaluation</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>ISIM object surface clocking</td>
<td>Half Pass imaging</td>
<td>Demonstrated capability during OGSE2, in evaluation</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>PMSA Cryo Gap</td>
<td>COC, ADM</td>
<td>Demonstrated capability during OGSE1 &amp; 2</td>
<td>No, aborted plan to use edge images</td>
<td></td>
</tr>
<tr>
<td>PM RoC</td>
<td>COC, ADM</td>
<td>Demonstrated pieces (ADM, RoC meas’m’t)</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Low freq PM WFE</td>
<td>COC</td>
<td>Demonstrated capability during OGSE1 &amp; 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Mid frequency PM WFE</td>
<td>COC</td>
<td>Demonstrated capability during OGSE1 &amp; 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>PM conic</td>
<td>COC, ADM</td>
<td>Demonstrated capability during OGSE1 &amp; 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Ambient PMSA WFE / Astigmatism</td>
<td>COC</td>
<td>Determined capability during OGSE1 &amp; 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Image Quality and WFE</td>
<td>Thermal Distortion – PM WFE &amp; RoC Change</td>
<td>COC Figure drift of PM over 2.5K DT</td>
<td>Data from OGSE2 in evaluation, looks promising</td>
<td>No</td>
</tr>
<tr>
<td>Thermal Distortion – OTE Alignment Change</td>
<td>Photogrammetry during warm up from cryo</td>
<td>Demonstrated during OGSE1</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Radiometric Sensitivity</td>
<td>PM to FSM Mask Alignment / Truant Path</td>
<td>Pupil Alignment Test</td>
<td>Demonstrated capability during OGSE2, in evaluation</td>
<td>No</td>
</tr>
<tr>
<td>PM Collection Area</td>
<td>COC (reflection area)</td>
<td>Demonstrated capability during OGSE1 &amp; 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Vignetting</td>
<td>Pass and a half</td>
<td>Demonstrated capability during OGSE 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Vignetting</td>
<td>Pass and a half</td>
<td>Demonstrated capability during OGSE 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Vignetting</td>
<td>SI images with FLAB illumination of SM</td>
<td>Demonstrated capability during OGSE 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Plate Scale</td>
<td>Pass and a Half</td>
<td>Demonstrated capability during OGSE 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>WFS&amp;C Demo</td>
<td>Pass and a Half, COC, photogrammetry</td>
<td>Data from OGSE2 in evaluation, looks promising</td>
<td>fine-range piston</td>
<td></td>
</tr>
<tr>
<td>WFS&amp;C Influence Functions</td>
<td>Pass and a Half, COC, photogrammetry</td>
<td>Data from OGSE2 in evaluation, looks promising</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Functional</td>
<td>Actuator command repeatability</td>
<td>CMUTS</td>
<td>Demonstrated during OGSE1 &amp; 2</td>
<td>No</td>
</tr>
<tr>
<td>PMSA Envelope Control Limit</td>
<td>COC</td>
<td>Demonstrated during OGSE1</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>WF Control Signal Path (PMSA, SMA motion control sign check test)</td>
<td>COC</td>
<td>Demonstrated capability during OGSE 1 &amp; 2, in evaluation</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Fine Guidance Loop</td>
<td>Half Pass, Pass and a Half</td>
<td>OGSE2 demonstrated feasibility with FGS jitter evaluation</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>
Thermal Pathfinder Test

Objectives:

- Verify safety of OTIS transient timeline
  - Execute OTIS cooldown profile showing that OTIS temperature constraints are achievable on the back plane, two Primary Mirrors Segments and secondary mirror assembly.

- Validate operation of key OTIS thermal/GSE cooler components
  - Demonstrate first system functionality of Space Vehicle Thermal Simulator
  - Demonstrate the GSE cryo-cooler operation in the OTIS test configuration and show that parasitic loads are acceptable

- Verify dynamic environment and response of payload

- Thermal Balance of PF with OTIS-like thermal performance – analysis process

- Pre-OTIS thermal personnel training
  - Preparation and In-Test Operation of OTIS-like Thermal Model
  - Thermal Model Correlation with OTIS-like Test Article
  - Exercise/Develop Contingency Procedures

Configuration:

- Pathfinder adds 10 mirror simulators and an AOS simulator, blanketing
- SVTS, IEC simulator, Sun-shield mockup
- Final 2 Auto Collimating Flat’s are installed (final test configuration)
- Floating configuration of hanging payload (use of the chamber vibration isolators)
- Pathfinder constraints and limitations maintained throughout test

Final Risk Reduction Test provides confidence in Readiness to conduct Flight OTIS Cryo Vac Test
TPF and HOSS in JWST Cleanroom at JSC
OTIS Integration & Test @ GSFC

ISIM Prime WG
- Deliver OTE to OTIS
- Measure OTE Master References

FIR WG
- Install ISIM Heat straps to BIF
- Lift from AOAS to ROF (NGAS HIF)

ISIM Prime WG
- Stow SMAS
- Reorient +V1 to +V2
- Lift from ROF to AOAS

ADIRWG
- Reorient +V3 to +V1
- Lift from AOAS to ROF (NGAS HIF)
- Reorient +V3 to +V1
- BATWings / Bumpers

Deployments WG
- Stow Wings with GSE bolts
- Reorient +V3 to +V2
- Pre-Env ADIR Deployment test setup
- Omni Boom and Antenna Integration
- Pre-Env ADIR deployment Test
- Reorient +V2 to +V3
- Pre-Env Wing Deployment Test
- Lift from ROF to IS (Harris HIF)

IEC WG
- Stow DTA
- Pre-Env DTA deployment Test
- FIRE V3 LRM and Replace

HR WG
- Walkout ADIR
- Post-Env TOR Metrology
- Stow ADIR
- Lift from IS (Harris HIF) to Aronson (NGAS HIF)

COC Test
- Reorient +V3 to +V1
- Stow PMSAs
- Install SMA shroud
- LIFT OTIS from Aronson to Deily (Switch from NGAS HIF to Vibe fixture)
- Stow Wings with NEAs

System Functional Test
- Walkout ADIR
- Post-Env TOR Metrology
- Stow ADIR
- Post-Env IEC NEA Test
- Stow Wings with GSE belts
- LIFT OTIS from IS to Aronson
- Reorient OTIS from +V3 to +V1
- Post-Env SMAS Motor Flick Test

Mechanical Environmental Test WG
- Mechanical Environmental Tests
- Build up OTIS for Environmental Testing
- Transport OTIS to Acoustics Test Facility
- Perform OTIS Acoustic Test
- Transport OTIS to SSDL, prep and transport to Vibe facility
- Perform OTIS Vibration Test
- Transport OTIS from Vibe facility to SSDL
- De-configure OTIS following Env Testing

PMSA WG
- Measure PMSA Stowed Gap

Prep, Load, & Ship OTIS to JSC

Deployments WG
- Post-Environmental Wing Deployment Test
- Prep OTIS for removal from NASA Vibe fixture
- LIFT OTIS from Deily to Aronson (NGAS HIF preinstalled on Aronson)
- Post-Env RD Deployment Test & Removal
- Reorient OTIS from +V3 to +V2
- Post-Env ADIR Deployment Test
- Reorient OTIS from +V2 to +V3
- Post-Env DTA Deployment Test
- Post-Env Deployable Frill Deployment Test
- Lift OTIS from ROF to Aronson Table

CoC / Sys Func WG
- Lift OTIS from Aronson to IS (Switch from NGAS HIF to Harris HIF)
- Walkout ADIR
- Post-Env TOR Metrology
- Stow ADIR
- Post-Env IEC NEA Test
- Stow Wings with GSE belts
- LIFT OTIS from IS to Aronson
- Reorient OTIS from +V3 to +V1
- Post-Env SMAS Motor Flick Test

* Indicates Deployment Test
Pre- and Post- Environmental Tests

– Tests planned before and after the mechanical environmental tests will verify that no unacceptable changes to the test article have been caused by the environments
– OTIS tests performed before and after mechanical environmental tests
  ● System Functional test
    – OTE, ISIM, and OTIS tests performed
  ● Deployment Tests
    – Deployable Frill
    – DTA
    – SMSS
    – PMBA Wings
    – ADIR
    – Bib
  ● Center of Curvature Test
  ● Alignment Checks
    – ISIM
    – SMA
    – AOS
  ● PMSA Gap Measurements
The OTIS Center-of-Curvature will be performed before and after the acoustic/vibration tests at GSFC.

The objective of the test is to show that the primary mirror segments (and potentially backplane) are not altered by the OTIS level vibration and acoustic tests occurring at GSFC.

The interferometer used measures at high speed (6Khz) allowing dynamic measurements for both model crosschecks and additional diagnostics.
OTIS Acoustic Test Description

- The OTIS Acoustic Test is a protoflight level test of OTIS in its stowed launch configuration.
- The Building 10 Acoustic Test facility at GSFC is used for this test.
- A tent assembly is used to protect the contamination sensitive test article while it is in the non-clean environment of the acoustic test facility.
Clean Tent and Dolly

Tent on Dolly

Tent on Work Platform, without ladders
The OTIS Vibration Test is a three-axis sinusoidal vibration test performed with the OTIS in the stowed/launch configuration.

The sine vibration test level is based on a response spectrum envelope of launch vehicle dynamic events, applied over a band of 5 to 100 Hz.

OTIS remains in the +V3 up configuration while each axis (V1, V2, V3) is tested in this fixed orientation.

A new vibration test system (VTS) is being installed for this test in the building 29 high bay at GSFC.

A tent assembly is used to protect the contamination sensitive test article while it is in the non-clean environment of the vibration test facility.
OTIS I+T is well underway

Pathfinder ambient and cryogenic optical testing has been incredibly valuable

All optical tests have been checked out

Only outstanding issue are vibration levels. Main impact was to test efficiency so taking a belt and suspender approach to addressing it:
  – Improvements in dynamics to be demonstrated during TPF testing
  – **Switch** to Hartmann type tests for pass and a half tests will make us less sensitive to vibration

Thermal Pathfinder testing to start in late summer and will check out thermal testing

Ambient integration will complete in early Fall followed by ambient environmental testing at Goddard

Cryogenic optical and thermal testing of OTIS on track for 2017 start