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

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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
- MGSE Install
- Pre-Commissioning Phase I
- MGSE Inspection, OGSInstall
- Commissioning Phase II

Completed Aug 12

Fall 14

JWST OTIS Integration and Test

Acronyms

- AOS: Aft-Optics Subsystem
- GSE: Ground Support Equipment
- MGSE: Mechanical Ground Support Equipment
- NGAS: Northrop Grumman Aerospace Systems
- OGS: Optical Ground Support Equipment
- PF: Pathfinder

Legend

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

Risk Reduction Activities

- Fall 14
- Fall 17

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
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

Chamber Isolator Units
Dynamically isolates OTIS Optical Test – Integration of 6 units complete

Cryo Position Metrology (CPM)
Photogrammetry System Integration Complete

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

USF Structural Frame – supports Metrology 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

Deep Space Edge Radiation Sink (DSERS)
Frame integrated

Mag Damper Cryo Test Article Delivered
Pathfinder being installed into shipping container at GSFC
Pathfinder mounted to the HOSS as seen from inside the chamber
Pathfinder in the chamber for OGSE1
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
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.

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

**Center of Curvature Object Assembly (COCOA) Multi-Wave Interferometer**

- 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

Half pass Prediction vs. Data
Pass and a Half Prediction Vs Data ("Stacked")

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

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><strong>Image Quality and Optical Alignment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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>Photogrammetry</td>
<td>Demonstrated capability during OGSE 2</td>
<td>mitigated by Hartmann test</td>
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<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>Photogrammetry</td>
<td>Demonstrated capability during OGSE 2</td>
<td>mitigated by Hartmann test</td>
<td></td>
</tr>
<tr>
<td>SIM to AOS alignment</td>
<td>Pass and a Half, Half Pass imaging &amp; Pupil Alignment</td>
<td>Combines OTRD 360, 361, 362, &amp; 363 results</td>
<td>No</td>
<td></td>
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<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>
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<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>
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<tr>
<td><strong>PM CSA Cryo Gap</strong></td>
<td>COC, PG</td>
<td>Demonstrated during OGSE1 &amp; 2</td>
<td>No, aborted plan to use edge images</td>
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<tr>
<td><strong>PM RoC</strong></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>
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<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>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td><strong>Image Quality and WFE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<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>
<td></td>
</tr>
<tr>
<td>Thermal Distortion – OTE Alignment Change</td>
<td>COC Figure drift of PM over 2.5K DT</td>
<td>Demonstrated capability during OGSE2, in evaluation</td>
<td>No</td>
<td></td>
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<tr>
<td><strong>Radiometric Sensitivity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<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>
<td></td>
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<tr>
<td>PM Collection Area</td>
<td>COC (reflection area)</td>
<td>Demonstrated capability during OGSE1 &amp; 2</td>
<td>No</td>
<td></td>
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<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><strong>Plate Scale</strong></td>
<td>Pass and a Half</td>
<td>Demonstrated capability during OGSE 2</td>
<td>No</td>
<td></td>
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<tr>
<td><strong>WFSC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<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>No</td>
<td></td>
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<tr>
<td>WFS&amp;C Influences Functions</td>
<td>Pass and a Half, COC, photogrammetry</td>
<td>Data from OGSE2 in evaluation, looks promising</td>
<td>No</td>
<td></td>
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<tr>
<td><strong>Actuator command repeatability</strong></td>
<td>CMUTS</td>
<td>Demonstrated during OGSE1 &amp; 2</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td><strong>PMSA Envelope Control Limit</strong></td>
<td>COC</td>
<td>Demonstrated during OGSE1</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td><strong>WF Control Signal Path</strong> (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>
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<tr>
<td>Fine Guidance Loop</td>
<td>Pass and a Half, 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

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**Final Risk Reduction Test provides confidence in Readiness to conduct Flight OTIS Cryo Vac Test**
TPF and HOSS in JWST Cleanroom at JSC
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.
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