JWST Observatory Status for JWST Space Telescope Users’ Committee (JSTUC)

August 25, 2022

Mike Menzel
This section will provide a summary of the top level performance metrics and observatory and systems following the successful completion of observatory commissioning.

- Observatory Status and Environments
- Technical Performance Metrics
  - Image Quality
  - Thermal / Cryogenic / Thermal Performance
  - Stray Light
  - Momentum Management and Propellant Life
  - RF Link Margins
- Issues
  - Micro-Meteors
  - CFDP Latency
  - Artemis Launch “EM-1” Impacts on DSN coverage
- Summary
The observatory was successfully launched on 12-25-22, 12:20:07 UTC.

Successfully completed all Mid-Course Corrections, and 5 station-keeping maneuvers. The observatory continues to follow its nominal trajectory. (See following charts)

All major deployments were successfully completed by 1-8-22.
- Deployment completion retired 295 of the 344 Single Point Failures

Successfully achieved all cryogenic operational temperatures.

Completed all OTE alignment and phasing activities.

There were 152 recorded anomalies through Commissioning. None have had any lasting impact on performance or estimated life.

Has experienced several solar proton events, flares and Coronal Mass Ejections (CMEs) with no lasting effects.

Has experienced up to 7 measurable impacts from micro-meteors.
- Six events were in family with predicts.
- One event was not in family with expectations, however optical performance still exceeds requirements by almost a factor of 2.
After a commissioning program that very closely fit into the nominally planned 180 days, the Early Release Observations (EROs) demonstrated Webb’s capabilities, showing the deepest observations of our universe, an exoplanet spectrum, stellar death, galactic mergers, and stellar birth.

Webb’s First Deep Field was presented to the White House on July 11, 2022.

President Biden stated: “We can see possibilities no one has ever seen before. We can go places no one has ever gone before.”

ERO’s were officially released to the public on July 12, 2022
Location in Trajectory as of L+242 d (1 of 2)

JWST Position L+242 d
(x,y,z)=(152,175 km, -746,208 km, -92,877 km)

Above Ecliptic Plane
Below Ecliptic Plane

Sun → Earth → L2 → Science Ops
Location in Trajectory as of L+242 d (2 of 2)

JWST Position L+242 d
(x,y,z)=(152,175 km, -746,208 km, -92,877 km)
JWST Environments

- JWST has experienced the full variety of anticipated “typical” operational environments during commissioning:
  - Solar Proton Events
  - Coronal Mass Ejections
  - Solar Flares
  - Sporadic Micro-Meteoroids (Velocity Distribution shown below) and five minor showers.
    - Lyrids
    - Aquariids
    - Herculids
    - Southern Delta Aquariids
    - Perseids

Sporadic Meteor Velocity Distribution
# Technical Performance Metrics

<table>
<thead>
<tr>
<th>Performance / Resource Parameters</th>
<th>Capability / Requirement</th>
<th>Estimate or Predict 10-21</th>
<th>Post Commissioning 7-2022</th>
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<tbody>
<tr>
<td><strong>Sensitivity Parameters</strong></td>
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<tr>
<td>NIRCam SI Sensitivity @ 2 microns (nJy)</td>
<td>11.4</td>
<td>9.56</td>
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<td>MIRI SI Sensitivity @ 10 microns (nJy)</td>
<td>700</td>
<td>513</td>
<td>462</td>
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<td>Straylight (MJy/ster @ NIR 2 microns)</td>
<td>0.091</td>
<td>0.080</td>
<td>0.060</td>
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<td>Straylight (MJy/ster @ NIR 3 microns)</td>
<td>0.07</td>
<td>0.065</td>
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<td>Straylight (MJy/ster @ MIR 10 microns)</td>
<td>3.9</td>
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<td>Straylight (MJy/ster @ MIR 20 microns)</td>
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<td>OTE Transmission* Ap m2 Revised (TBR)</td>
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<td>21.286</td>
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<td><strong>Image Quality Parameters</strong></td>
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<tr>
<td>Strehl (NIR 2 microns)</td>
<td>0.80</td>
<td>0.856</td>
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<td>Strehl (MIR 5.6 microns)</td>
<td>0.80</td>
<td>0.962</td>
<td>0.962</td>
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<td>NIRCam Channel Wavefront Error (nm)</td>
<td>150</td>
<td>126</td>
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<td>NIRSpec Channel Wavefront Error (nm)</td>
<td>238</td>
<td>168</td>
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<tr>
<td>NIRISS Channel Wavefront Error (nm)</td>
<td>180</td>
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<td>MIRI Channel Wavefront Error (nm)</td>
<td>421</td>
<td>174</td>
<td>140</td>
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<td>EE Stability at 2 microns Over 24 hours</td>
<td>2.30%</td>
<td>0.41%</td>
<td>0.20%</td>
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<tr>
<td>EE Stability at 2 microns Over 14 days</td>
<td>3.00%</td>
<td>2.40%</td>
<td>0.53%</td>
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<td>Image Motion rms for 15 sec Sliding Window for NIRCam (mas)</td>
<td>6.6</td>
<td>5.7</td>
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<td><strong>Operations Parameters</strong></td>
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<td>Observing Efficiency</td>
<td>70%</td>
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<td>78.0%</td>
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<td>Slew Time for 90 Degree Slew with 5 RWAs (min)</td>
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<td>59.6</td>
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<td>Momentum Accumulation LV1 (Nms/d)</td>
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<td>Momentum Accumulation LV4 (Nms/d)</td>
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<td><strong>Thermal Parameters</strong></td>
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<td>Cryo Parasitic Margin (NIRCam)</td>
<td>60%</td>
<td>79.7%</td>
<td>79.7%</td>
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<td>Cryo Parasitic Margin (NIRSpec FPA)</td>
<td>60%</td>
<td>76.1%</td>
<td>76.1%</td>
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<td>Cryo Parasitic Margin (FGS/NIRISS)</td>
<td>60%</td>
<td>80.4%</td>
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<tr>
<td>Cryo-Cooler Line Load Margin (Pinch Point / Steady State)</td>
<td>83%</td>
<td>260%/288%</td>
<td>260%/288%</td>
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<tr>
<td>Cryo-Cooler OM Load Margin (Pinch Point / Steady State)</td>
<td>83%</td>
<td>245%/154%</td>
<td>245%/154%</td>
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<tr>
<td><strong>Data and Link Parameters</strong></td>
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<tr>
<td>S-Band Uplink Margin (dB)</td>
<td>3.00</td>
<td>6.90</td>
<td>26.30</td>
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<td>S-Band Downlink Margin (dB)</td>
<td>3.00</td>
<td>4.40</td>
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<td>Ka-Band Downlink Margin (dB)</td>
<td>3.00</td>
<td>6.41</td>
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<td><strong>Observatory Resources</strong></td>
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<td>Observatory Wet Mass (kg) as of 7-2016</td>
<td>6310</td>
<td>6161</td>
<td>6161</td>
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<td>Observatory CG Offset (mm)</td>
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<tr>
<td>Observatory CG Offset (mm)</td>
<td>38.0</td>
<td>38.0</td>
<td>38.0</td>
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<tr>
<td>Propellant Budget (kg)</td>
<td>300</td>
<td>251</td>
<td>251</td>
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<td>Observatory Power Load (W)</td>
<td>1808</td>
<td>1802</td>
<td>1802</td>
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<tr>
<td>Observatory Power Generation (W)</td>
<td>2073</td>
<td>2073</td>
<td>2073</td>
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<td>Max Battery Discharge Time (Min)</td>
<td>458</td>
<td>458</td>
<td>458</td>
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</tbody>
</table>
Key Level 2 optical metrics are specified in terms of:

- OTE Aperture x Transmission (MR-211)
- Strehl Ratio (MR-110 and MR-116)

Detailed descriptions of the optical metrics will be presented in the OTE, Science Performance and Science Instrument Sections.

Optical Throughput:

- Unobstructed area measured from pupil image 25.44 m² > 25.431 m²
- Table at the upper right gives the EOL predictions for Aperture X Transmission based on contamination levels measured at the launch site:
  - Minimum margin of 5% at wavelength of 3.1 microns

Strehl Ratio:

- Strehl at 2 microns required to be 0.80
- Current BOL estimate for NIRCam B Short Wave channel at 2 microns Strehl is 0.84.
- EOL estimate for NIRCam B Short Wave channel at 2 microns is 0.82.
- Currently the Observatory is Diffraction Limited at a wavelength of 1.1 microns

Encircled Energy (EE) Stability:

- EE Stability is required to be less than 2.3% in 24 hours and less than 3% for 14 days following a hot to cold slew.
- EE stability has been measured to be less than 0.2% for 24 hours and less than 0.53% for 14 days.
Image Quality (2 of 2)

Post Phasing Engineering Images

Measured LOS Stability
The observatory telescope has successfully reached all its operational temperatures.
- Thermal Health is Green (all systems on Side-A)
- Only 1 sensor lost (SMSS IB-Hinge Pin)

Primary Mirror (PM) and Secondary Mirror (SM) temperatures shown on the upper right.
- Secondary mirror 5K colder than expected
- Center section warmer than predicted (1-6K)
- Wings close to predicted (slightly cooler)

All Science Instrument (SI) instruments are within operational temperature ranges and tuned to SI Team requested Targets within those ranges, as shown in the table on the lower right.
- Stability is also with requirements < 25mK/day (Req 50mK/day)

The MIRI has been cooled to its operating temperatures via the MIRI cryo-cooler.
- Measured cooler load vs Predicted at measured interface temperatures is extremely close. (124mW predicted prelaunch)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Flight (K)</th>
<th>Target (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIRSpec OA</td>
<td>35.57</td>
<td>35.5</td>
</tr>
<tr>
<td>NIRSpec FPA</td>
<td>42.80</td>
<td>42.8</td>
</tr>
<tr>
<td>FGS</td>
<td>38.48</td>
<td>38.5</td>
</tr>
<tr>
<td>NIRCam</td>
<td>38.52</td>
<td>38.5</td>
</tr>
<tr>
<td>MIRI</td>
<td>6.03</td>
<td>6.0</td>
</tr>
</tbody>
</table>

| Cooler Load | Measured 119 mW | Predicted 118 mW |
The Observatory Bus is operating within required temperature ranges.

- Thermal Health is Green (all thermal control systems on Side-A)
- Observatory has experienced Roll and Pitch solar aspect angles across entire FOR and TCS has demonstrated proper heater & temperature control throughout.
- No sensors or heaters lost

STA heater control parameters tweaked on-orbit as planned (CAR-747) to improve temperature stability over entire FOR.
Stray Light Performance

- NIR Stray light performance is driven by scattering. Estimates for NIR stray light are:
  - 0.06 MJy/SR at $\lambda = 2$ microns
  - 0.04 Mjy/SR at $\lambda = 3$ microns
  - Well below requirements of 0.091 MJy/SR at $\lambda = 2$ microns and 0.070 MJy/SR at $\lambda = 3$ microns.

- Stray light path from Sky to Instruments found to arrive at NIRCam and NIRISS detectors after glancing reflections on internal hardware
  - This is mitigated by small “keep out zones” for bright objects and calibrations.

- MIR Stray Light levels are driven by observatory temperatures.
  - Plot to the right shows measured MIR Stray Light levels against predicts
  - In flight measurements show excellent agreement with predictions
The large sunshield, observatory attitude changes, and shadowing effects conspire to produce unbalanced torques resulting in significant momentum accumulation in the Reaction Wheels Assemblies (RWAs).

- Sunshield geometry is designed to minimize momentum accumulation.
- Momentum accumulation (Nms / day) is plotted as a function of Roll and Pitch attitude as shown on the following chart. (Torque Tables).

Momentum accumulation can be managed via observation scheduling. The Ground Segment defined LV1 and LV4 metrics such that if Torque Tables have values lower than these, there is a high probability that momentum can be effectively managed via scheduling:

- LV1 = The mean momentum buildup per day within a roll band of $\pm 1^\circ$.
- LV4 = The mean momentum buildup per day within a roll band of $\pm 4^\circ$.

Required LV1 and 4 metrics as well as measured on-orbit values shown in table on lower right.

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>LV1</td>
<td>22</td>
<td>4.3</td>
<td>3.2</td>
<td>16.2</td>
</tr>
<tr>
<td>LV4</td>
<td>23</td>
<td>4.9</td>
<td>3.5</td>
<td>16.4</td>
</tr>
</tbody>
</table>
Pitch Torque Table Shows values higher than predicted but well within the +/- 12 Nms/day error band for the model prediction.
Because of the injection accuracy of the Ariane LV, and the timely execution of the Mid Course Correction Maneuvers, JWST has excellent propellant margins.

- Propellant life currently exceeds 20 years.

Current propellant levels:
- Hydrazine: 144.89 kg
- Oxidizer: 104.63 kg

Projected Propellant Life:
- Table to the right shows the pre-launch DV and propellant allocations
- Predicted rates from the budget:
  - 5.36 kg Fuel per year (see blue boxes)
  - 2.94 kg Ox per year (see green boxes)
- Subtract fuel and Ox for EOL maneuver from current propellant levels
  - Hydrazine: 144.17 kg
  - Oxidizer: 103.78 kg
- Remaining propellant life limited by Hydrazine to 26.9 years.
RF Link Margins

- All Rf link margins remain at very healthy levels.
  - See tables on the right show pre-launch RF margin estimates.

- Measured RF Link margins have exceeded these pre-launch estimates:
  - Ka-band downlink margin at 28 Mbps: 8.6 dB (Average)
  - S-Band downlink margin at 40 Kbps thru the MGA: 6.23 dB (Average)
  - S-Band uplink margin at 16 kbps: 11.58 dB
The primary mirror has experienced 7 measurable micro-meteor hits on our primary mirror and are averaging about 1 per month as expected based on our analysis.

The resulting optical errors from 6 of these were well within our expectations and within what we had budgeted for optical wavefront error (WFE).

One of the seven had WFE considerably higher than our expectations. However even after this event our optical performance is still twice as good as our requirements.

This event could well be a rare statistical anomaly but out of an abundance of caution we have been investigating possible mitigation strategies.

Since we have over 20 years of fuel, it is wise to consider methods that could ensure all parts of the observatory perform at their best for that long.
The Project has assembled a team that has been investigating a balanced approach of restricting certain pointing directions, that have the highest likelihood of the most energetic micro-meteors without putting undue restrictions on science efficiency and targets of opportunity.

- The team consists of experts from Project, mirror manufacturer and the NASA Meteoroid Environment Office (MEO) at the Marshall Space Flight Center (MSFC).
- The team has been investigating potential mitigation methods such as pointing restrictions to quantify their benefit and weigh that against their impact to science and operational efficiency.
- These methods will be in addition to the defensive maneuvers that were already anticipated as a mitigation for the known periodic meteor showers.
  - Such maneuvers are currently implemented for previous mission such as HST.

Project engineering will be making their recommendations in September.
The Ka-Band downlink of science data uses a high reliability Class 2 Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol (CFDP).

- CFDP Class 2 uses an acknowledged protocol:
  - Receiving system detects errors or missing data and declares fault
  - Missing or erroneous data re-transmitted

Time delays (latency) in the ground system Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol (CFDP) processing during Ka-Band Solid State Recorder playbacks can result in on-board timers running out resulting in:

- Accumulation of on-board faults that may mask other faults that occur simultaneously
- Extended time duration to close downlink transactions:
  - Cannot use full contact time for playback
  - Lower playback availability → less science data can be collected
DSN CFDP Latency Anomaly  (2 of 4)

CFDP Transaction Overview

- Time:
  - Metadata PDU
  - File Data (FD) PDUs
  - EOF PDU
  - ACK (EOF) PDU
  - NAK PDU
  - ACK (FIN) PDU
  - FIN PDU

- Notification of Completion:
  - Files Ready for Transfer

- S&OC:
  - S&OC processing to generate ACK (EOF) PDU encapsulated in command packet
  - NAK PDU
  - NAK CLTU(s) to be uplinked
  - S&OC processing to generate NAK PDU encapsulated in command packet
  - FIN PDU
  - FIN CLTU(s) to be uplinked
  - S&OC processing to generate FIN PDU encapsulated in command packet

- DSN:
  - ACK (EOF) CLTU(s) to be uplinked
  - S&OC processing to generate ACK (EOF) PDU

- Spacecraft:
  - ACK (FIN) PDU

Note:
- $T_1$ is the Earth receive time of the EOF PDU by the DSN.
- $T_2$ is triggered by receipt of EOF PDU from S/C, $T_1$.
- $T_3$ is triggered by receipt of the EOF PDU from S/C at $T_2$, and when DSN has not received all File Data (FD) PDUs for the transaction.
- $T_4$ is triggered after receipt of EOF PDU from S/C at $T_1$ and after the DSN CFDP Entity determines that all File Data (FD) PDUs have been received (signaling transaction is complete on the ground).
DSN engineering generated a fish-bone diagram with potential root causes, and have isolated the most probable causes in the TCP congestion control software within the Data Collection and Distribution (DCD) systems.

- Dropped packets in the Wide Area Network (WAN) can cause this congestion control software to reset resulting in ramp-up in throughput. Results in data back-ups.
  - See diagram on the upper right
- Depending on the frequency and distribution of packet drop-outs significant latencies can develop.
  - Simulation result below.

**DCD Devlab with WAN simulator simulating TCP drops:**

Each drop causes DCD throughput to significantly drop and slow ramps back up. Consecutive drops cause the throughput to drop below the throughput required to handle the JWST data rate.
The issue is under Anomaly Management Board (AMB) control.

- The last AMB meeting was held on 6-18-22
- The approved path forward from this meeting:
  1. Continue implementing DSN troubleshooting recommendations as needed with MOM approval (see previous slide 18)
  2. Continue root cause investigation
  3. Flight control room has discretion to halt PB at first instance and contact DSN for further coordination, as needed
  4. Move DCD to low latency queue with voice (120Kbps) on CBWFQ [Proposed for THIS WEEK (Week June 13th)]
  5. Complete testing of updated DCD TCP congestion algorithm
  6. Continue testing to explore IBM Aspera solution to maximize WAN bandwidth

While investigations continue DSN contact time will remain at 12 hours per day for normal operations (buffer to ensure adequate SSR playback time)
 Artemis EM-1 Impacts

- Artemis’s EM-1 will require a significant amount of DSN antenna resources.
- JWST will have significantly decreased ground station coverage with some prolonged outages.
  - Exact DSN coverage depends on EM-1’s launch date, but instead of the normal 12 hours of DSN coverage per day, there are days of 2-4 hours or even 0 hours
  - Some launch contingency scenarios include multiple 40-50 hour outages.
- Without at least 8 hours of DSN coverage per day, JWST must reschedule science as planned.
  - Time critical science can be accommodated
- Significant DSN outages also cause undesirable reconfigurations onboard
  - The Engineering team has evaluated options to minimize the impact of these reconfigurations
- In all cases, the first two weeks of the EM-1 mission have the most pain.
- In general, the earlier EM-1 launches, the less impactful it is for JWST.
Summary

- JWST has been successfully launched and deployed on-orbit.

- It has completed the majority of its major observatory level tests and performed its observatory level functions.

- It’s measured observatory level performance has met all specifications with healthy margins.

- We have experienced anomalies, but so far the majority have been addressed and or have not had significant impacts to mission safety or performance.
  - Mission Systems Engineering is participating in efforts to address DSN ground system issues associated with CFDP latency.
  - MSE and the Flight Ops Team will trend meteoroid impacts and assess performance degradation.