Exploration Systems Development

NASA Advisory Council Meeting
March 2, 2016
Agenda

- ESD Overview
- Program Accomplishments and Status
  - Space Launch System (SLS)
  - Ground Systems Development and Operations (GSDO)
  - Orion
- Cross-Program System Integration Status
Exploration Systems Development

OVERVIEW
Journey to Mars

- Hubble Space Telescope
- International Space Station
- Space Launch System
- Orbiters
- Rovers and Landers
- Deimos
- Phobos
- Mars Transit Habitat
- Orion Crewed Spacecraft
- Solar Electric Propulsion
- Asteroid Redirect Mission
- Deep Space Habitat
- Commercial Cargo and Crew
- Missions: 6-12 Months
  Return: Hours
  Earth Reliant
- Missions: 1-12 Months
  Return: Days
  Proving Ground
- Missions: 2-3 Years
  Return: Months
  Earth Independent
Transition from ISS to Cislunar Space: Framework

*There are several other considerations for ISS end-of-life*
## DRAFT: Phase 1 Flight Test Objectives

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>FLIGHT TEST OBJECTIVE</th>
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</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Demonstrate Orion’s capability to extract co-manifested payload from SLS fairing.</td>
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<tr>
<td>Transportation</td>
<td>Determine Orion’s ability to support missions with at least 4-Crew longer than 21 days in conjunction with additional elements.</td>
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<td>Transportation</td>
<td>Evaluate Orion’s depress/repress for EVA contingency operations.</td>
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<td>Transportation</td>
<td>Evaluate Orion’s off-axis (tail-to-sun) performance.</td>
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<td>Transportation</td>
<td>Evaluate EUS TLI Performance with Orion plus Co-Manifested Payload.</td>
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<td>Transportation</td>
<td>Evaluate high-power electric propulsion systems.</td>
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<td>Transportation</td>
<td>Evaluate high-efficiency, high-power solar arrays in deep space.</td>
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<tr>
<td>Habitation Working in Space</td>
<td>Demonstrate crew accommodations for Beyond-LEO conditions.</td>
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<tr>
<td>Habitation Working in Space</td>
<td>Evaluate the performance of electrical components in a deep-space radiation environment.</td>
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<tr>
<td>Habitation Working in Space</td>
<td>Evaluate cislunar transit habitat airlock and EVA system servicing accommodation for ability to support contingency EVA operations.</td>
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<tr>
<td>Habitation Working in Space</td>
<td>Evaluate cislunar transit habitat airlock and EVA system servicing accommodation for ability to support nominal deep space mission EVA operations.</td>
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<tr>
<td>Operations Working in Space</td>
<td>Demonstrate transition between crewed and uncrewed operations, including configuration for remote/dormant operations and reactivation for crewed support.</td>
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<tr>
<td>Operations Working in Space</td>
<td>Demonstrate human spacecraft operations in the presence of communications latency.</td>
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<tr>
<td>Operations Working in Space</td>
<td>Demonstrate independent (On-board) mission and trajectory design/planning capability.</td>
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<tr>
<td>Operations Working in Space</td>
<td>Demonstrate Earth-independent deep space navigation.</td>
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<tr>
<td>Operations Working in Space</td>
<td>Evaluate stowage strategies to handle logistics and trash within available stowage volume for deep space missions.</td>
</tr>
<tr>
<td>Exploration Working in Space</td>
<td>Demonstrate collection and return of geologic asteroid samples.</td>
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<tr>
<td>Exploration Working in Space</td>
<td>Demonstrate research sample acquisition, handling, analysis, and curation requiring environmentally controlled conditions with no cross-contamination permitted.</td>
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<tr>
<td>Staying Healthy</td>
<td>Demonstrate/evaluate space radiation protection and monitoring.</td>
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<tr>
<td>Staying Healthy</td>
<td>Demonstrate/evaluate human health, performance, and environmental health in a hostile and closed environment.</td>
</tr>
<tr>
<td>Staying Healthy</td>
<td>Evaluate the effects of deep space on complex organisms, plants, food, medicines, and animal models.</td>
</tr>
</tbody>
</table>
Beginning human exploration beyond LEO as soon as practicable helps secure our future in space.
<table>
<thead>
<tr>
<th>Date</th>
<th>Program</th>
<th>Program Milestone</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep-15</td>
<td>Orion</td>
<td>ACM Mass Sim Start</td>
<td>Complete</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>First EDU Power Dist. Unit Delivered</td>
<td>Complete</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>First EM-1 Weld (Tunnel to Bulkhead)</td>
<td>Complete</td>
</tr>
<tr>
<td>Oct-15</td>
<td>SLS</td>
<td>ESAB handover VAC (to Boeing)</td>
<td>Complete</td>
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<tr>
<td></td>
<td>GSDO</td>
<td>GSDO CDR Kickoff</td>
<td>Complete</td>
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<tr>
<td></td>
<td>SLS</td>
<td>ICPS STA Production Complete</td>
<td>Complete</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>Orion CDR Board</td>
<td>Complete</td>
</tr>
<tr>
<td>Nov-15</td>
<td>Orion</td>
<td>AM Mass Sim Start</td>
<td>Complete</td>
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<tr>
<td></td>
<td>Orion</td>
<td>ESM STA Arrival @ Plum Brook</td>
<td>Complete</td>
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<tr>
<td></td>
<td>Orion</td>
<td>Heat Shield Design Complete</td>
<td>Complete</td>
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<tr>
<td>Dec-15</td>
<td>GSDO</td>
<td>GSDO CDR Board</td>
<td>Complete</td>
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<tr>
<td></td>
<td>Orion</td>
<td>CM Primary Structure Close-Out Weld Start</td>
<td>Complete</td>
</tr>
<tr>
<td>Jan-16</td>
<td>Orion</td>
<td>EM-1 Ogive Production Start</td>
<td>Complete. Learning curve with tooling resulted in slower than planned weld ops. Assessing downstream schedule.</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>Start VAC Weld Confidence Article</td>
<td>Complete</td>
</tr>
<tr>
<td>Feb-16</td>
<td>Orion</td>
<td>ESM STA Ready for Test</td>
<td>On Track – Test Readiness Review (TRR) scheduled on 2/25/16. Team is working through ESM travelled work combined with Plum Brook Mechanical Vibration Facility (MVF) issues</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>Engine Controller EM-5 Delivery to SSC</td>
<td>Complete</td>
</tr>
<tr>
<td></td>
<td>GSDO</td>
<td>SCCS 3.0/3.2 valid. Complete (Haz Ops C&amp;C S/W)</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>EM-1 JM Build Start</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>Start SITF-Q Testing</td>
<td>Under Review. Possible slip to March 2016 due to emulator availability</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>CM Structure Delivery to O&amp;C</td>
<td>Complete. Delivered on 2/1/16 (was January 2016)</td>
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## ESD HQ Milestones
### Mar 2016-Aug 2016

<table>
<thead>
<tr>
<th>Date</th>
<th>Program</th>
<th>Program Milestone</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>Mar-16</td>
<td>SLS</td>
<td>EM-1 Motor First Segment Cast (Aft)</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>ITL-02: Dual String C&amp;DH Integration Complete</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>S/W Rel. 12 (Green Run)</td>
<td>On Track</td>
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<tr>
<td></td>
<td>SLS</td>
<td>SPIE CDR Board Part 2</td>
<td>On Track</td>
</tr>
<tr>
<td>Apr-16</td>
<td>Orion</td>
<td>CM Pressure Proof Test</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>ESM CDR</td>
<td>Under Review – ESA recommending delay to June. Forward plan is under assessment.</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>ESM FM-1 Structural Assembly Complete</td>
<td>Under Review - ESA working to complete structure in Torino in April and holding delivery date to Brehmen. Some traveled work to Brehmen may result. Holding downstream milestones including ESM on dock at KSC in Jan 2017 while working mitigations.</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>CMA Composite Aft Wall Delivery</td>
<td>On Track</td>
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<tr>
<td></td>
<td>Orion</td>
<td>CMA Inner Wall Delivery</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>LVSA STA Production Complete</td>
<td>On Track</td>
</tr>
<tr>
<td>May-16</td>
<td>SLS</td>
<td>Flight Intertank Panels to MAF</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>ESM S/W Emulator Delivery</td>
<td>On Track</td>
</tr>
<tr>
<td>Jun-16</td>
<td>ESD</td>
<td>Build to Sync Kickoff</td>
<td>On Track. Due to ESA SM CDR slip, team assessing common resource impacts, bottlenecks and mitigations.</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>QM-2 Static Test</td>
<td>Moved to June (from May) to accommodate additional test data collection and instrumentation.</td>
</tr>
<tr>
<td></td>
<td>GS/DO</td>
<td>SSCS 3.3/3.4 Valid. Complete</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>Core Stage STA VAC Welds Complete</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>Orion</td>
<td>Orion Emulator delivery to SLS</td>
<td>On Track</td>
</tr>
<tr>
<td>Jul-16</td>
<td>SLS</td>
<td>VAC Welding Complete</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>ESD</td>
<td>Build to Sync Exit Board</td>
<td>On Track</td>
</tr>
<tr>
<td>Aug-16</td>
<td>Orion</td>
<td>OMS-E Flight Engine Delivery</td>
<td>On Track. Some schedule threat due to Teflon seal part availability, shelf conditions of OMS engine parts.</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>Flight LVSA Assembly Operations at AWF Complete</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>Facilities Ready for Engine Section (ES) STA Tests</td>
<td>On Track</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>CoF Facilities Complete for LOX Structural Test</td>
<td>On Track</td>
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### Exploration Systems Development

#### Top Concerns

<table>
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<tr>
<th>Concern</th>
<th>Current Status</th>
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<tr>
<td>Integrated avionics and software verification and validation (V&amp;V), Integrated Test Lab (ITL) capacity, distributed V&amp;V process, emulator performance, agile software development process productively metrics and cross-program interdependencies.</td>
<td>In-work: Limited deferred content and re-planning has occurred and is a watch item, Integrated Avionics Software-Integrated Technical Team (IAS ITT) metrics established. ITL use improving.</td>
</tr>
<tr>
<td>Integrated test and verification (T&amp;V) plan involving distributed multi-site activities such as structural dynamics testing, environmental test, and functional check out leading to integrated flight certification traceable to requirements closure and Certification of Flight Readiness (COFR) with sufficient resources and test.</td>
<td>In-work: CDRs data informing T&amp;V, Enterprise V&amp;V Team (EVVT) focus planning in work, T&amp;V resources a watch item, T&amp;V activities are currently in progress.</td>
</tr>
<tr>
<td>Funding uncertainty impacts to program/cross-program technical integration.</td>
<td>Improving: favorable FY 2016 appropriations received. Funding uncertainty for out years remains a watch item.</td>
</tr>
<tr>
<td>Schedule threats related to integrated critical path: Orion Command Module (CM) and European Space Agency (ESA) service module, core stage delivery for green run, readiness of ground software to support final system integration.</td>
<td>Watch item: ESA SM CDR and FM-1 delivery to Bremen under review. GSDO GFAS re-plan, and SLS post VAC ATP are watch items.</td>
</tr>
<tr>
<td>GSDO mobile launch outfitting and V&amp;V including ground system control software/Ground Flight Application Software (GFAS) and dependencies on cross-program flight/ground hardware interfaces and software. Ground processing first flight learning curve.</td>
<td>In-work: GFAS re-plan complete but post re-plan status is a watch item, final dependency agreements are still in work. Platforms and Mobile Launcher are making progress.</td>
</tr>
<tr>
<td>Orion ESA Service Module (ESM) prop system redundancy and associated impacts on schedule/CDR completion. CM/ESM structural analysis and environmental T&amp;V planning and resource availability for parallel Operations and Checkout (O&amp;C) and GRC work, flight computer processor throughput, preparations for CM outfitting at O&amp;C.</td>
<td>Orion T&amp;V plan to be completed by March, ESA CDR delay and FM delivery to Bremen under review, ESM prop redundancy issues resolved by NLT design implementation, T&amp;V resources a watch item.</td>
</tr>
<tr>
<td>SLS implementation of post VAC ATP welding and assembly operations at MAF through green run test. SLS ascent acoustic loads analysis. Interim Cryogenic Propulsion Stage (ICPS) safety analysis to support EM-1. EUS design development for EM-2.</td>
<td>Improving: VAC weld schedules complete, weld confidence articles in work. EUS is baseline for EM-2. Green run test schedule under review.</td>
</tr>
<tr>
<td>Long term productions and operations sustainability at the rate of 1 flight per year after EM-2 by reducing cost. Mission planning for EM-2 and beyond including on-ramp for low-cost opportunities for development tech objectives and capability enhancements. EM-co-manifested payload options being evaluated.</td>
<td>P&amp;O Study as part of PPBE to further identify cost reduction opportunities, numerous program efforts also in work. Dedicated mission planning team established. Mission planning resources - watch item.</td>
</tr>
<tr>
<td>On-orbit Micro Meteoroid and Orbital Debris (MMOD) exposure risk and related mission planning including EM-2 first crewed flight trajectory options.</td>
<td>In-work: MMOD environment, vehicle susceptibility, and EM-2 mission profile being evaluated.</td>
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Space Launch System Accomplishments

- Launch Vehicle Stage Adapter Test Article Fabrication
- Nozzle installation into the aft booster segment for QM 2
- RS 25 flight engine 2059 installed for testing at Stennis Space Center
- Steel towers rising for new SLS test stands at Marshall Space Flight Center
- SLS Core Stage test article progress, Michoud Assembly Facility
- Interim Cryogenic Propulsion Stage test article complete
SLS Recent Performance

Program
- SLS CDR briefings complete – October 2015
- SLS Design Certification Review (DCR) – January 2018

Interim Cryogenic Propulsion Stage (ICPS) & Adapters
- ICPS structural test article (STA) production complete – October 27
- Completed forward cone to forward ring weld of Launch Vehicle Stage Adaptor (LVSA) Structural Test Article (STA) – December 2015
- Began EM-1 ICPS LOX Tank Build-up – December 2015
- Completed LVSA STA aft cone welding – January 2016
- Completed LVSA C2 Confidence Weld – February 2016
  - SPIE CDR 2 Board planned for March 2016 (Kickoff held February 2016)

Stages
- Engine Section Weld Confidence Article (WCA) Vertical Assembly Center (VAC) Weld Complete – December 28
- CS Pathfinder Awarded to Radiance Technologies – January 19
- LH2 Tank WCA VAC Welds Complete – January 22
- Started LOX Tank WCA VAC Welds – February 2016
  - Engine Section Structural Qualification Article Weld on VAC – March 2016
SLS Recent Performance (cont.)

Booster
- Qualification Motor 2 (QM-2) nozzle assembled and installed
- Production Simulation Hardware for Booster Processing (Pathfinder) Delivered to GSDO
  - Pathfinder aft skirt delivered to GSDO Jan 20th
  - One inert aft and center segment delivered via rail to KSC on Feb 2nd
- EM-1 Left & Right Hand Booster Production progressing
  - EM-1A (left) forward segment cylinders complete refurbishment; ready to begin insulation
  - EM-1B (right) center forward segment completed insulation X-ray with no indications
- Started EM-1 Aft Skirt refurbishment – Feb 2016
  - QM-2 Test Firing - June 2016

Engines
- RS-25 production restart contract signed – Nov 19, 2016
- RS-25 Engine 2059 installed into SSC Test Stand A-1 for testing – Nov 2016
- Flight Engine Control Unit (ECU) Production began – Jan 2016
- Completed Engineering Model 5 Controller ship to SSC – Feb 2016
- Completed ECU Software Build 3 Hardware-in-the-Loop verification & validation – Feb 2016
Avionics / Software

- Complete development testing of Core Stage Avionics in Software Integration Test Facility – Development (SITF-D) – Dec 2015
- Stages Redundant Inertial Navigation Unit (RINU) Development Test data delivered to support validation & verification – Jan 14, 2016
- Began formal testing on Flight Software Release 12 – Jan 22, 2016
- On track to begin qualification testing of Core Stage Avionics in Software Integration Test Facility – Qualification (SITF-Q) – Mar 2016

Facilities

- 6 of 7 tiers of LH2 Test Stand (4693) erected – Jan 2016
  - Preparation in work to begin Crosshead & Final Tier installation - April 2016
- Complete erection of LOX Test Stand (4697) all three tiers – Feb 2016
GSDO Program Status
Ground Systems Development & Operations Accomplishments

- First Work Platform for Space Launch System Installed in VAB
- Conducted the Critical Design Review
- Completed Phase A Testing of the Orion Service Module Umbilical
- Started Construction of Flame Trench at Launch Pad B
- Completed Command and Control Software Release 3.2
- Received First Shipment of Booster Pathfinder Hardware for V&V Testing at RPSF
GSDO Recent Performance

Vehicle Assembly Building
• Platform K-South installation lifting proved problematic during the final pin insertions into the corbel rails platform due to alignment and rotation issues
• A spreader beam tool (currently being fabricated) will be used to keep the corbels aligned during lifting and installation operations
• Platform installation completion by March 2017 will be a challenge and GSDO is working to minimize the impact

Mobile Launcher
• Potential impact to ground support equipment (GSE) install schedule due to additional scope required for Installation Construction Contract – delays attributed to greater than expected magnitude of changes as well as GSE sub-system ICD changes
• Issues and concerns for using scaffolding to access aft end of integrated launch vehicle are emerging and being studied

LETF Umbilical Testing
✓ Orion Service Module Umbilical (OSMU) Phase A Testing complete (simulated plates, winch testing)
✓ OSMU Phase B preparations are in-work
✓ ICPS umbilical test set-ups are in-work – serial schedule with OSMU
Multi-Purpose Processing Facility (MPPF) Development

- Ground Support Equipment (GSE) Installation 90% complete – all GSE installed by July 2016
- MPPF verification and validation (V&V) planning and Site Activation efforts are well underway
  - GSE Subsystem (V&V) test design/review activities are in progress
  - Integrated Site Activation Team was kicked-off on January 25 to ensure daily integration of activities leading up to and throughout the V&V phase
  - V&V Phase is scheduled to start in July 2016

Crawler Transporter

Recently completed:
- Gearbox Assemblies refurbishment are substantially complete

On-going work:
- Steering Arm refurbishment - 7 of 8 complete and re-installed
- Jacking, Equalizing, Leveling (JEL) cylinder upgrade replacements. All new cylinders have been installed – final hook-ups are in-work. Two spares are on-hand and placed into stores

Future:
- Initial standalone V&V starts in April
Pad B Development Status

Recently completed projects:

✓ New liquid oxygen (LO2) vaporizer system (supports LO2 sphere) is complete
✓ Heating, ventilation, and air conditioning (HVAC) upgrades are substantially complete

On-going Projects:

• Environmental control system (ECS) Refurbishment project is ~50% complete
• Water supply refurbishment/upgrade projects are ~90% complete
• Bypass piping/valves project is ~40% complete
• Flame trench/flame deflector project is ~9% complete

Future projects:

• New liquid hydrogen (LH2) separator system and the catacomb roof reinforcement projects are currently in the procurement process
• New LH2 sphere for EM-2 – design requirements and statement of work for A&E contract are in-work – target award for design in Spring 2022
GS.DO Recent Performance (cont.)

Spaceport Command and Control System (SCCS)

Current Releases:
- SCCS 3.2 Validation testing completing; no significant problems noted
- SCCS 3.3 development completed successfully on schedule January 15

Future Releases:
- SCCS 3.4 will have all required content to support hazardous operations verification and validation testing -- complete by 3/11/16
- SCCS 4.0 Schedule challenges
  - SCCS 4.0 will have required content for ground operations support
  - SCCS 4.0 start date threatened due to delayed transition of SCCS 3.2 and SCCS 3.3 developers to SCCS 4.0 content
  - Overall schedule is challenged by contractor hiring difficulties for software developers in a highly competitive environment

Ground and Flight Application Software Teams (GFAST)

- Successfully incorporated the updated GFAST schedule into the integrated master schedule to support GS.DO critical path analysis
- Collaboration between GFAST and other Programs has improved significantly
  - GFAS team members working closely with SLS/Orion flight system counterparts to determine specifics of ground-to-flight interfaces and cross program dependencies
  - GS.DO/GFAST tracking ground-to-flight software dependencies with respect to planned GFAS software drop requirements

Firing Room 1 software testing activities
Orion Program Status
Orion Accomplishments

Orion EM 1 crew module pressure vessel welding is completed at Michoud Assembly Facility in New Orleans.

The completed pressure vessel arrives at the Operations and Checkout Building at the Kennedy Space Center.

European Service Module Structural Test Article (ESM STA) at Glenn Research Center Plum Brook Station in Ohio.

Launch Abort Motor structural qualification test at Orbital ATK in Utah.

Final Engineering Parachute Drop Test, Army Yuma Proving Ground in Arizona.

Orbital Maneuvering Engine on the ESM STA at Glenn Research Center Plum Brook Station in Ohio.
Orion Recent Performance

Program
- Orion CDR board held October 2015
- Orion DPMC December 2015
- Orion Orion APMC March 2016
- ESM CDR April 2016
- Post CDR Program Sync May 2016

Crew Module (CM)
- Finished welding EM-1 pressure vessel that is the CM primary structure
- Shipped pressure vessel to KSC to begin spacecraft assembly February 2016
- Proof pressure test in April 2016
- Initial power-on by January 2017

Launch Abort System (LAS)
- EM-1 Jettison Motor build starts February 2016
- Attitude Control Motor hot fire test (HT-11) October 2016
Orion Recent Performance (cont.)

Service Module

- Service module is comprised of two elements: a European Service Module (ESM) and a Crew Module Adaptor (CMA)
- ESM Structural Test Article (eSTA) version of the ESM built by Thales Alenia Space Italia
- eSTA delivered to NASA’s Plum Brook Station November 2015 and integrated with CMA STA.
  - ESM EM-1 flight structure complete by Thales Alenia Space Italia and delivered to Airbus in Bremen, Germany April 2016
  - ESM and STA EM-1 flight articles ready for mating into the EM-1 SM Spring 2017

The service module will be shaken at NASA’s Plum Brook station in Sandusky, Ohio, to recreate the vibrations of launch, and be subjected to acoustic and shock environments.
Cross-Program System Integration Status

Agenda

• CSI technical performance and accomplishments
• CSI products schedule
• Interdependencies
• Cross-Program Integration Team top technical issues
• EM-2 Planning
• Technical performance metrics
• Independent assessments
CSI Technical Performance and Accomplishments

• Recent Major Cross-Program Accomplishments (November – February)
  – Baseline Cross-Program Flight Safety System (FSS) Test Plan (November)
  – Baseline Cross-Program Integrated Launch Operations Implementation Plan (December)
  – Cross Program Integrated Vehicle Model Test Plan (December)
  – Completed GSDO CDR (December 2015)
  – Manifested EM-1 Secondary Payloads at the HEO Flight Planning Board (January)
  – Hydrogen Burn-Off Igniter (HBOI) fix, to angle each RS-25 directed upward 6-deg relative to Baseline Design to ensure excess hydrogen burn-off (January)
  – Baseline the Umbilical Release and Retract Test (URRT) Plan (February)
  – Baseline the VAB Program Specific Engineering Test (PSET) Plan (February)
  – Baseline Cross-Program Integrated Vehicle Loads Control Plan (February)
  – Baseline Cross-Program Integrated Verification Test (IVT) Plan (February)

• Near-term forward work
  – Update Cross Program S&MA Plan Rev B (March)
  – Baseline ESD Mishap Preparedness and Contingency Plan (March)
  – Complete SLS SPIE CDR2 (March)
  – Baseline Cross-Program Pad Program Specific Engineering Test (PSET) Plan (March)
  – Baseline Cross-Program Comm System End-to-End (CS ETE) Test Plan (March)
  – Baseline Certification of Flight Readiness (CoFR) Plan (March/April)
  – Baseline Cross-Program Countdown Sequencing Test (CST) Plan (April)
  – Complete Orion ESM CDR (April/May)
  – Baseline Cross-Program Dynamic Rollout Test (DRT) Plan (May)
  – Baseline Cross-Program Wet Dress Rehearsal (WDR) Test Plan (May)
Cross Program Interdependencies – Metrics

**77 active Interdependencies; 155 active Cross-Program Control Milestones**

### Cross-Program Agreements Progress

<table>
<thead>
<tr>
<th>Date Reported</th>
<th>Total Items</th>
<th>Total Active</th>
<th>Deferred</th>
<th>Total Closed/Withdrawn</th>
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**Total Active vs. Closed (delivered) Items Progress**

**Elevated Interdependencies**

Closed: Green, Active: Red

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CPIT Top Technical Issues

- **Hydrogen Burn Off Igniter (HBOI) / Hydrogen Pop loads on the core stage**
  - Concern over GH2 build up prior to RS-25 ignition
  - HBOIs will be canted 6 degrees upward to counter downdraft effect. Crosswinds did not require any changed in HBOI position
  - GSDO assessing the impact of vertically staggering the nozzles under the core stage engine to counter the effect of water (rooster tail) on HBOI particles (while maintaining 6 degree upward cant).

- **Integrated Test Lab (ITL) Capacity/throughput**
  - Original ITL oversubscription reduced from >1000 shifts to approximately 34 shifts over
  - Managing residual threats of ground and flight software testing tracked as TPR 12543
Emerging Cross Program
Issues/Concerns

- **Orion-GSDO ICDs, Volume 1 (Hardware)**
  - 30 TBX’s remaining to be burned down by March; 81% of TBXs have been successfully closed
  - Continue to work with ESM to gain concurrence of ICD updates as part of the ESM CDR

- **ESM procured design incorporates single fault tolerant bellows propulsion design**
  - GSDO set up a team to assess impact and any potential hazard mitigations (continuous leak monitoring and contingency depress and de-service at all KSC facilities), Feb, 2016
  - GSDO recommended addition of isolation valve upstream of bellows; Orion investigated but was found to not be practical to implement for EM-1
  - Orion proceeding with 0 Fault Tolerance bellows for EM-1; Reviewed by JPCB for approval, Feb, 2016
Emerging Cross Program Issues/Concerns

- **Orion Avionics Command Parameter Definition Disconnect**
  - Orion command parameters do not meet C3I Volume 4 approved specifications
  - Potential impact to GS DO critical path for Operational Readiness

- **Orion Flight SW emulator Updates (SOCCRATES)**
  - SOCCRATES needs to be upgraded to Class C, Safety Critical for formal GFAST software verification testing
  - GS DO has requested several functionality updates
  - LM/Orion is reviewing changes for contractual considerations

- **SLS Flight SW Release 14 delivery date delay**
  - SLS estimates work required for FSW Release 14 and associated emulator updates and additional content will impact schedule 8 weeks
  - SLS will discuss impact to the JICB accordingly

- **GS DO Ground Operations Software (GFAST)**
  - GFAST development is highly dependent on agreements for products (CUI, OMRS, LCC, XTCE) to be delivered on time by other programs.
  - OMRS and LCC development supports GFAS personnel have access for early review of developing OMRS from Orion and SLS.
Emerging Cross Program
Issues/Concerns

• **OSMU Involvement with URRT**
  – Performing the mechanical release and retract with the OSMU could damage the ground and/or flight plate and cause a significant risk to continued processing and launch
  – Trade study results, including S&MA risk assessment, planned for JICB / JPCB in May timeframe

• **Production Umbilical Plate Collet Delivery**
  – Redesign in mid-2015 was performed to minimize the amount of movement of the plungers and prevent premature release of the mechanism.
  – Flight hardware deliveries sliding into July/August timeframe due to design issues seen during development testing.
    • Collet would not release properly during Boeing testing.
    • Progress status reviewed on January 28th
EM-2 Mission Planning

• With the selection of the EM-1 Mission being a DRO mission the goal of EM-2 is:
  – Complete residual FTO’s not accomplished on EM-1
  – Accomplish risk reduction activities for future more complex missions for EM-3+

• Missions should include capabilities relevant to potential near term deep-space missions
  – DRMs in the ESD ConOps are intended to be design driving cases not the mission selected
  – Goal is to maintain current SLS/Orion FTO’s while demonstrating as many Exploration Objectives on EM-1 and EM-2 as cost, schedule and risk allows

• Need to resolve the crew risk issues for first flight and select a mission that meets FTOs with acceptable risk posture
  – Radiation
  – MMOD
  – ECLSS
  – Abort capability
  – Etc.
EM-2 Mission Options

- **EM-2 Baseline DRM**
  - High Lunar Orbit (HLO)

- **EM-2 Option 1 DRO/NRO**
  - Executes the DRO mission (EM-1 repeated)

- **EM-2 Option 2 Hybrid**
  - Hybrid mission to complete the remaining FTO’s
  - Options to check-out ARCM capabilities will be developed separately
EM-2 Mission - HEO/Lunar Flyby

1 Orbit in HEO
(~30 hour period)
1 Orbit Around
Moon (~10.8
days)

2 Views (Earth-Moon Rotating, Pulsating
Frame)
EM-2 Mission Planning Summary

• EM-2 mission is not finalized
  – Programs are using the HLO as a “baseline” to develop capability

• A detailed risk reduction activity to understand risk posture and impact on ground and flight test plans is underway
  – Mission Analysis and Integrated Architecture (MAIA) team contains representatives from ESD, SLS, Orion and GSPO as well as OS&MA, OCE, HMTA and the Crew Office
  – Final mission selected will involve ESD and HEOMD

• EM-2 mission baselined will factor in
  – Mission requirements will be governed by ESD and HEOMD Flight Test Objectives and risk posture for crew and mission
  – Current mission planning would allow the test and demonstration of the capabilities desired by Agency
Major ESD/CSI Independent Assessments In Progress

- End-to-End trajectory optimization ongoing and performing trade studies in launch period and launch window
- Combined Modeling & Simulation of System Behavior at SLS/MPCV/GSDO Interfaces
- NESC Modeling of Crawler/Transporter (CT), Mobile Launcher (ML), and Forcing Functions
- Peer Review of SLS and Orion Programs Modal Test, Development Flight Instrumentation, and Dynamic Model Correlation Plans – ESD impacts in work
- Evaluation of ORDEM 3.0 with Available On-Orbit Assets
- Enterprise Verification and Validation Assessment – newly started by NESC
- Review of the Orion-ESM Interfaces
- Independent Verification of Abort Loads (NESC work deferred until FY17 due to cost)
- ESD Data Solution Architecture (ARC/NESC)*
- Cross-functional Closure Processes (ARC)*
Backup
Acronyms

- HBOI- Hydrogen Burn Off Igniter
- ITL- Integrated Test Lab
- ESM- European Service Module
- GCS- Guidance Control System
- GFAST- Ground Flight Application Software Team
- CUI- Controlled Unclassified Info
- LCC- Launch Commit Criteria
- XTCE- Telemetry & Command Exchange
- OMRS- Operational Maintenance Requirements and Specifications
- SCCS- Spaceport Conditioning and Control System
- EGSE- Electrical Ground Support Equipment
- C3I- Command Control Communication
- FSW- Flight Software
- OSMU- Orion Service Module Umbilical
- VSS- Variable Stiffness Span
- ICPSU- Interim Cryogenic Propulsion Stage
- EUS- Exploration Upper Stage
- ICD- Interface Control Document
- IRN- Interface Revision Notice
- HIS- Human Systems Integration
- HF- Human Factors
- ACO- Architectures & ConOps
- FEM- Finite Element Models
- VAC- Verification Analysis Cycle
- FRC- Flight Readiness Cycle
- URRT – Umbilical Release and Retract Test
- CAIDA – Customer Avionics Interface Development and Analysis -- KSC Ground System Simulation Lab
- SOCCRATES – Orion Flight Software Simulator