Exploration Systems Development

NASA Advisory Council Meeting

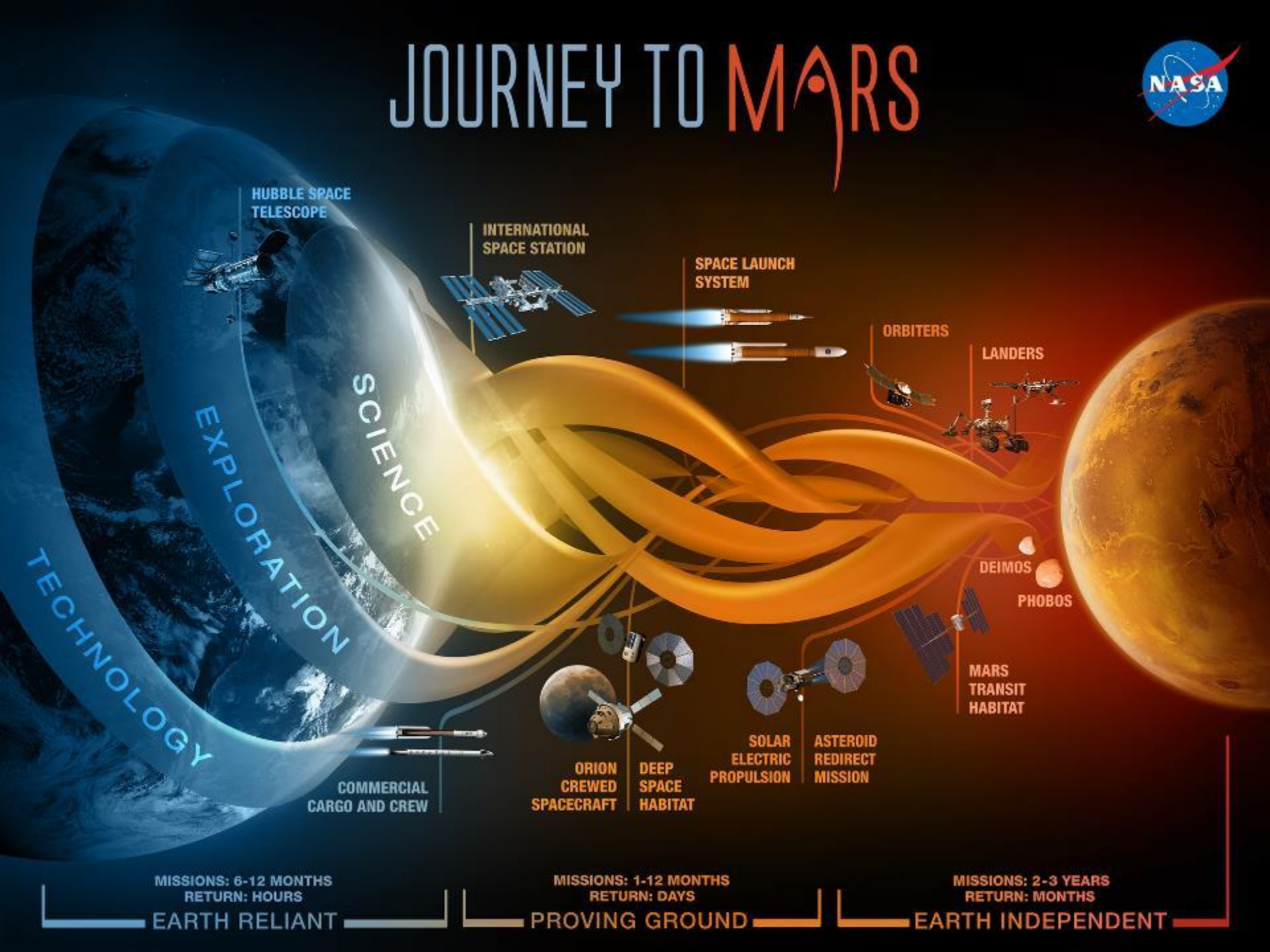
November 4, 2015

Agenda

- **ESD Overview**
- **Program Status**

ESD Overview

JOURNEY TO MARS



MISSIONS: 6-12 MONTHS
RETURN: HOURS
EARTH RELIANT

MISSIONS: 1-12 MONTHS
RETURN: DAYS
PROVING GROUND

MISSIONS: 2-3 YEARS
RETURN: MONTHS
EARTH INDEPENDENT

SLS, Orion, and Ground Systems

Beginning human exploration beyond LEO as soon as practicable helps secure our future in space.

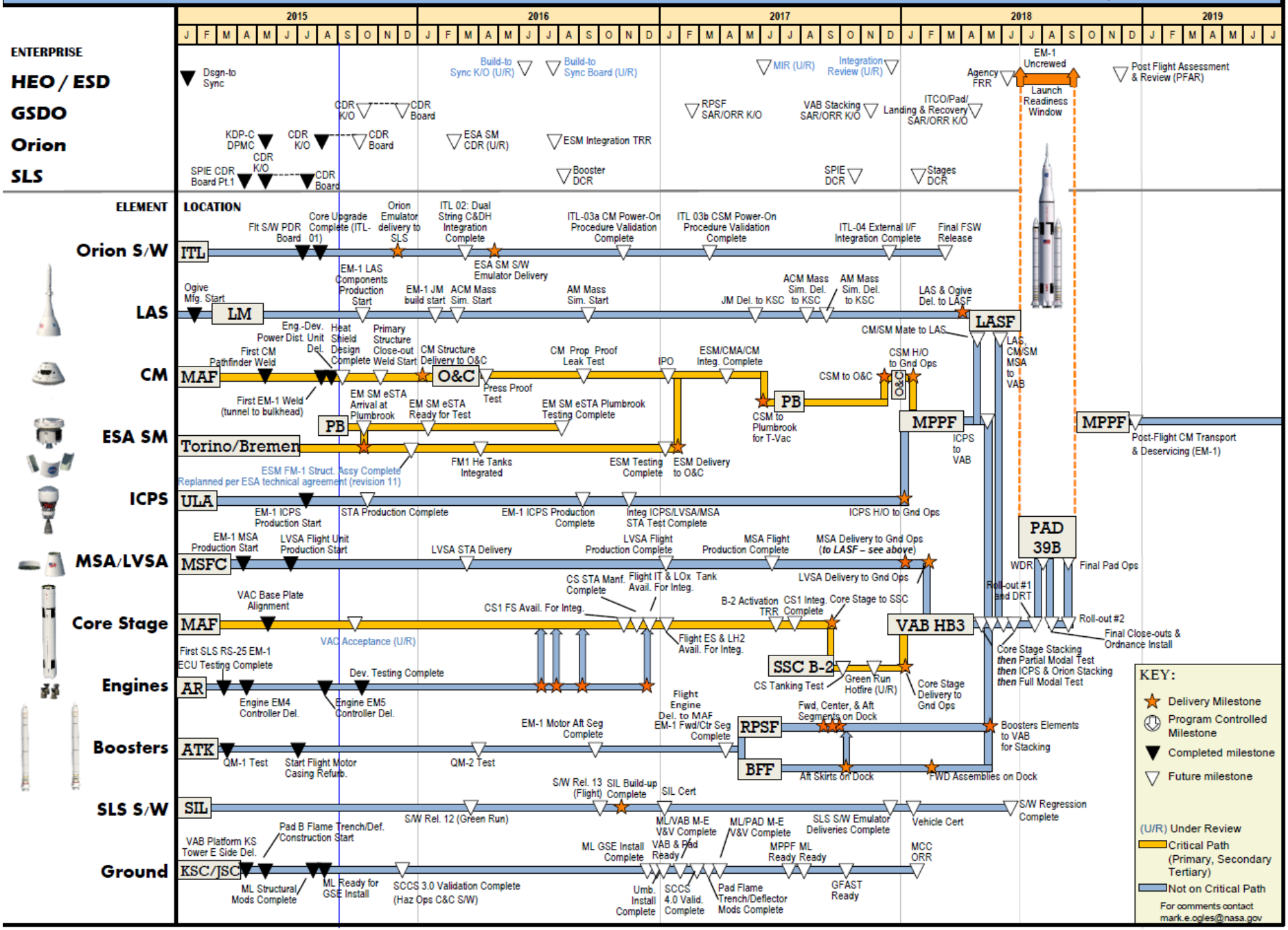
Space Launch System

Ground Systems Development & Operations

Orion Crewed Spacecraft

ESD EM-1 INTEGRATED MISSION MILESTONE SUMMARY

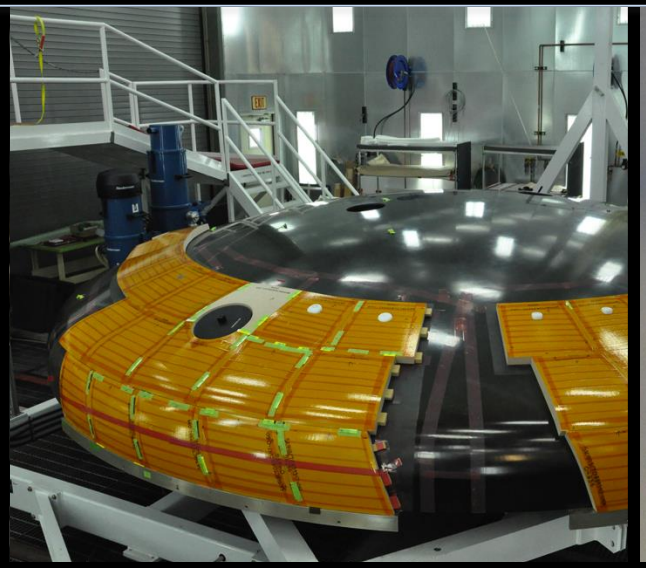
NASA ESD
Chart Updated: 09/10/2015, Rev C



Orion Program Status

Orion Accomplishments

First weld of Orion Exploration Mission-1 crew module pressure vessel Michoud Assembly Facility



A manufacturing development unit of Orion's heat shield is being built at Lockheed Martin's facility in Denver

Orion's most challenging parachute drop test to date a success in August in Yuma, Arizona

Pieces for the Orion spacecraft that will fly on EM-1 being prepared for welding at MAF

The Orion Crew Module Adapter simulator arrives at Plum Brook Station Space Power Facility in Sandusky, Ohio

Launch Abort System

Prime Contractor: Lockheed Martin
Manufacturer Location: Denver, Colorado

Status

- Abort Motor test article case complete
- Jettison Motor test article case assembly in process
- Attitude Control Motor re-designed controller Engineering Development Unit initial design complete

Upcoming Milestones

- Attitude Control Motor hot fire test (HT-11) – April 2016

Abort motor test article case
July 2015

Crew Module

Prime Contractor: Lockheed Martin
Manufacturer Location: Michoud Assembly Facility, Louisiana
Operations & Checkout Facility, Kennedy Space Center, Florida

Status

- First weld on EM-1 crew module – September 2015
- EM-1 crew module barrel final milling complete and all pressure vessel components at Michoud – October 2015

Upcoming Milestones

- Closeout weld – December 2015
- On-dock at KSC – January 2016

Orion Avionics and Software
Integrated Test Lab

Prime Contractor: Lockheed Martin
Manufacturer Location: Denver, Colorado

Status

- NASA/Lockheed Martin Integrated Test Lab official opening at Lockheed Martin, Denver – July 2015
- Integrated Test Lab initial power on – September 2015

Upcoming Milestones

- ESA avionics and electrical ground support equipment delivery – April 2016
- Command Module subsystem integration completion – November 2016

Orion Integrated Test Lab (ITL)
July 2015

Service Module

European Service Module (ESM) and Crew Module Adapter (CMA)

ESM: International Partner: European Space Agency (ESA)
ESA's Prime Contractor: Airbus
Manufacturer Location: Bremen, Germany

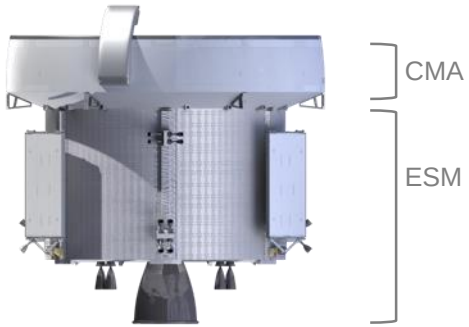
CMA: NASA Prime Contractor: Lockheed Martin

Status

- ESM Structural Test Article being assembled and tested at Thales Alenia Space Italia (TASI).

Upcoming Milestones

- ESM Structural Test Article testing in October 2015 at TASI.
- ESM structural test hardware ships to Plum Brook, Ohio – November 2015



European Service Module (ESM) Structural Test Article during shock tap test at TASI. July 2015

Fairings

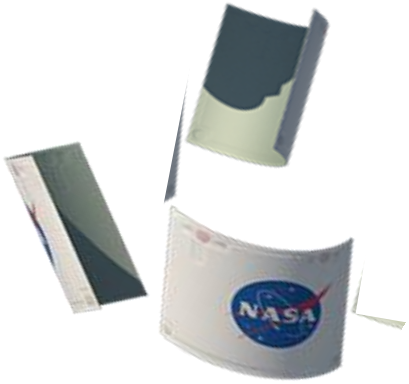
Prime Contractor: Lockheed Martin
Manufacturer Location: Sunnyvale, California

Status

- Early EM development test conducted using EFT-1 test fairings with no issues.

Upcoming Milestones

- Critical Design Review – December 2015
- Assembly and build on track for on-time delivery early 2017.
- EM qualification test at Plum Brook in Sandusky, Ohio – April 2017

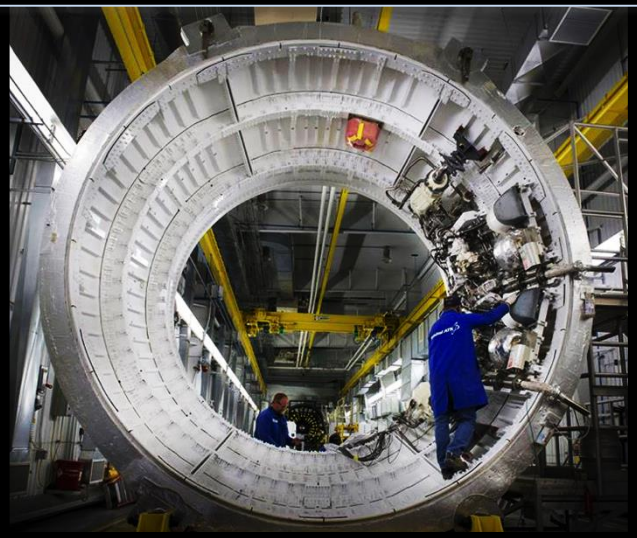


First EM-1 Fairing Separation Test.
June 2015

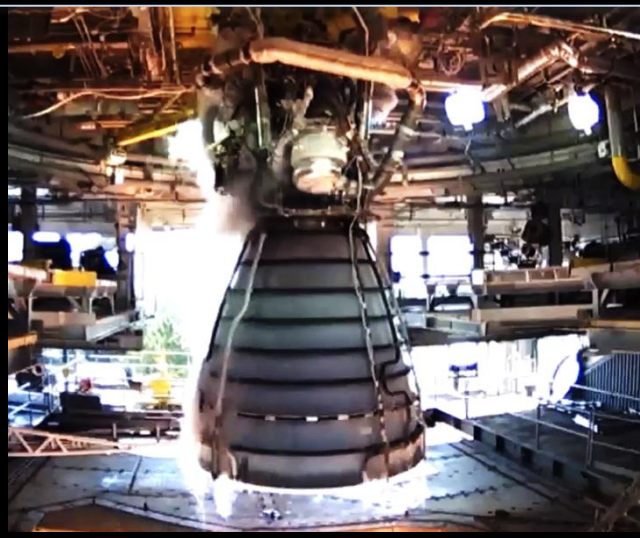
SLS Program Status

Space Launch System Accomplishments

Launch Vehicle Stage Adapter Test Article fabrication



Booster Test Article in progress for second qualification firing



RS-25 engine test conducted at Stennis Space Center

Steel towers rising for new SLS test stand at Marshall Space Flight Ctr.

SLS Core Stage hydrogen tank progress, Michoud Assembly Facility

Pegasus barge completed, in dock at Stennis Space Center

Orion (OSA) and Launch Vehicle (LVSA) Stage Adapters

Prime Contractor: OSA, MSFC Engineering; LVSA, Teledyne Brown Engineering
Manufacturer Location: Marshall Space Flight Center

Status:

- First OSA flew successfully on EFT-1 in December 2014
- OSA EM-1 test article currently complete
- LVSA contract awarded to Teledyne Brown Engineering – January 2014
- OSA EM-1 rings and panels delivered – August 2015
- LVSA test article forward cone weld complete – October 2015

Upcoming Milestones:

- LVSA: Test article scheduled for completion – March 2016

OSA test article stage adapter being readied for structural testing at Marshall Space Flight Center.

LVSA Vertical Weld Tool (VWT) forward basket tooling at Marshall Space Flight Center

Interim Cryogenic Propulsion Stage (ICPS)

Prime Contractor: Boeing / United Launch Alliance
Manufacturer Location: Decatur, Alabama

Status:

- Production of EM-1 ICPS begins – July 2015
- ICPS flight software PDR – August 2015
- ICPS Structural Test Article handover to Boeing – October 2015

Upcoming Milestones:

- Delivery of ICPS test article to MSFC – October 2016

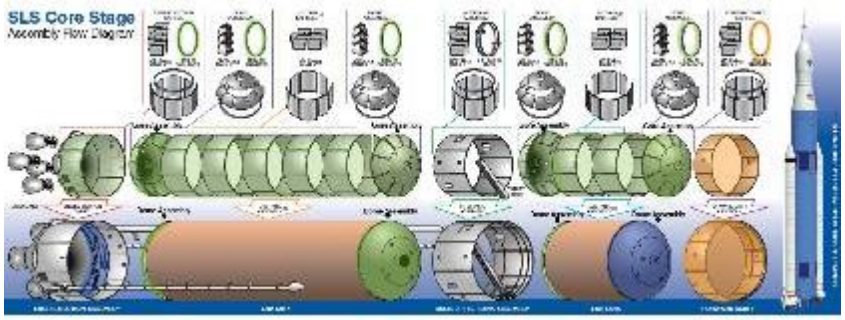
ICPS STA turnover to Boeing (above), October 2015, and EM-1 flight domes (below) September 2015

Core Stage

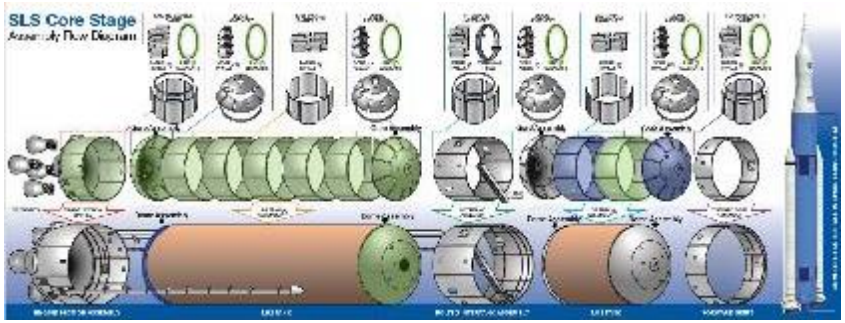
Prime Contractor: Boeing
Manufacturer Location: NASA Michoud Assembly Facility, New Orleans, Louisiana

Status:

- Foundations completed for new structural test stands at Marshall – January 2015
- Qualification rings completed, and 6 of 8 flight rings completed
- LOX (liquid oxygen) tank qualification barrels completed; EM-1 barrels in-work
- LH2 (liquid hydrogen) tank qualification and EM-1 flight barrels completed
- Engine section barrels completed



Qualification (above) and EM-1 flight (below) production status



Upcoming Milestones:

- Vertical Assembly Center (VAC) hand-over to NASA – October 2015
- First structural test stand complete – July 2016
- Core Stage structural testing to begin at Marshall – February 2017

Solid Rocket Boosters

Prime Contractor: Orbital ATK
Manufacturer Location: Promontory, Utah

Status:

- Successful test firing of Qualification Motor-1 demonstrated 5-segment solid rocket motor to high temperature operation conditions – March 2015
- Completed the QM-2 aft segment propellant casting – May 2015
- EM-1 booster aft skirt and nose cone refurbishment begins – August 2015

Upcoming Milestones:

- QM-2 – Q3 FY16

Aft Segment Cast for Second SLS Booster Qualification Test. March 2015

RS-25 Engines

Prime Contractor: Aerojet Rocketdyne
Manufacturer Location: Canoga Park, California

Status:

- Engine adaptation hot-fire testing February 2015 through the summer 2017
- Engineering Model – 1 Controller to the Software Integration Laboratory (SIL) – July 2015
- Engineers at Marshall Space Flight Center are developing and testing 3-D printing technologies to reduce cost of engine parts

Upcoming Milestones:

- RS-25 production restart contract signing – November 2015
- Next RS-25 hot firing – Q2 FY16

Seven successful tests of RS-25 E0525 completed in 2015

SLS Software and Avionics

Prime Contractor: Boeing, Orbital ATK
Manufacturer Location: Huntsville, Alabama and Clearfield, Utah

Status:

- Booster avionics system was shipped to Marshall from Orbital ATK's Avionics Lab in Clearfield, Utah – February 2015
- Completed Testing of Release 11 of the avionics software – September 2015

Upcoming Milestones:

- Flight Imaging Launch Monitoring Real-Time System (FILMRS) for cameras to Software Integration Test Facility – June 2016

The Software Integration Test Facility (SITF) at Marshall Space Flight Center – First Light kickoff began the facility integration testing and checkout. SLS Core Stage will use the SITF to perform vehicle-level avionics verification. January 2014

GSDO Program Status

Ground Systems Development & Operations Accomplishments

Platform H is the newest platform to be delivered to the VAB at KSC

Simulation tests in Firing Room 4 at the Launch Control Complex at KSC

Modifications complete to Mobile Launcher base and tower structure at KSC

ICPS Umbilical arm guided into vertical position at the LETF at KSC

Ribbon cutting for Small Class Vehicle Launch Pad 39C

Ground Systems

Prime Contractor: Multiple
Manufacturer Location: Multiple

Status:

- Umbilical testing in the Launch Equipment Test Facility (LETF) is well underway
- Mobile Launcher structural modifications are complete and ready to start Ground Support Equipment installation after contract award in August
- 11 different construction contracts are in-work on various modifications at Launch Pad 39B, including flame trench and sound suppression system
- Crawler-transporter gearbox refurbishment and hydraulic lift cylinder upgrades are going well
- Vehicle Assembly Building High Bay 3 platform construction is ~30% complete with second pair of platforms on-site
- Multi-Payload Processing Facility modifications and ground support equipment installations are ~80% complete
- Aft Skirt Electrical Umbilical Structural Test completed
- Mobile Launcher ground support equipment installation contract awarded
- Launch Pad 39B flame trench refurbishment construction begun (ongoing)

Upcoming Milestones:

- Complete Multi-Payload Processing Facility (MPPF) phase 2 facility GSE installation – 2nd Qtr 2016

Mobile Launcher structural modifications are complete. July 2015

Cross Program Integration

CSI Technical Performance and Accomplishments

Recent Major Cross-Program Accomplishments

- Completed SLS CDR (July)
- Completed Landing and Recovery Trade Study (July)
- Completed Integrated MRB Face-to-Face at KSC (July)
- Developed ITL high level test objectives for SLS and GSDO (July)
- Conducted SLS/GSDO OMRS familiarization sessions (over 150 in attendance)
- Conducted Integrated Medical Model TIM and CE review (July)
- Held Range Safety ITT Face-to-Face with 45th Space Wing on Range Safety Flight Ops concepts (July)
- Completed Orion CDR (October)

Near-term forward work

- Respond to Design-to-Synch RFA's from the SRB (16 of 21 remain open)
- Preparation, review, and approval of products for GSDO CDR (kickoff in October)
- Complete Level 1 Requirements Update (Block 1B, 2B and secondary payloads)
- Planning and preparation for Build-to-Sync

Cross-Program Integration Team Top Technical Issues

- **Hydrogen Burn Off Igniter (HBOI)/Hydrogen Pop loads on the SLS core stage**
  - Concern over GH2 build up prior to RS-25 ignition
  - All HBOI tests for downdraft and crosswind have been completed and correlated with computational fluid dynamics models.
  - 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 to counter the effect of water (rooster tail) on HBOI particles (while maintaining 6 degree upward cant)
  - Expected to close the issue after this assessment (11/2)

- **Integrated Test Lab Capacity/throughput**
  - Concern that there may not be sufficient testing time available to test Orion software as well as the cross-program tests required
  - Significant progress on re-planning resulted in significant reductions in over-subscription
    - Orion Program plan includes off-loading ITL testing to other Orion avionics labs and approved adding additional assets to minimize over subscription
  - Review/approve Orion testing plans for pre and post DD-250 at Vehicle Integration Control Board (11/30/15)
  - Complete Integrated Schedule for Cross-Program Integrated Testing (IAS ITT) (11/30/15)
  - Integrated Avionics System ITT to coordinate response to NESC recommendations (12/20/15)
  - Finalize verification requirements compliance matrix details and close issue (12/20/15)

CPIT Top Technical Issues Closed Since Last Quarter

- **Crew recovery in allotted 2 hr timeframe for nominal mission may not be possible**
  - Completed Landing and Recovery Trade for as soon as possible crew recovery in July
  - Final recommendations approved by JICB
    - ESD, Safety & Mission Assurance, Chief Engineer, Crew Office, Health & Medical, Orion, GSDO and DOD team
  - Multiple methods of recovery available for crew (helicopter, ribbed boat, LPD)
    - Method selected will depend on crew health, location of landing zone, sea state, weather, etc.
  - Issue closed. Off-nominal recovery still in work. (8/5/15)

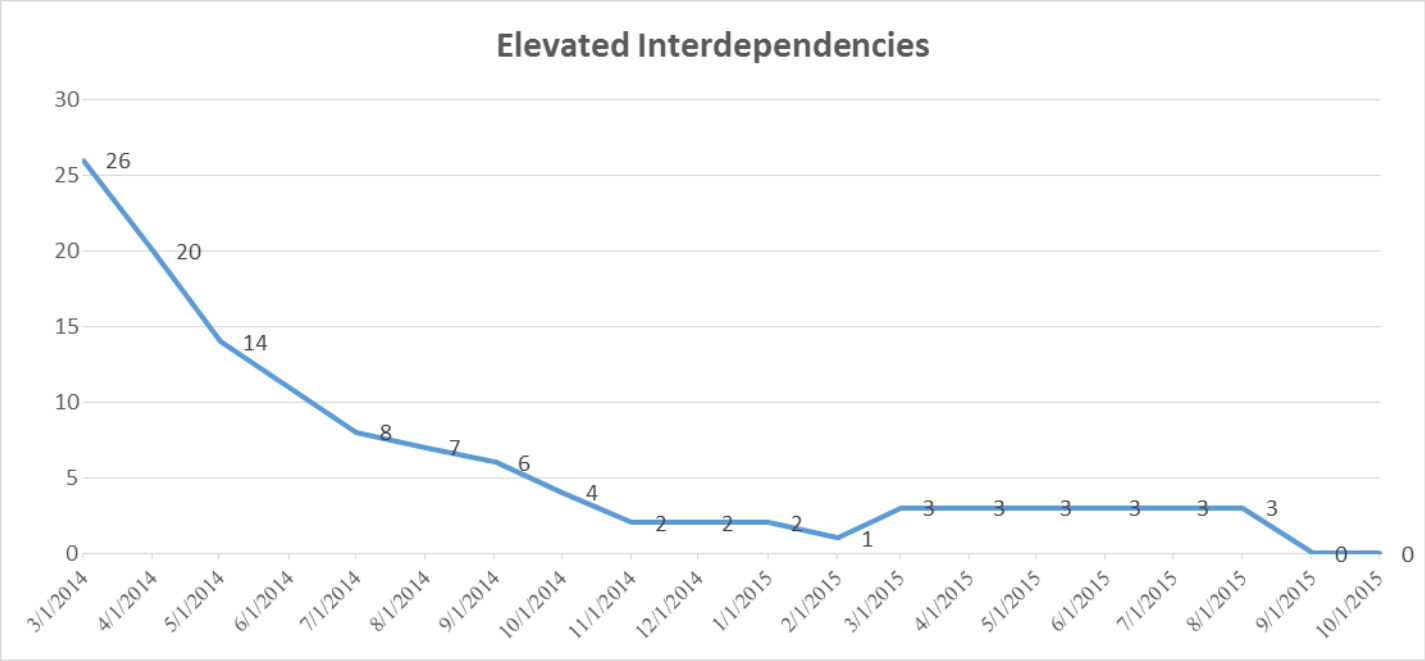
- **SLS ICPS Micrometeoroid and Orbital Debris (MMOD) on EM-1**
  - Updated ORDEM 3.0 models drive ICPS MMOD to be a large contribution to overall mission LOV.
  - Trade Study completed. Result was to recommend performing the trans-lunar injection (TLI) burn on Rev 1 instead of Rev 2. Other options were either too performance limiting or had schedule impacts. Risk significantly reduced with Rev 1 TLI.
  - Orion performed an assessment of subsystem impacts to on-orbit checkout time prior to committing to TLI and feels it can be accomplished.
  - ECB accepted Rev 1 TLI.
  - Issue closed for EM-1 (10/2/15)

CPIT Top Technical Issues Closed Since Last Quarter
(continued)

- **Collet Vibration Test Failure**
  - Premature disengagement during Orion vibration qualification test
  - Boeing tested and was able to reproduce the failure.
  - Design fix was implemented on the test hardware to confirm suitability. Alteration resulted in hardware passing vibe. Fix to be implemented on final design of flight hardware.
  - Issue closed (10/23/15)

Elevated Interdependencies

No Elevated Interdependencies at this time

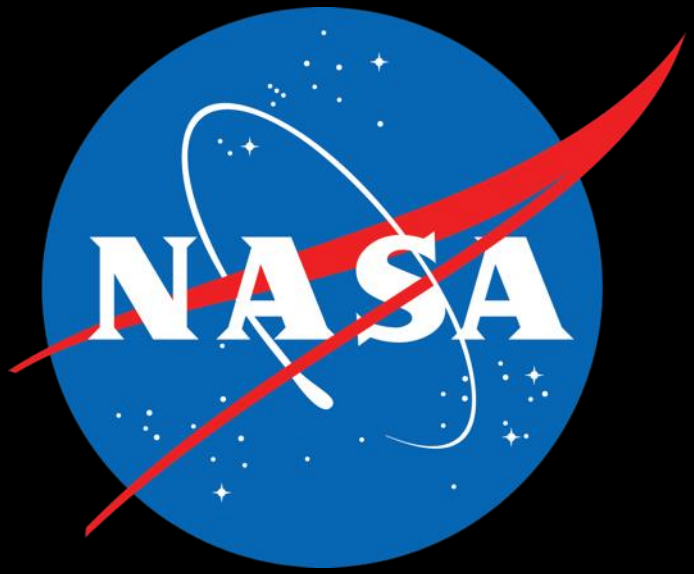


The team has managed Interdependencies through normal business processes and raised internally within Program management as needed to resolve minor issues

ESD Top Concerns

ESD Top Concerns

Concern	Current Status
Integrated avionics and software V&V, Integrated Test Lab capacity, distributed V&V process, emulator performance, agile software development process productively metrics and cross-program interdependencies.	Improving: Integrated Avionics Software-Integrated Technical Team (IAS ITT) F2F; metrics for schedule threat analysis in-work.
Integrated T&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 COFR with sufficient resources and test.	Improving: CDRs data informing T&V, Enterprise V&V Team (EVVT) Focus Planning In Work, T&V resources a watch item.
Funding uncertainty impacts to program/cross-program technical integration, interfaces, EM-2 (EUS) mission definition and content, interdependencies management, ground infrastructure, and efficiency of program planning and implementation.	FY 2016 appropriations anticipated to help provide some near term definition. Funding uncertainty remains a watch item.
Schedule threats related to integrated critical path: CM and ESA service module, core stage delivery for green run, readiness of ground software to support final system integration.	VAC completed ATP, CM PV will deliver on time. ESA SM (see next 3 items).
GSDO mobile launch outfitting and V&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.	Improving: ML contract awarded, GFAST re-plan complete, final Orion/SLS dependency agreements in work.
Orion ESA Service Module (ESM) prop system redundancy and associated impacts on schedule/CDR completion. CM/ESM structural analysis and environmental T&V planning and resource availability for parallel O&C/GRC work, flight computer processor throughput, preparations for CM outfitting at O&C.	Orion T&V plan to be completed by March ERB, ESA CDR delay until April (but holding delivery), ESM redundancy issues being resolved, T&V resources a watch item.
SLS preparation for and 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. Decision on EUS for EM-2. Complete re-planning of contract activities.	Improving: VAC ATP complete, post-ATP operations in work. ICPS Structural Test Article delivered, EUS decision by late December, contract re-planning in work.
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.	P&O Study as part of PPBE to further identify cost reduction opportunities, numerous program efforts also in work. Dedicated mission planning team established.
On-orbit Micro Meteoroid and Orbital Debris (MMOD) exposure risk and related mission planning.	In-work: MMOD environment, vehicle susceptibility, and EM-2 mission profile being evaluated.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