National Aeronautics and
Space Administration

DEEP SPACE
EXPLORATION SYSTEMS

EXPLORATION SYSTEMS DEVELOPMENT UPDATE

NASA ADVISORY COUNCIL – NOVEMBER 29, 2017

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EXPLORATION SYSTEMS DEVELOPMENT

Exploration Systems Development Top Concerns and Progress

Integrated avionics and software verification and validation (V&V): Orion and Space Launch System (SLS) flight software build phase progressing with some content deferral between releases being tracked. Test facility capacity and software content prioritization remain watch items particularly with Integrated Test Lab (ITL) overlap between EM-1 to EM-2. "Switch over" capability is being evaluated as are additional resource commitments to increase flight software production and ITL capacity for near and long term.

Actual Orion and SLS software release content and forward planning dates with associated functionality versus need dates at Exploration Ground Systems (EGS) continue to be negotiated and mitigated. EGS updating Spaceport Command and Control System (SCCS) schedules based on challenges to software development. Cross program integrated software (SW) critical path schedule has been updated and is being monitored.

Verification and validation (V&V): Deep into test implementation phase with Structural Test Article (STA) testing at multiple locations including Denver, MSFC, GRC, KSC, and WSTF, component level tests at suppliers and functional tests at element production sites all going on in parallel.

Crew Module (CM) STA, European Service Module (ESM) STA, and Launch Abort System (LAS) STA are at Denver, have completed element level test, and are now at the integrated level test. Orion Service Module Propellant Qualification Model (PQM) testing at WSTF temporarily on-hold to evaluate a thruster firing test anomaly.

SLS Engine Section (ES) STA testing at MSFC began 9/20/17 and has successfully completed all test cases for Block 1; currently into ultimate load cases one month ahead of schedule, limit load conditions being correlated to structural model. Liquid Hydrogen (LH2) STA is being instrumented at MAF and then will ship to MSFC for testing. Monitoring test schedule versus STA hardware delivery with updated delivery dates. Continuing to monitor structural analysis resource availability with concurrent certification (Block 1) and development (Block 1B).

Launch Equipment Test Facility (LETF) testing continues to make measured progress with completion of Interim Cryogenic Propulsion Stage (ICPS) umbilical and Core Stage Intertank Umbilical (CSITU) test. Continue to monitor completion of LH2 Tail Service Mast Umbilical (TSMU) versus Mobile Launcher (ML) need date.

Budget: FY18 continuing to operate under CR and evaluating program funding disconnects if it extends to a full year CR. Out-year funding uncertainty still impacts EM-1 and EM-2 (Exploration Upper Stage – [EUS]) mission definition and content, interdependencies management, ground infrastructure, and efficiency of program planning and implementation. Out-year funding uncertainty and potential for program planning updates remain watch items.

Exploration Systems Development Top Concerns and Progress

EGS: Launch Equipment Test Facility (LETF) experiencing some delays due to first time test issues and technician turnover/availability. Mobile Launcher (ML) also experiencing delays due first time build issues, availability of technicians for second shift operations, and LETF umbilical test and delivery status. ML multi element verification and validation schedule being re-planned accordingly and there continues to be margin.

Spacecraft Command and Control Software (SCCS) development continues to be reviewed against internal SW build/test efficiencies. The availability of experienced SW developers is a watch item. Ground/Flight Application Software (GFAS) evaluating cross program dependencies and operations working group status on systems functionality between Orion and EGS.

Launch Commit Criteria (LCC)/Operations and Maintenance Requirements and Specifications (OMRS) requirements being developed and progress being monitored against need dates. LCC/OMRS/Work Authorization Document (WAD) burn-down metrics in place and progress being made.

Orion: EM-1 Crew Module (CM) and Crew Module Adapter (CMA) production at Operations and Checkout (O&C) making good progress. CM completed Initial Power On (IPO) with hybrid avionics installed followed by successful CMA IPO (August 28). Hybrid avionics delivered. EM-1 heat shield thermal proof test complete and results are being evaluated.

ESM production/delivery continues to be a significant schedule concern with potential impacts to the start date for ESM/CM/CMA integration. Continuing to work with ESA/Airbus on ESM Assembly and Integration Test (AI&T) proficiency which has significantly improved. However, subtier suppler issues continue to drive significant schedule risk with ESA delivery. The ESM Pressure Control Assembly (PCA) solenoid-valve/latching-valve are under review. A sealing issue has been replicated in test, redesign is in work, and assembly/integration options are being evaluated. The ESM Gas On-Off Valve (GOOV) valves for the nitrogen (N2) distribution system are also under review. Some have experienced a bellow leak issue which has been replicated, and a fix has been identified. ESM delivery schedule is being evaluated accordingly. ESM is also evaluating N2 pressurant tank status and delivery of the Power Control and Distribution Unit (PCDU).

Exploration Systems Development Top Concerns and Progress

SLS: LH2 qualification tank proof test complete and is being prepared with simulators and instrumentation prior to shipment to MSFC as a Structural Test Article (STA). Liquid Oxygen (LOX) flight tank has completed proof testing. Significant progress has been made in addressing first time build manufacturing efficiencies for core stage integrated assembly at MAF however Engine Section (ES) component availability and overall Assembly Integration and Test (A&IT) status continue to be monitored closely. Core Stage is in the enterprise secondary critical path and has minimal margin to December 2018 delivery to SSC for Green Run. Increased technician staffing at MAF combined with streamlined operations, better communications, schedule focus with near term milestone tracking, and strong corporate commitment are being applied to support delivery date commitment to SSC.

All four EM-1 flight engines (with controllers and certified software) have been delivered-in-place at SSC and are awaiting Core Stage integration. ICPS flight element has successfully completed Hardware Acceptance Review by EGS and is in storage in the Space Station Processing Facility (SSPF). Solid Rocket Motor (SRM) Propellant Liner Insulation (PLI) flight hardware status and future manufacturing approach continues to be evaluated.

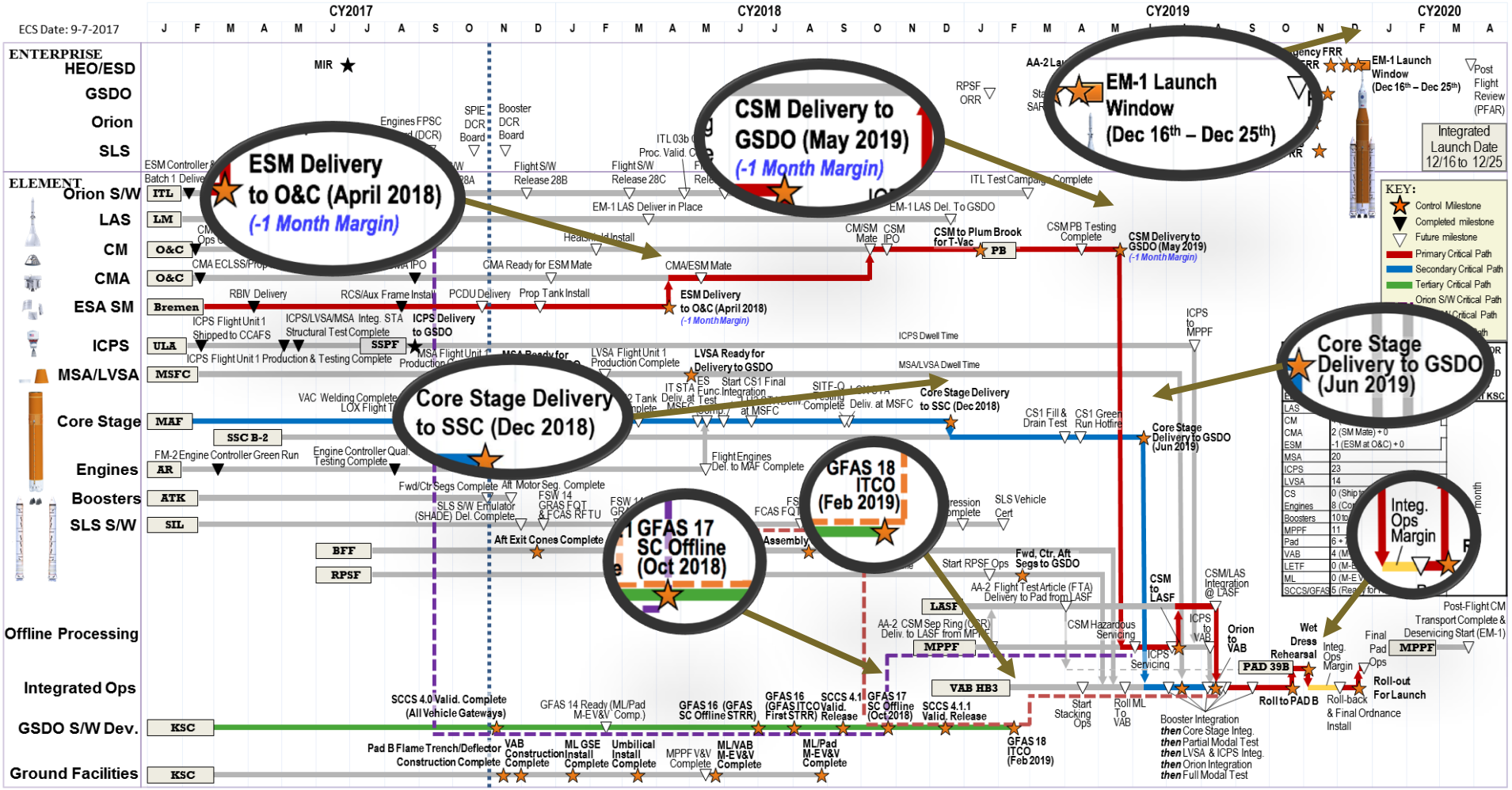
Long Term Sustainability: Productions and operations (P&O) sustainability at the rate of one flight per year after EM-3 by reducing production cost. Significant progress is being made on reducing RS-25 cost with a number of additive manufactured components completing initial build for subsequent testing. Additional areas of evaluation include learning curve efficiencies after completing initial hardware builds and future procurement contract efficiencies.

EM-2: A significant amount of EM-2 flight hardware is now in flow including long lead components such as the Orion Crew Module (CM) primary structure. Challenges of a first crewed flight and related mission planning; first assembly, integration, test and flight of EUS; first assembly, integration, test and flight of the Environmental Control and Life Support System (ECLSS) for the crew; and first assembly, integration, test and flight co-manifested Power and Propulsion Element (PPE) payload. Evaluating inherent risk of ML reconfiguration between Block 1 and 1B. ESM delivery for EM-2 also a watch item.

Deep Space Gateway: Initial mission planning guidelines for Phase 1 activities are being refined. Exploration Systems Development Cross-Program Systems Integration (CSI) is supporting deep space gateway mission planning, Systems Engineering and Integration (SE&I) efforts, as well as early PPE development planning.

EM-1 Integrated Mission Milestone Summary

Version Date: 11-7-2017



Recent Accomplishments

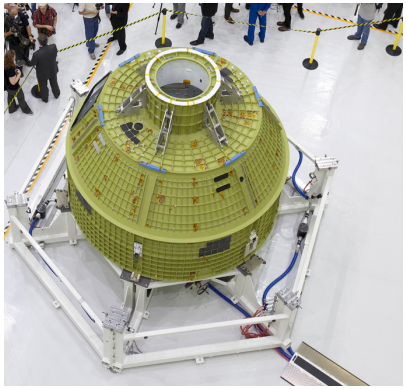
- Orion completed flight software release 28A
- Orion Crew Module and Crew Module Adapter initial power on (IPO) tests completed
- Key components delivered for European Service Module (ESM), including Reaction Control System Pods, Cold Plates, Water Tank, and Gas Tank Simulators
- Orion Initiated alternative designs for at-risk ESM components
- SLS Vertical Assembly Center (VAC) Welding Completed on LH2 Flight Tank
- SLS engine section structural qualification testing started
- SLS booster nozzle assemblies completed
- EGS Vehicle Assembly Building (VAB) fire protection and platform work completed
- EGS Core Stage Intertank Umbilical installed on Mobile Launcher
- EGS Spacecraft Command and Control Software (SCCS) progressing, with SCCS 4.0 system test 25% complete

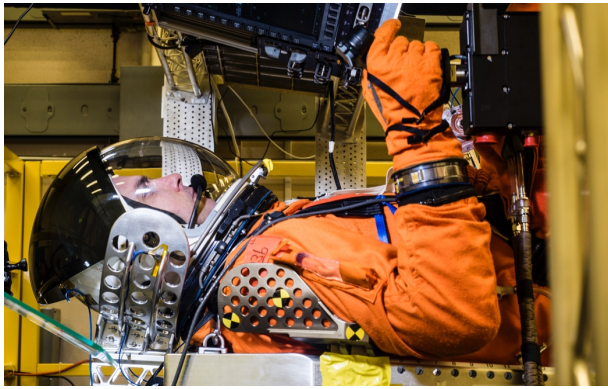
Improvements to Increase Confidence in Schedule Performance

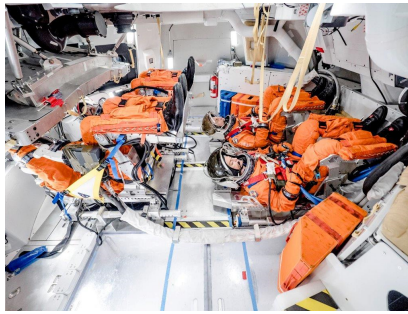
Numerous changes have been implemented to increased confidence in enterprise schedule performance, including:

- Cross-Program Systems Integration (CSI)
  - Director CSI is now solely focused on Systems Engineering and Integration
  - Key personal assignments are in work to provide additional support
    - Support for increased volume of real time decision velocity
    - Evaluation of critical schedule items such as: green-run test, modal survey, and hardware transport, and intricate cross program deliverables with high interdependence such as: loads analysis, hardware verification, and software verification
    - Establish pre-planned contingency to address changes to schedule sequencing
- Program and Strategic Integration (PSI)
  - Improved schedule visibility and management
    - Established weekly ESD schedule review
  - Restructure of PSI schedule management organization to provide additional focus on Enterprise level schedule analysis
    - PSI Schedule Analysis Team (PSAT) established
    - Addition of key personnel to conduct Enterprise schedule analysis
    - Update to Enterprise schedule analysis tools to support Enterprise level assessments
  - Increased strategic evaluation of schedule risk and robustness measures
    - Improved integrated performance assessment process to enable trend analysis and early anticipation of issues/problems to enable timely decision making
- Corporate commitment and management attention at the highest levels
  - Senior executive reviews led by the Acting Administrator

orion

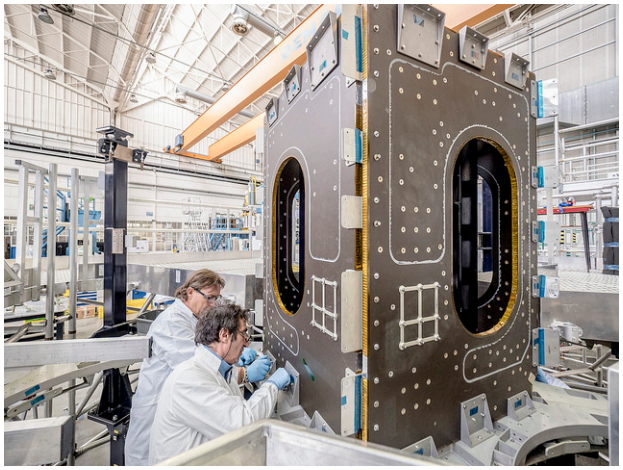






EM2

Solar cells



ESM Composite Square Tube

EM1 & EM2 motors

ESM Radiator

EM-1 Launch Abort System (LAS)

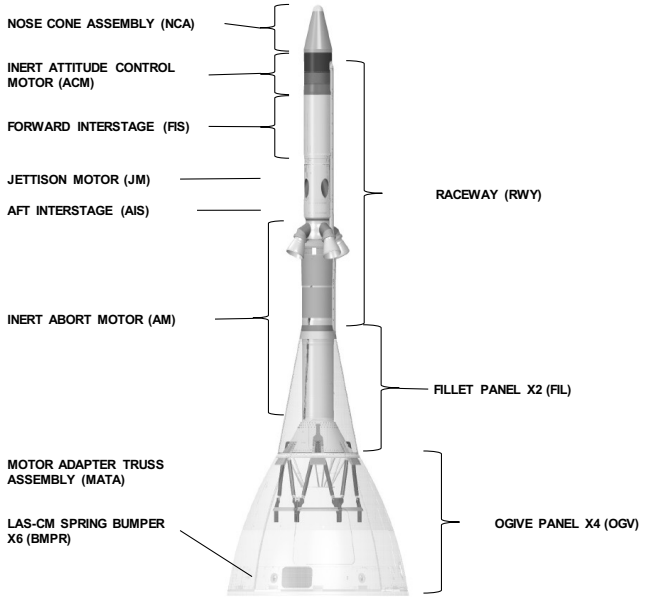
(Lockheed)

- ✓ LAS Attitude Control Motor hot fire test (HT-11), April 2017
- ✓ LAS Abort Motor firing, June 2017
- ✓ LAS EM-1 Abort Motor (inert) cast September 2017
- ✓ LAS EM-2 Abort Motor (active) cast September 2017

- – EM-1 LAS Jettison Motor delivery to KSC, January 2018
- – EM-1 LAS ogive delivery to KSC, March 2018

Attitude Control Motor

Abort Motor



Orion Structural Qualification

(Lockheed – Denver)

Crew Module (CM) Structural Test Article (STA)

- ✓ Shipped to Denver, April 2017
- ✓ Completed stiffness load test, September 2017

European Service Module (ESM) STA

- ✓ Shipped to Denver, June 2017
- ✓ Completed ESM STA, August 2017
- ✓ Installed Solar Array Wings, August 2017

Launch Abort System (LAS) STA

- ✓ Shipped to Denver, April 2017
- ✓ Completed load test, August 2017.

Combined

- CM/SM STA , December 2017
- LAS/stack mate, January 2018
- Combined stack testing (acoustic, modal, pyro shocks, stiffness), April 2018
- EM-1 prerequisite test complete, January 2019

Crew Module Structural Test Article

Service Module Structural Test Article

Launch Abort System Structural Test Article

EM-1 Crew Module (CM)

(KSC O&C Building)

- ✓ CM proof/leak tests, July 2017
- ✓ CM harness test, August 2017
- ✓ CM initial power up, August 2017
- ✓ CM subsystem integration, August 2017
- ✓ CM heatshield thermal/proof test, October 2017
- ✓ CM module level test, November 2017

- – CM thermal cycle testing, December 2017
- – CM Direct Field Acoustics Test (DFAT), July 2018
- – CM/SM Mate, December 2018

EM-1 Crew Module (CM)

EM-1 Crew Module Adapter (CMA)

(KSC O&C Building)

- ✓ CMA proof/leak tests, February 2017
- ✓ CMA harness tests, August 2017
- ✓ CMA initial power up, August 2017

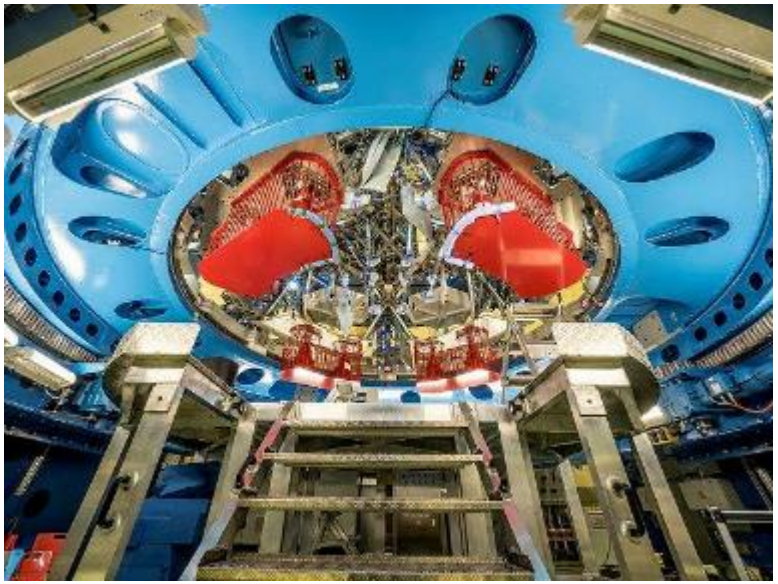
- ✓ CMA subsystem integration, September 2017
- – CMA assembly operations and end-to-end testing, September – December 2017

EM-1 Service Module

(Bremen, Germany)

- ✓ Installed ESM Thermal Control Unit, June 2017
- ✓ Installed ESM Reaction Control System (RCS) Thruster, October 2017

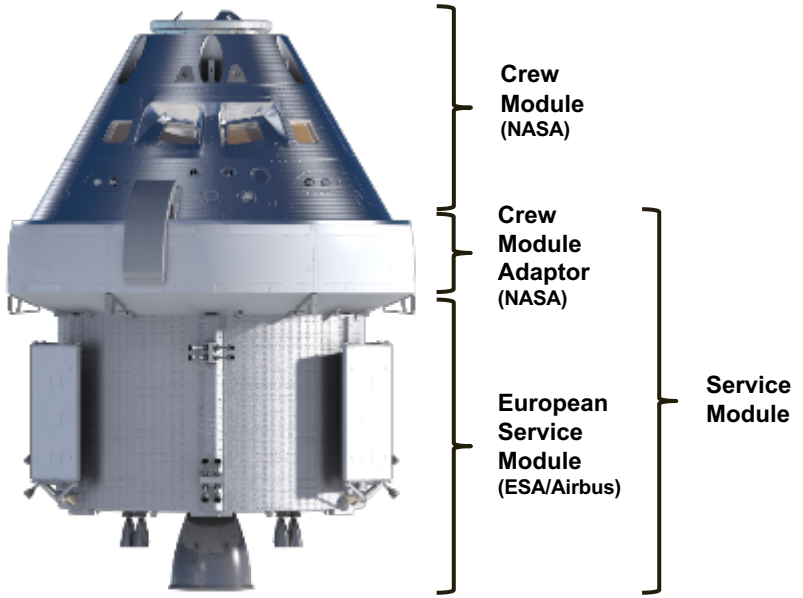
- Propellant Qualification Motor (PQM) test under review
- Deliver nitrogen distribution system valves to Thales Alenia Space Italia – U/R
- Deliver Pressurant Control Assembly (PCA) valves to Lampoldshausen - U/R
- ESM Power Control and Distribution Unit (PCDU) delivery, December 2017
- ESM Prop Tank #4 delivery, December 2017
- ESM Prop Tanks installed, December 2017
- ESM N2 Tank install, February 2018
- ESM Orbital Maneuvering System Engine (OMS-E) install, February 2018
- ESM PCA delivery to Airbus, March 2018
- ESM Functional Tests:
  - Thermal Control System, April 2018
  - Power System, May 2018
  - Electromagnetic Compatibility (EMC), May 2018
- ESM on dock at KSC, TBD



EM-1 Service Module

EM-1 CMA/ESM (KSC O&C Building)

- CMA Ready to Mate, May 2018
- CMA/ESM mate, July 2018
- CMA/ESM proof/leak test, August 2018
- SM initial power up/functional tests, October 2018 – February 2019
- SM thermal cycle test, August 2018
- SM Direct Field Acoustics Test (DFAT), September 2018
- CM/SM Mate, December 2018



CMA/ESM Mate | CMA/ESM proof/leak test | SM initial power up/ functional tests | SM thermal cycle test | SM DFAT | CM/SM Mate

Flight Software/Integrated Test Lab

(LM/Denver)

Software Development

- ✓ Flight Software load 27A released on 1/26/17 (Nominal Ascent Mission Sequencing, Nominal Entry, Descent, and Landing (EDL), Orbit Attitude Control with ESM Reaction Control System (RCS))
- ✓ Flight Software load 27B released on 4/28/17 (Pre-launch sequencing, Initial CM Fault Detection Isolation & Recovery (FDIR))
- ✓ Flight Software load 28A released on 9/14/17 (Nominal Mission including On-Orbit, CM FDIR except prop)
- – Flight Software load 28B on schedule for 12/5/17 (Optical Navigation, Burn Plan Management, CM prop FDIR)
- – Flight Software load 28C on schedule for 3/08/18 (Ascent Aborts, Safe Mode, ESM FDIR)

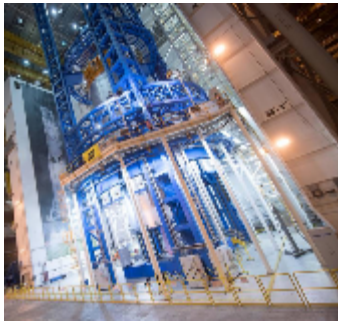
26A/B FSW Release	27A FSW Release	27B FSW Release	28A FSW Release	28B FSW Release	28C FSW Release
✓	✓	✓	✓		

Integrated Test Lab (ITL)

- ✓ Cross Program Testing Completed
  - ✓ Successfully completed first integrated test of the EM-1 Spacecraft Radio Frequency (RF) system with the Mission Control Center through the Deep Space Network (March 2017)
  - ✓ Successfully completed first integrated test of the EM-1 Power and Data Units (PDUs) with the SLS ICPS Common Core Unit (CCU) computer (April 2017)
- ✓ ITL-03 CM (July 2017)
  - ✓ Successfully executed 95% of ATLO IPO and functional checkout procedures awaiting few minor updates
- – ITL-SM (ECD: January 2018)
- – ITL-03 CSM (ECD: June 2018)
- – ITL Test Campaign verification complete Jan 2019
- – ITL Test Campaign validation complete March 2019

ITL-01 Single String	ITL-02 Dual String	ITL-03 CM	ITL-SM	ITL-03 CSM	ITL Test Campaign
✓	✓	✓			

sls



EM2

EM-2 forward and center-forward booster segments

EM-2 Core Stage Engine Section

EUS RL-10 EngineP7001 Injector LO2 Plate

EUS RL-10 Engine P7001 Chamber Structural Jacket

EM-1 ICPS/MSA/LVSA

(MSFC/ULA-Decatur)

- ✓ EM-1 Interim Cryogenic Propulsion Stage (ICPS) ship to United Launch Alliance at Cape Canaveral Air Force Station for final outfitting
- ✓ EM-1 ICPS Delivery to KSC, July 2017 (store in Space Station Processing Facility)
- ✓ EM-1 ICPS Hardware Acceptance Review, Oct 2017

- EM-1 OSA Production Complete, January 2018 (U/R)
- Orion Stage Adapter (OSA) Delivery to KSC, January 2018 (U/R)
- Launch Vehicle Stage Adapter (LVSA) Thermal Protection System (TPS) application complete, February 2018
- EM-1 LVSA Production Complete, July 2018
- LVSA Delivery to KSC August 2018

ICPS in SSPF

LVSA preps for Insulation

OSA in bracket installation

EM-1 Stages

(Boeing - MAF)

Forward Skirt
- Barrel Weldment
- Structural Assy.
- TPS App.
- Integration
- Forward Join

ECD Dec

LOX Tank
- Barrels Welded
- Domes Welded
- VAC Welding
- Hydrostatic Proof
- NDE/Baffle Install
- Clean (int/ext)
- Sensor Install
- TPS App.
- Sensor Install
- Sump Install
- Cover Install & TPS Closeout
- Forward Join

ECD Dec

Intertank
- Panels & Thrust Beam Fabricated
- Structural Assy.
- TPS App.
- Integration
- Forward Join

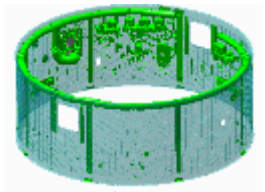
ECD Jan

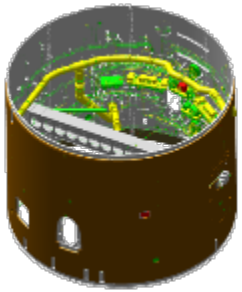
LH2 Tank
- Barrels Welded
- Domes Welded
- VAC Welding
- Pneumatic Proof
- NDE
- Clean (int/ext)
- Sensor Install
- TPS App.
- Sensor Install
- Manifold Prep
- Covers Install & TPS Closeout
- Aft Join

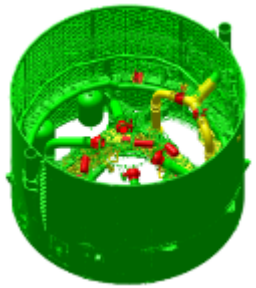
ECD Dec

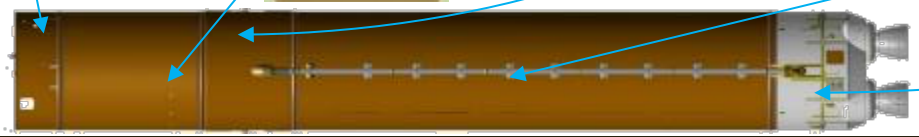
Engine Section
- Barrel Weldment
- Thrust Struct. Assy.
- ES Structural Assy.
- Integration
- Boat Tail Stack
- Aft Join

ECD May









Complete
In-Work/Next
Not Started

- ☑ Weld Confidence Articles
- ☑ All CS-1 VAC Complete
- ☐ FS Complete
- ☐ IT Complete
- ☐ LOX Tank Complete
- ☐ Forward Join
- ☐ LH2 Tank Complete
- ☐ ES Complete
- ☐ Aft Join
- ☐ Final Join

SLS Structural Test Article Testing
(MSFC)

- ✓ Complete Integrated Spacecraft and Payload Element Structural Test, April 2017
- ✓ ES Structural Test Article (STA) ready to ship, April 2017
- ✓ Core Stage Pathfinder Delivered – October 2017
- ✓ ES STA structural test complete, November 2017
- ✓ IT Test Facility ready, November 2017

- – IT STA ready to ship, January 2018
- – LH2 STA ready to ship, June 2018
- – IT STA structural test (Wet Dress Rehearsal Run) begin, August 2018
- – LO2 STA ready to ship, September 2018
- – LH2 STA structural test (Green Run) begin, February 2019
- – LO2 STA structural test (Design Certification Review Run) begin, March 2019

Core Stage Pathfinder Delivered

ISPE STA & Stand - Testing Started

Engine Section STA Stand

LH2 Tank STA Stand

LO2 Tank STA Stand

Intertank STA Stand

Stands:	✓ ICPS/LVSA Stand Ready	✓ ES STA Stand Ready	✓ LH2 Stand CoF complete	✓ LOX Stand CoF Complete	☐ Intertank STA Stand Ready	IT= Intertank ES = Engine Section ISPE = ICPS/LVSA LVSA = Launch Vehicle Stage Adapter
STAs and Testing:	✓ ICPS/LVSA STA Complete	✓ Start ICPS/LVA Testing	✓ ES STA Complete	☐ LH2 STA Complete	☐ LO2 STA Complete	☐ IT STA Complete

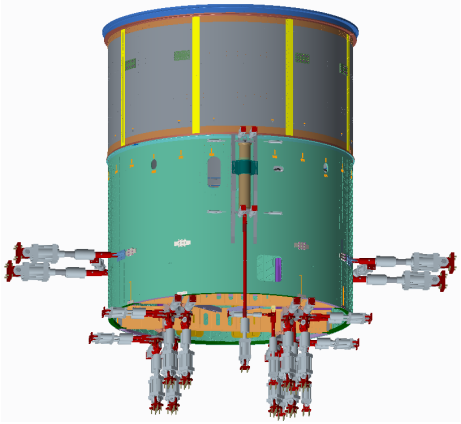
Engine Section (ES) Structural Qualification

ES Structural Qualification Test began on September 20, 2017

The test was required to ensure that the ES of the SLS Core Stage can withstand the forces of launch and flight.

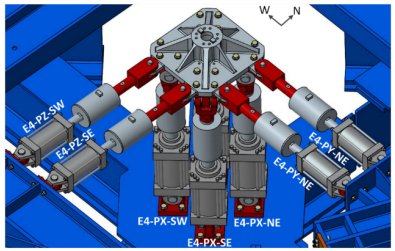
While being chilled with liquid nitrogen, 55 hydraulic load actuators applied axial, shear, and bending moment loads to the ES test article.

- Test cases enveloped all flight and Green Run environments and applied loads up to 3.5 million pounds
- The Influence Case Series determined the ES's response to individual load components; the Limit Load Case series tested the ES to 100% of design limit; and the Ultimate Load Case series subjected the ES to 140% of design limit loads

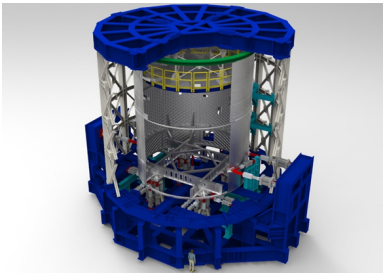


Loads are applied at the engine gimbal mounts, SRB attachment fittings, and the Thrust Vector Control clevises

ES STA on the Pegasus barge



Engine Gimbal with Load Actuators



ES Qualification Structural Test Stand

- Engine Section and Simulator Weight = 60,000 lbs
- Test Stand Weight 840 tons

Location	Uniaxial Strain Gages	Rosette Strain Gages	Total Strain Gages	Load Cells	Deflections	PhotoG	Temps	Pressures	Humidity	Total Channels
SQA	942	446	2,280	0	64	384	67	0	0	2,795
Sim	24	0	24	0	12	0	38	0	0	74
STE	0	0	0	55	27	0	6	6	1	95
Channels	966	1,338	2,304	55	103	384	111	6	1	2,964

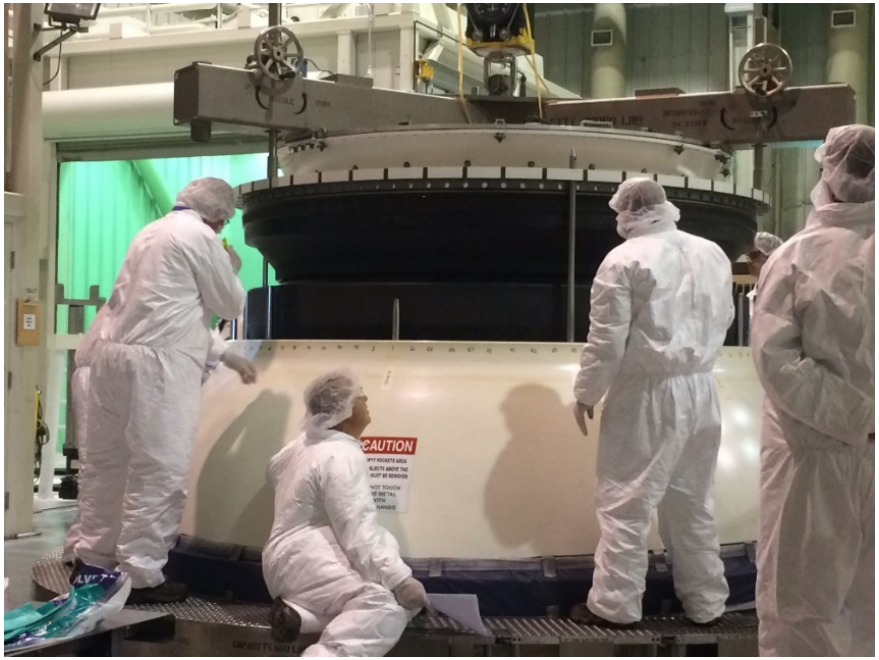
Data from nearly 3000 sensors was collected to perform post-test structural and thermal model correlation.

EM-1 Boosters

(ATK - Utah)

- ✓ All Booster Separation Motors are cast and finalized.
- ✓ EM-1 Left & Right Hand Booster Production progressing
- ✓ All EM-1 Segment Casting complete
- ✓ All EM-1 Segment NDE complete
- ✓ Both Aft skirts structural refurbishment complete
- ✓ Both EM-1 nozzle assemblies complete and installed in aft segments
- ✓ 8 of 10 Segments Finalized and in Storage
- ✓ Avionics Qualification Complete, October 2017

- − Propellant-liner-insulation (PLI) evaluation and testing in work
- − EM-1 Segments Delivered, March 2018 (U/R)



Nozzle installations into aft segments complete.

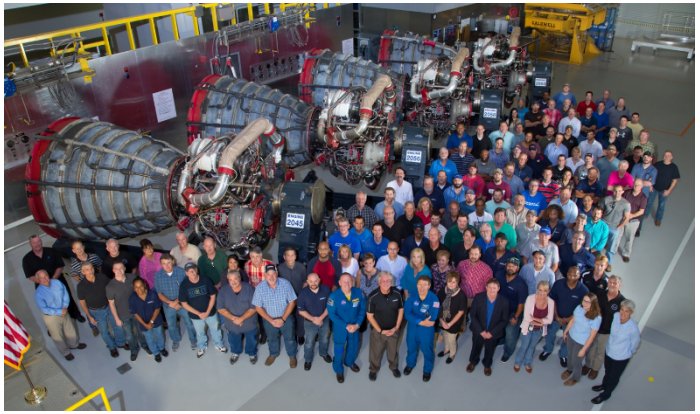
EM-1 Engines

(AR - SSC)

- ✓ Held RS-25 Production Re-start IBR – May 2016
- ✓ Engine 0528 RS-25 (LOX Pump Pressure) Complete - Feb 2017
- ✓ Engine Control Unit (ECU) Flight Model (FM) -1 to 3 ATP Complete - Apr 2017
- ✓ Engine 0528 ECU Green Run Testing:
  - ✓ ECU FM2: Mar 2017
  - ✓ ECU FM3: May 2017
  - ✓ ECU FM6: July 2017
  - ✓ ECU FM7: Aug 2017
- ✓ Flight release of ECU Software Complete
  - ✓ 1 of 2 Software Green Run Tests complete – Aug 2017
  - ✓ 2 of 2 Software Green Run (Engine 2063 w/FM4) Tests complete – Oct 2017
- ✓ EM-1 RS-25 Engines Deliver in Place – Oct 2017
  - *The EM-1 Flight Engines are Engine 2045, Engine 2056, Engine 2058, and Engine 2060*
- ✓ ECU Qualification Complete – Nov 2017

- – RS-25 Production Restart Development Hot Fire Testing Begins – Dec 2017
- – 1st EM-2 (EM-1 spare) Engine (2063) Complete – Feb 2018

Final Engine Adaptation / Software Cert Hot-fire Test



All 4 EM-1 Engines Delivered-in-place

Software Test Lab
(MSFC)

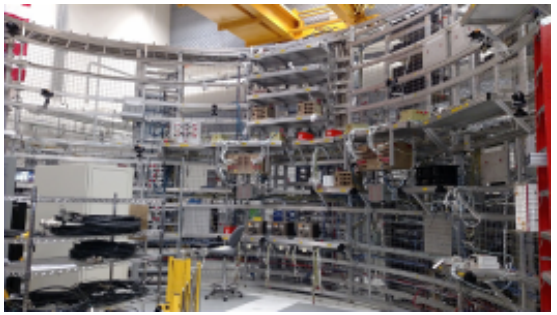
Software

- ✓ Deliver Flight Software Release 13, December 2016
- ✓ Complete Sprint 5 Flight Software Release 14, March 2017
- ✓ Complete Sprint 6 (final sprint) Flight Software Release 14, May 2017
- − Complete Release 14 Green Run Application Software (GRAS), December 2017
- − Complete Release 14 Flight Control Application Software (FCAS), October 2018

FSW 11 Release (Engineering)	FSW 12 Release (Engineering)	FSW 13 Release	FSW 14 Release (GRAS)	FSW 14 Release (FCAS)
✓	✓	✓	☐	☐

Software Integration Test Facility (SITF) - Qualification Testing

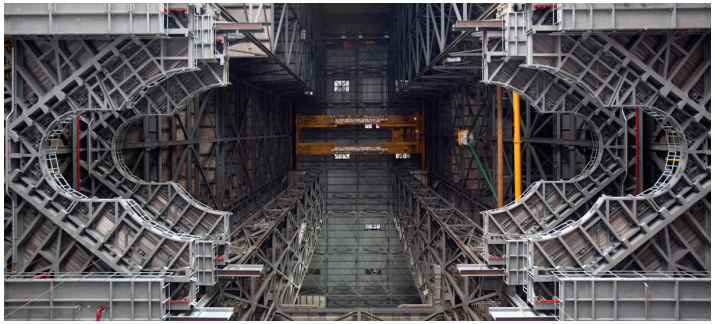
- ✓ Complete Phase 1 (Pwr Quality & Verif), May 2016
- ✓ Complete Phase 2 (C&DH & FSS Dry Run), October 2016
- ✓ Complete Phase 3 (Flt Ctrl & TLM Dry Run), June 2017
- − Complete Phase 4 (Final Avionics Verif), June 2018



SITF Qualification Testing

SITF Development	SITF Qual Test Ph 1 Comp	SITF Qual Test – Ph 2 Comp	SITF Qual Test – Ph 3 Comp	SITF Qual Test Complete
✓	✓	✓	✓	☐

egs

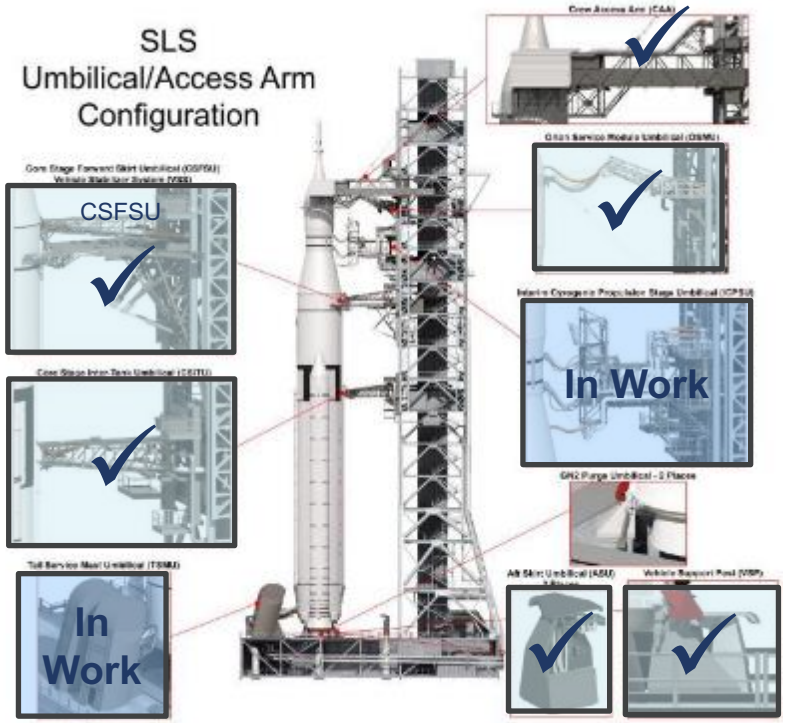


Umbilical Production and LETF Testing

(LETF - KSC)

The LETF is testing 6 day per week / 2 shift per day. LETF Testing and Mobile Launcher (ML) ground support equipment & umbilical installation is EGS's secondary critical path.

- ✓ Completed testing of Orion Service Module Umbilical (OSMU), Core Stage Forward Skirt Umbilical (CSFSU), and Aft Skirt Electrical Umbilical (ASEU), December 2016
- ✓ Completed Core Stage Inter-tank Umbilical (CSITU) testing, August 2017
- ✓ Crew Access Arm (CAA) delivered from fab shop - October 2017
- Ready to deliver Vertical Stabilizer to ML – Dec 2017
  - Testing underway
- Ready to deliver Interim Cryogenic Propulsion Stage Umbilical (ICPSU) to ML – Jan 2018
  - ICPSU HW design mods complete; testing in work
- Ready to deliver LO2 TSMU to ML – Jan 2018
  - Testing underway
- Ready to deliver LH2 TSMU to ML – March 2018
  - Testing underway



✓ Orion Service Module Umbilical (OSMU)	✓ Core Stage Forward Skirt Umbilical (CSFSU)	✓ Aft Skirt Electrical Umbilical (ASEU)	✓ Core Stage Inter-tank Umbilical (CSITU)	Interim Cryo Propulsion Stage Umbilical (ICPSU)	LH2 and LO2 Tail Service Mast Umbilical (TSMU)

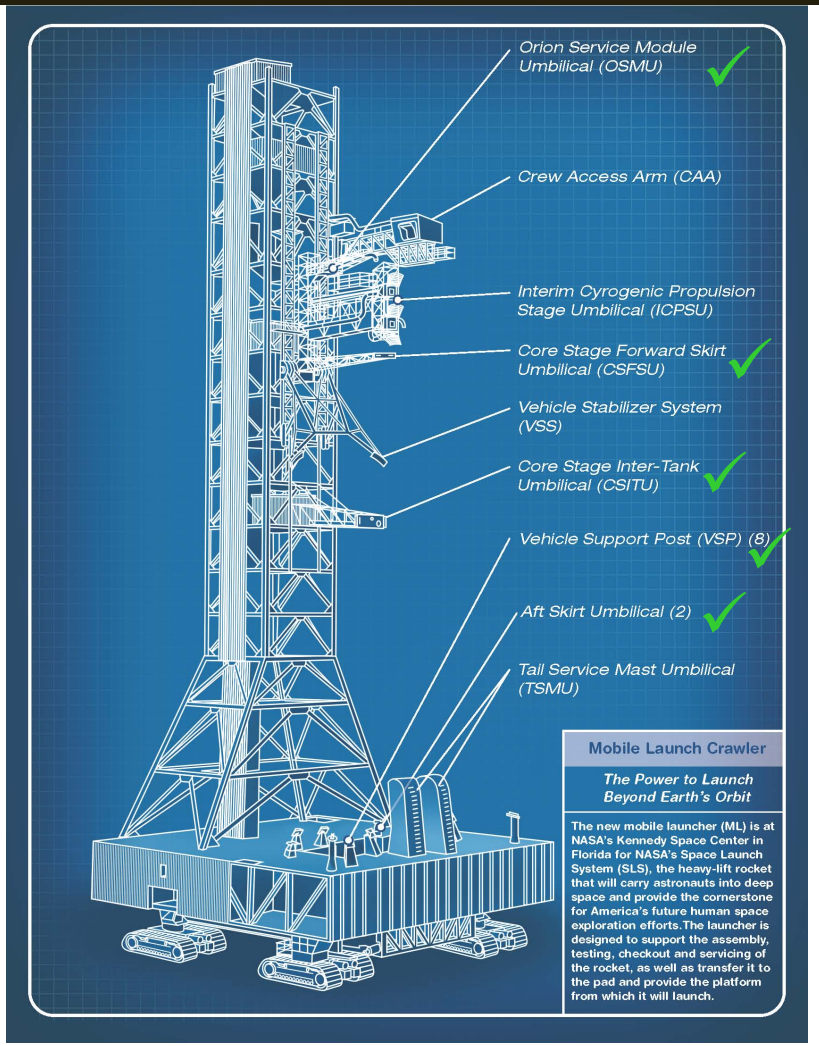
Mobile Launcher

(KSC)

- ML V&V re-plan is being incorporated into program schedule due to delays on ground support equipment installation phase
  - Cable installations are well underway
  - Cryo pipe installation is started – critical path
  - Environmental Control System (ECS) bracket installations are in-work – duct work to follow in Spring

✓ As of September 2017, five sets of umbilicals/attach points have been installed on the ML
  - ✓ Orion Service Module Umbilical
  - ✓ Core Stage Intertank Umbilical
  - ✓ Core Stage Forward Skirt Umbilical
  - ✓ Vehicle Support Posts (8)
  - ✓ Aft Skirt Electrical and Pneumatic Umbilicals (2 each)
  - Crew Access Arm
  - Vertical Stabilizer

- All other launch accessories are in the LETF
- ML Roll to VAB to begin ML/VAB Multi-Element (ME) V&V start April
- ML/VAB ME V&V start April 2018



VAB
(KSC)

- ✓ All platforms have been installed
- ✓ Platform outfitting complete
  - ✓ Platforms Functional Testing/Turnover to Ops complete
  - ✓ Elevators are complete
- Fire protection systems
  - Fire Suppression Water Supply – Fire Alarm/Fire Suppression testing ongoing
- Handling and Access Installation
  - ✓ F-1 Handling & Access platforms installation is complete
  - Platform D & E underway
- ML/VAB Multi-Element (ME) V&V start April 2018

Pad 39B (KSC)

- Flame Trench Project Status
  - Overall: 90% complete
  - Bricks: 100% complete
  - Deflector: 82% complete

- Environmental Control System (ECS)
  - Refurbishment 97% complete (duct, chilled water piping, insulation, control wiring installation, instrumentation waiting final inspection; stub tower framework erection complete; pre-functional tests continuing).

- LH2 Storage Tank Fill
  - LH2 Separator 100% complete

- Pad ME V&V, Sept 2018

Flame Trench/ Flame Deflector

LH2 Separator

Multi-Payload Processing Facility (MPPF)

- ✓ Crew Module Ammonia Servicing Subsystem (CMASS) Hazard Testing complete May 2017

MPPF V&V underway - forecast completion June 2018

- Only three more major activities remaining
  - GCS, Hypers, Orion Pallet handling

Crew/Service Module (CSM) Servicing Stand

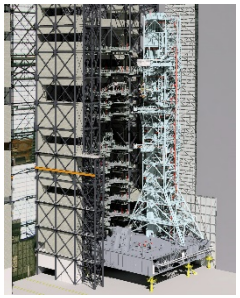
- Processing May 2019 thru July 2019

MPPF Orion servicing stand

Spaceport Command & Control System (SCCS)

SCCS 3.6.3 – **Retired; SCCS 4.0 will replace 3.6.3 in Fire Rooms ~Dec 2017**
SLS interface for GFAS dev; MPPF V&V testing

MPPF Hazardous Testing



MEVV @ VAB

MEVV @ Pad

SCCS 4.0 – System Test Complete, In Validation
Orion, ICPS interface for GFAS dev; ME V&V testing

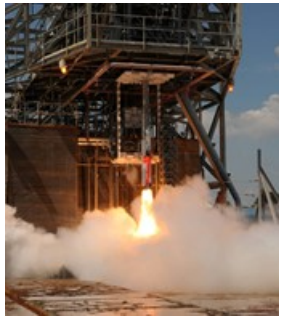
- [x] SCCS 3.6.3 Validated Release
- [x] SCCS 4.0 Engineering Release
- [ ] SCCS 4.0 Validated
- [ ] SCCS 4.1 Engineering Release
- [ ] SCCS 4.1 Validated
- [ ] SCCS 4.1.1 Engineering Release
- [ ] SCCS 4.1.1 Validated

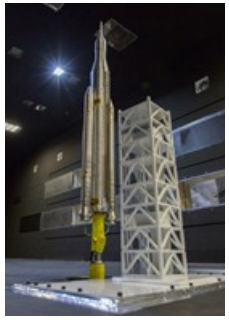
Ground Flight Application Software (GFAS)

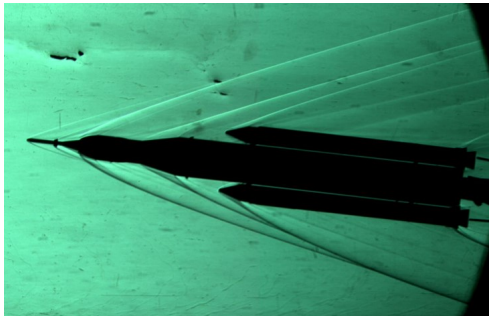
LCC-FR1

- [x] GFAS Drop 10 & 11
- [x] GFAS (ECLSS/Hypers) V&V Complete
- [ ] GFAS Ready for ML/Pad ME V&V
- [ ] GFAS SC Offline Ready (SAR)
- [ ] GFAS ITCO Ready (SAR)

cross-program systems integration







CSI Technical Performance –

Recent Major Accomplishments (August to October 31)

- Received Finite Element Models and started Verification Analysis Cycle (VAC)-1R coupled loads analysis, final verification analysis cycle (Aug-Sept)
- Modal test plan updated, maturing plans and schedules for integrated test and checkout flow (Aug-Sept)
- Successful completion of 22 of 120 planned tests to implement and verify functionality and data flows across communications, network, and tracking architecture (Aug-Oct)
- Closed 4 CPIT Top Issues: EUS Reaction Control System thruster sizes for Orion prox ops and docking (adequate margin at 0.025 deg/s), Crew Time on Back (tracking mitigation steps in risk plan), 500K changes/second (tracking mitigation steps in risk plan), and Dissimilar Flight Termination System (FTS) Notification Incompatibility (Orion-SLS hardware modification agreement) (Aug-Oct)
- Completed B1B Integrated Abort Design Cycle (Sept)
- Completed Flight Control and Recontact Cross-Program Integrated Hazard Analysis (CPIHA) tabletop review (Sept)
- Provided EM-2 Block 1B (B1B) reference trajectory for initial guidance and navigation development in Exploration Upper Stage (EUS) Design Analysis Cycle-2 (DAC-2) (Sept)
- ~ 66 % of Operations Maintenance Requirements and Specifications (OMRS) records have been approved (1365) with 714 left and 136 modified since approval; ~ 39 % of Launch Commit Criteria (LCC) have been approved (177) with 277 left, 58 LCCs are out for review at this time (Oct)
- Completed phase 2 of the Independent Assessment (IA) “Significant Issues and Close Calls in Human Spaceflight Relevance to ESD,” presented to Aerospace Safety Advisory Panel (Oct)
- Baselined charter for ESD Safety and Engineering Panel (ESERP), established to review ESD system safety analysis, evaluate safety residual risk, and assess acceptability of the CPIHA products as it relates to the safety residual risk (Oct)
- Interface documentation very mature – 1127 requirements in 15 documents, tracking 23 TBXs (Oct)
- Ascent Manual Steering human rating discussion at ESD Control Board (Oct)

CSI Technical Performance –
Near Term Forward Work (November-January)

- Conduct ESERP Kick-Off/Orientation to bring members and back-ups to a clear understanding of the purpose and scope of the ESERP (Nov/Dec)
- Release change request to establish HEOMD-005 Exploration Concept of Operations (Nov/Dec)
- Continue developing EM3 Near Rectilinear Halo Orbit (NRHO) reference trajectory (Nov-Dec)
- Track Key Verification Requirements (KVR) closures scheduled for next 90 days: EGS – 28 and SLS - 2 (Nov-Jan)
- Draft version of Trajectory Design Data Package (TDDP) (Nov-Jan)
- Perform IA “Aggregate Risk Pilot Study” (Nov/Dec) and “Gap Assessment of NPR 8705.2c for Deep-Space, Exploration-Class Missions” (Dec)
- Deliver EM-1 Launch and Landing Mission Table for recovery planning launch dates into 2020 (Dec)
- Delivery of Abort Probabilities and Landing Zones (Dec)
- Update EM-1 Spectrum Management Plan (Dec)
- Perform assessment for EM-2 Backup Control Center recommendation (Dec)
- Baseline initial subset of CPIHA (Dec) in preparation for ESERP review (Jan)
- Complete the EM-2 annular scan data to assess availability, lighting, etc. and aborts analysis (Jan)
- Conduct Underway Recovery Test 6, including initial run of night ops (Jan)
- Perform Rendezvous, Prox Ops and Docking analysis and requirements integration work to support Deep Space Gateway (DSG) (Jan)
- Perform Mission Ground rules and Assumptions integration and coordination with DSG (Jan)
- Propose Level 1 Flight Test Objectives associated with Power Prop Element (Jan)

CPIT Top Technical Issues

Concern	Current Status
Interim Cryo-Propulsion Stage (ICPS) Umbilical Loads: • Initial ICPS integrated loads >200% over hardware design loads.	• Revised modeling showed reduced loads at the flight vehicle interface. • Failures have occurred on the ground side of the interface during testing requiring hardware modifications to reduce loads. • Joint Integrated Control Board (JICB) approved set of modifications which have been implemented and series of tests at ambient and cryo conditions. • Testing in work with scheduled 10/24 completion.
Orion Pad Stay Time: • SLS and Orion derived differing requirements for pad stay with exposure to winds.	• Crew Module (CM)/Service Module (SM) separation bolts have fatigue/fracture concern, testing (static and fracture) and analysis underway • Tiger team addressing issue
Launch Availability: • Launch opportunities are limited	• Actions identified that can improve launch probability; studies in work to determine feasibility
Solid Rocket Booster (SRB) Nozzle Throat Plug (Emerging) • Plug material may potentially damage RS-25 engine nozzles	• Tiger team formed to evaluate design solutions
EM-2 Loads and Orion Primary Structural Design Loads (Emerging) • Assessments of Block 1B Design Analysis Cycle (DAC) 1R section load and other critical interfaces show increases over the design and verification baseline	• Joint Loads Integration Task Team (JLTT) to approve loads assumptions including uncertainty factors
Integration Issues with Potential Use of Orion Simulator (Emerging) • Potential to cause additional analysis and add another rollout	• Tiger team formed. Will bring potential risks for use of a simulator to JICB

Major ESD/CSI Independent Assessments In Progress

- **Independent modeling and simulation of separation events**
  - Ascent trajectory analysis using VAC-1R started and runs planned for Dec/Jan.
  - Block 1B DAC2 Baseline Ascent Trajectory model updates in progress.
- **Peer Review of Enterprise Modal Testing**
  - Started independent assessment of ML Only modal test
- **Independent Verification of Pre Launch Loads**
  - Independent verification of SLS methodology and loads predictions for pre-launch, liftoff, and ascent gust.
  - Pre-launch stacking radial cryogenic shrinkage has a profound effect on pre-load. Final report in process.
- **Micrometeoroid and Orbital Debris (MMOD) Pressure Vessel Failure Criteria**
  - Hypervelocity Impact Testing on Composite Overwrapped Pressure Vessels (COPVs) to validate models.
  - Performing one more tank test. Final report in work.
- **SLS Liftoff Environment Models (MSFC Request)**
  - Assessment of liftoff environment design math models for acoustics, booster ignition overpressure, RS-25 nozzle flow transient.
- **Independent Verification of SLS Ascent Loads.**
  - Task to assess transonic and Max Q regimes. Independent loads will be computed to assess/verify the static-aero-elastic and buffet event methodologies.
  - Completed evaluation of existing models.
- **Space Weather Architecture**
  - Review Space Weather monitoring and forecast options.

Backup

Acronyms and Abbreviations

Acronym	Definition
ACM	Attitude Control Motor
AI&T	Assembly, Integration, and Testing
AIS	Aft Interstage
AM	Abort Motor
ASEU	Aft Skirt Electrical Umbilical
ASPU	Aft Skirt Pneumatic Umbilical
ATCS	Active Thermal Control System
ATLO	Assembly, Test and Launch Operations
ATP	Authority to Proceed
BALT	Barometric Altimeter
C&DH	Command and Data Handling
CAA	Crew Access Arm
CAD	Computer Aided Design
CCU	Common Core Unit
CAP	Cross-Agency Priority Goal
CDR	Critical Design Review
CM	Crew Module
CMA	Crew Module Adapter
CoF	Construction of Facilities
COPV	Composite Overwrapped Pressure Vessels
CPIHA	Cross-Program Integrated Hazard Analysis
CR	Continuing Resolution
CS	Core Stage
CSFSU	Core Stage Forward Skirt Umbilical
CSITU	Core State Intertank Umbilical
CT	Crawler Transporter
DFAT	Direct Field Acoustics Test
DOF	Degree of Freedom
DOLILU	Day of Launch Initialization Load Update
ECLSS	Environmental Control and Life Support System
ECS	Environmental Control System
ECU	Engine Controller Unit
EDL	Entry, Descent, and Landing
EF	Enhanced Fujita
EGS	Exploration Ground Systems
EM	Exploration Mission
ES	Engine Section
ESA	European Space Agency
ESD	Exploration Systems Development
ESI	Exploration Systems Integration
ESM	European Service Module
EUS	Exploration Upper Stage
FCAS	Flight Controller Application Software
FDIR	Fault Detection Isolation& Recovery
FIL	Fillet Panel
FIS	Forward Interstage
FM	Flight Model
FS	Forward Skirt

Acronym	Definition
FSS	Fixed Service Structure
FSW	Flight Software
FTE	Full Time Equivalent
FWD	Forward
GAHLE	GSDO Advanced Hardware LCS Emulator
GAO	Government Accountability Office
GFAS	Ground/Flight Application Software
GFAST	Ground/Flight Application Software Team
GPRA	Government Performance and Results Act
GPSR	Global Positioning System Receiver
GRAS	Green Run Application Software
GRC	Glenn Research Center
GSE	Ground Support Equipment
IA	Independent Assessment
IBR	Integrated Baseline Review
ICD	Interface Control Document
ICPS	Interim Cryogenic Propulsion Stage
ICPSU	Interim Cryogenic Propulsion Stage Umbilical
IPO	Initial Power On
IRD	Interface Requirements Document
ISPE	Integrated Spacecraft and Payload Element (ICPS/LVSA)
IST	Integrated Structural Test
IT	Intertank
ITCO	Integrated Test and Checkout
ITL	Integrated Test Lab
JM	Jettison Motor
KSC	Kennedy Space Center
LAS	Launch Abort System
LCC	Launch Commit Criteria
LCN	Launch Commit Criteria (LCC) Change Notice
LCS	Launch Control System
LETF	Launch Equipment Test Facility
LH2	Liquid Hydrogen
LO2	Liquid Oxygen
LOM	Loss of Mission
LOX	Liquid Oxygen
LVSA	Launch Vehicle Stage Adapter
MAF	Michoud Assembly Facility
MATA	Motor Adapter Truss Assembly
MIR	Mission Integration Review
ML	Mobile Launcher
MPCV	Multi-Purpose Crew Vehicle
MPPF	Multi-Payload Processing Facility
MSA	MPCV Stage Adapter
MSFC	Marshall Space Flight Center
N2	Nitrogen
NCA	Nose Cone Assembly

Acronym	Definition
NDE	Nondestructive Evaluation
NOA	New Obligational Authority
O&C	Operations and Checkout
OGV	Ogive Panel
OML	Outer Mold Line
OMRS	Operations and Maintenance Requirements and Specifications
OMS-E	Orbital Maneuvering System Engine
OSA	Orion Stage Adapter
OSMU	Orion Service Module Umbilical
P&O	Production and Operations
PCA	Pressure Control Assembly
PDU	Power Distribution Unit
PLI	Propellant Liner Insulation
PPE	Power Propulsion Element
PQM	Propellant Qualification Model
PV	Pressure Vessel
QM	Qualification Motor
R&D	Research and Development
RCN	Requirements Change Notice
RCS	Reaction Control System
RF	Radio Frequency
RFI	Request for Information
RWY	Raceway
SAW	Solar Array Wings
SCCS	Spaceport Command and Control System
SIL	System Integration Lab
SITF	Software Integration Testing Facility
SLS	Space Launch System
SRM	Solid Rocket Motor
SSPF	Space Station Processing Facility
SSC	Stennis Space Center
STA	Structural Test Article
SW	Software
SW	Space Wing
THSS	Thrust Vector Control Hydraulics Support System
TIM	Technical Interchange Meeting
TLM	Telemetry
TPS	Thermal Protection System
TSMU	Tail Service Mast Umbilical
TVC	Thrust Vector Control
ULA	United Launch Alliance
V&V	Verification and Validation
VAB	Vehicle Assembly Building
VAC	Vertical Assembly Center
WAD	Work Authorization Document
WSTF	White Sands Test Facility