

Exploration Systems Development Update

Tom Whitmeyer, Assistant Deputy Associate Administrator for
Exploration Systems Development

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Building to Exploration Mission-1 (EM-1)

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European Service Module Critical Design Review	✓	LVSA Manufacturing Complete	✓	Core Stage Green Run Hot Fire Test
Crew Module Pressure Proof Test	✓	Mobile Launcher (ML) Umbilicals Installed	✓	Crew and Service Module Delivery to EGS
Booster Qualification Motor 2 Test	✓	VAC Welding Complete on Core Stage	✓	Ground Flight Application Software Complete
Crew Module Propellant Pressure Proof Test	✓	Launch Pad Flame Trench Construction Complete	✓	Booster Stacking in VAB
VAB Verification & Validation Complete	✓	Parachute Tests Complete	✓	Core Stage Arrival at KSC
RS-25 Flight Engines Complete	✓	European Service Module Delivered to KSC	✓	Core Stage Stacking with Boosters in VAB
ICPS Delivered to KSC	✓	Crew Module and Service Module Mate		CM/SM Mating with Launch Abort System
Crew Module Initial Power On	✓	All Underway Recovery Tests Complete		Orion Mating with SLS in VAB
VAB High Bay Construction Complete	✓	Core Stage Integration		Wet Dress Rehearsal at Launch Pad
Multi-Payload Processing Facility Construction	✓	ML Ground Support Equipment Installation Complete		Roll-out for Launch



Launch of EM-1

Orion Spacecraft

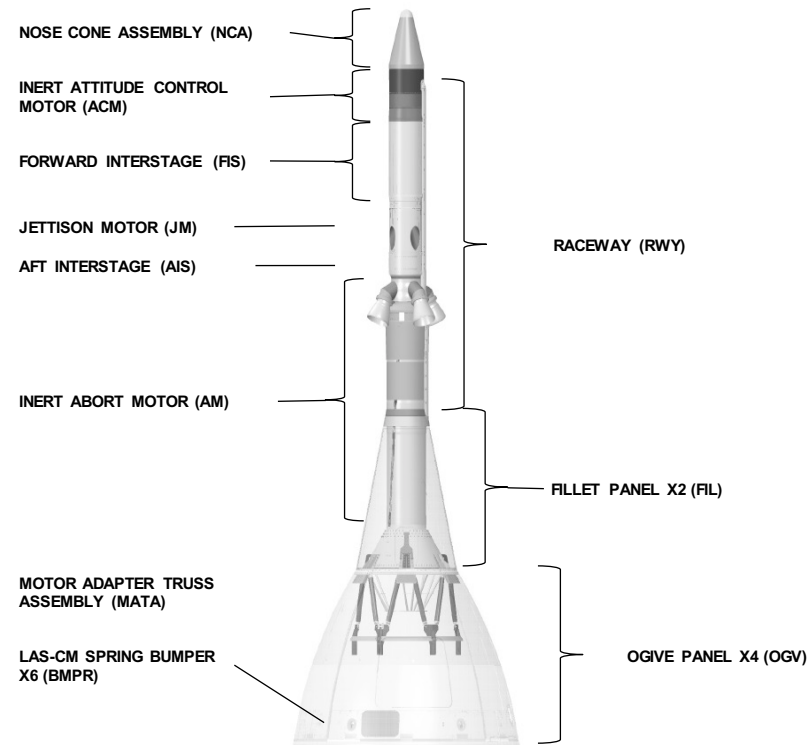
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EM-1 and Ascent Abort (AA)-2 Launch Abort System (LAS) (Lockheed)

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- ✓ LAS EM-1 Fillets & Ogive panels delivered to Michoud Assembly Facility (MAF) - November 2017
- ✓ EM-1 LAS Fairing Assembly Components - February thru July 2018 (ship in place)
- ✓ AA-2 LAS Abort Motor On Dock (O/D) KSC - August 2018
- ✓ AA-2 LAS Jettison Motor (JM) O/D KSC - September 2018
- EM-1 LAS Jettison Motor delivery available – December (ship in place)
- AA-2 LAS Attitude Control Motor O/D KSC – December 2018
- AA-2 LAS Fairing Assembly Components O/D KSC - August thru December 2018
- AA-2 Launch - April 2019



Graphical Representation of LAS During AA-2 Test



Viewing the AA-2 Crew Module Test Article

Ogive & Fillet Panels Fabrication complete

EM-1 Fairing components available

AA-2 Motors O/D KSC

EM-1 Jettison Motor Available

AA-2 Fairing components O/D KSC

AA-2 Launch

EM-1 Crew Module (CM) (Kennedy Space Center Operations & Checkout (O&C) Building)

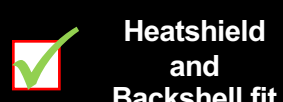
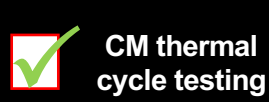
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- ✓ CM module level test completed - November 2017
 - ✓ 28 test procedures, functionally tested all systems
- ✓ CM thermal cycle testing completed - December 2017
 - ✓ 2 full cycles, 28F to 127F
- ✓ Heatshield and Backshell fit ups completed - January 2018
- ✓ Heatshield painting and fitcheck completed - February 2018
- ✓ Propylene Glycol Water (PGW) accumulator R&R
- ✓ Heatshield Installation – August 2018
- Side Hatch installation & leak tests – January 2019
- Reinstall reworked avionics (hybrid issue) – (troubleshooting last component) – February 2019
- CM Direct Field Acoustics Test (DFAT) – March 2019
- CM Complete - April 2019
- CM/Service Module (SM) Mate - May 2019



EM-1 Heat Shield Installation at KSC



EM-1 Crew Module Adapter (CMA) (KSC O&C Building)

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- ✓ CMA subsystem integration completed - September 2017
- ✓ CMA end-to-end testing completed - December 2017
- ✓ Temp installation of Star Trackers - April 2018
- ✓ Install T-0 flight plate - April 2018
- ✓ Reinstall reworked avionics (hybrid issue) - May 2018
- ✓ Complete functional retests – August 2018
- ✓ Ready to mate with European Service Module – September 2018



EM-1 CMA in Clean Room



CMA subsystem integration



CMA assembly operations and end-to-end testing



Install T-0



Install reworked avionics



Complete functional tests

European Service Module Arrival

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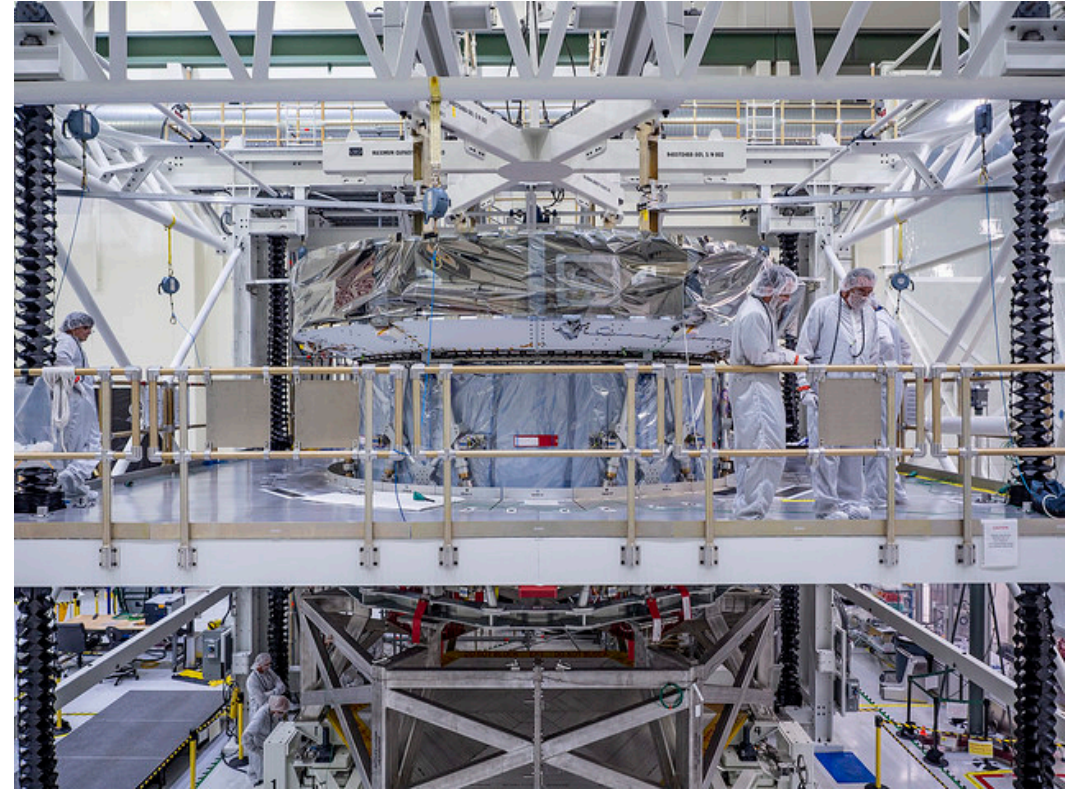
EM-1 Service Module (ESM)

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- ✓ ESM on dock at KSC – November 2018
- Step-1 Propellant Qualification Motor (PQM) testing complete - December 2018



Nov 5 - Bremen, Germany. Orion's European Service Module is loaded on the Antonov airplane for transport to Kennedy Space Center.



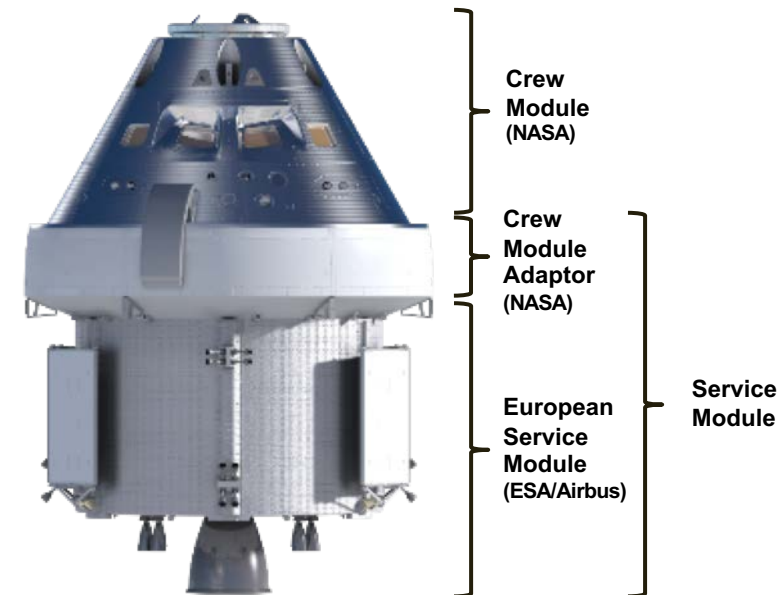
Nov. 14 - At the Operations and Checkout Building at Kennedy Space Center, Lockheed Martin technicians work to mate Orion's crew module adapter to the European Service Module.

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

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Integration Ops & Tests (KSC)
Testing (Plum Brook)
Final Work (KSC)

- ✓ CMA Ready to Mate – September 2018
- ✓ SM Delivery to KSC - November 2018
- ✓ CMA/ESM mate - November 2018
 - CMA/ESM proof/leak test – January 2019
 - SM initial power up and functional tests – January 2019
 - SM thermal cycle test - February 2019
 - SM Direct Field Acoustics Test (DFAT) - April 2019
 - CM/SM Mate - May 2019
 - CM/SM Transport to Plum Brook – July 2019
 - CM/SM Environmental Testing (thermal vac, thermal balance, EMI/EMC) complete – October 2019
 - CM/SM Transport to KSC – November 2019
 - CM/SM Complete – January 2020
 - CM/SM Turnover to EGS – January 2020





Flight Software/Integrated Test Lab (Lockheed Martin/Denver)

Software Development

- ✓ Flight Software load 28A released on 9/14/17 (Nominal Mission including On-Orbit, CM Fault Detection Isolation and Recovery (FDIR) except prop)
- ✓ Flight Software load 28B released on 12/19/17 (CM prop FDIR, EM-1 Onboard Network Config, Solar Array Control)
- ✓ Flight Software load 28C released 3/08/18 (Guidance, Navigation, and Control (GNC) commands, Ballistic Entry, Initial ESM FDIR, Video, Burn Plan Management)
- ✓ Flight Software load 28D released 5/31/18 (ESM FDIR, Ascent Aborts, Initial Backup Flight Software (BFS)/Safe Mode, Optical Navigation)
- ✓ Flight Software 28D-Patch 1 released on 6/28/18
- ✓ Flight Software load 28E released 9/24/18 (GN FDIR, Partial GNC SM FDIR and Safe Mode, BFS and Redundancy Management)
- ✓ Flight Software Load 28E-Patch 1 release 10/25/18
- Flight Software Load 28E–Patch 2 release 12/17/18

<input checked="" type="checkbox"/> 28A/B FSW Released	<input checked="" type="checkbox"/> 28C FSW Release	<input checked="" type="checkbox"/> 28D FSW Release	<input checked="" type="checkbox"/> 28D-Patch 1 Release	<input checked="" type="checkbox"/> 28E FSW Release	<input checked="" type="checkbox"/> 28E Patch 1 Release	<input type="checkbox"/> 28E Patch 2 Release
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Integrated Test Lab (ITL)

- ✓ Completed 18 Nominal, Off Nominal and FDIR mission tests thru 2017
- ✓ ITL-03 CM Subsystem Integration & Assembly, Test, and Launch Operations (ATLO) Check out (C/O) ITL gap testing complete - February 2018
- ✓ ATLO IPO & CSM 28D functional testing complete – September 2018
- ATLO mission & CSM 28E testing complete – May 2019
- ITL Test Campaign verification testing complete – August 2019

<input checked="" type="checkbox"/> Gap testing	<input checked="" type="checkbox"/> 28D functional testing	<input type="checkbox"/> 28E mission testing	<input type="checkbox"/> CSM testing complete	<input type="checkbox"/> ITL Test Campaign Verif complete
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EM-2 Orion Progress

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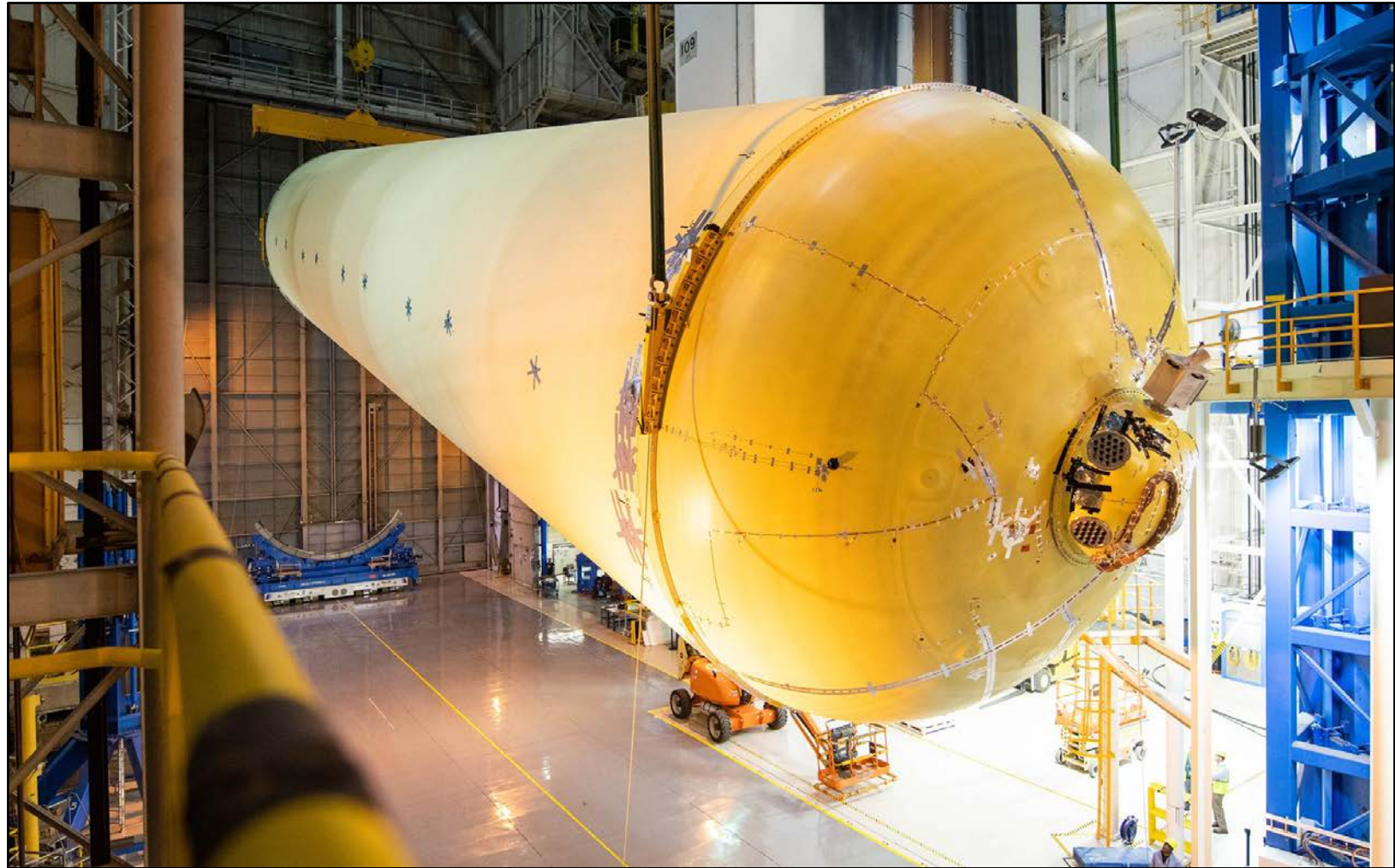


Space Launch System (SLS)



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EM-1 ICPS/OSA/LVSA (Marshall Space Flight Center/ULA-Decatur)

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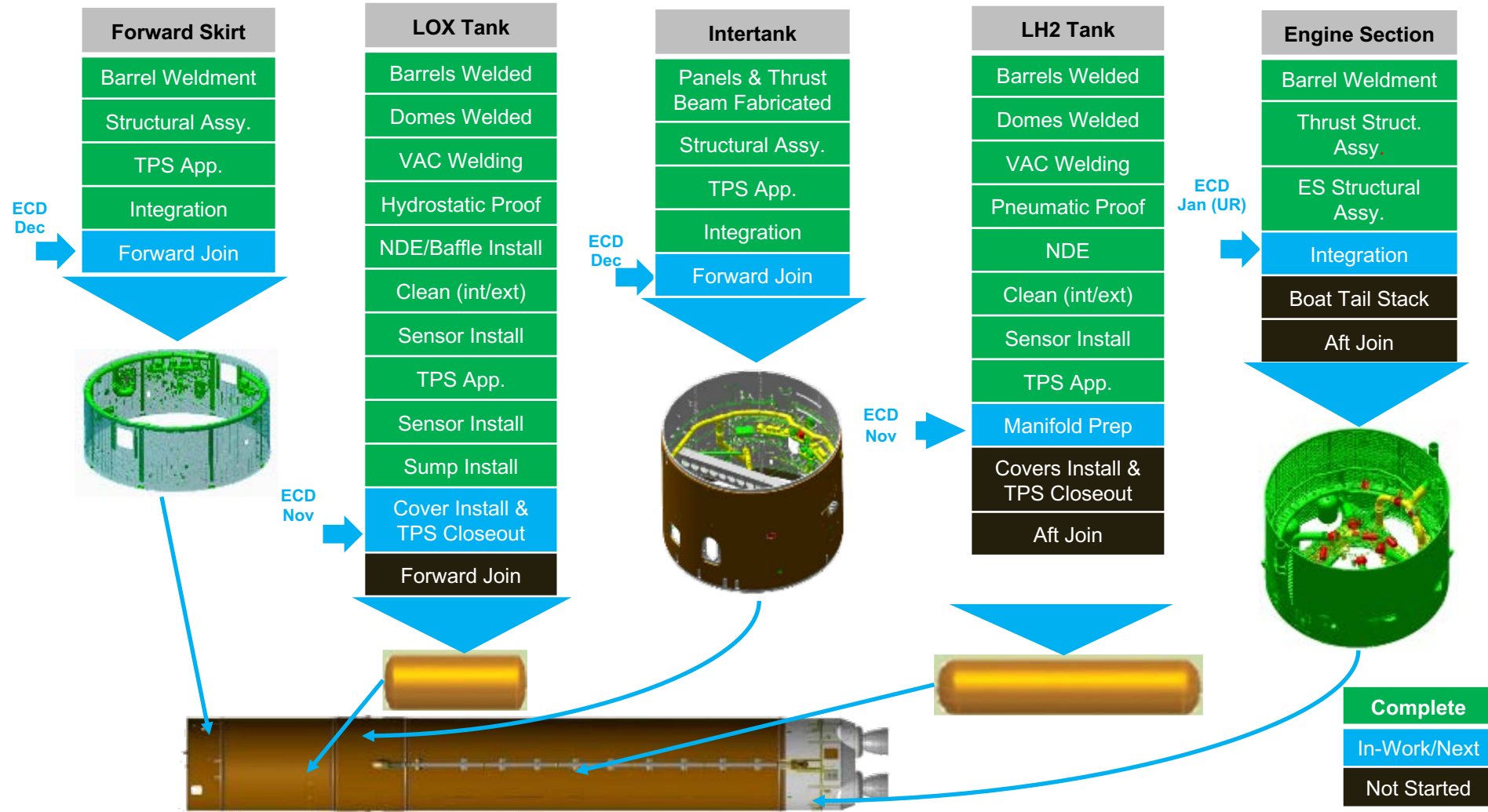
- ✓ Interim Cryogenic Propulsion Stage (ICPS) ship to United Launch Alliance at Cape Canaveral Air Force Station for final outfitting
- ✓ ICPS Delivery to KSC - July 2017 (store in Space Station Processing Facility (SSPF))
- ✓ ICPS Hardware Acceptance Review - Oct 2017
- ✓ Orion Stage Adapter (OSA) Production Complete - January 2018
- ✓ OSA Delivery to KSC – April 2018 (store in SSPF)
- ✓ Launch Vehicle Stage Adapter (LVSA) Thermal Protection System (TPS) application complete - April 2018
- ✓ Secondary Payload Deployment Electrical Ground Support Equipment (EGSE) delivery to KSC – Sep 2018
- LVSA Production Complete – Jan 2019
- LVSA Delivery in Place – Jan 2019 (awaiting EGS readiness to receive)



Thermal Insulation Application Complete on LVSA

EM-1 Stages (Boeing - MAF)

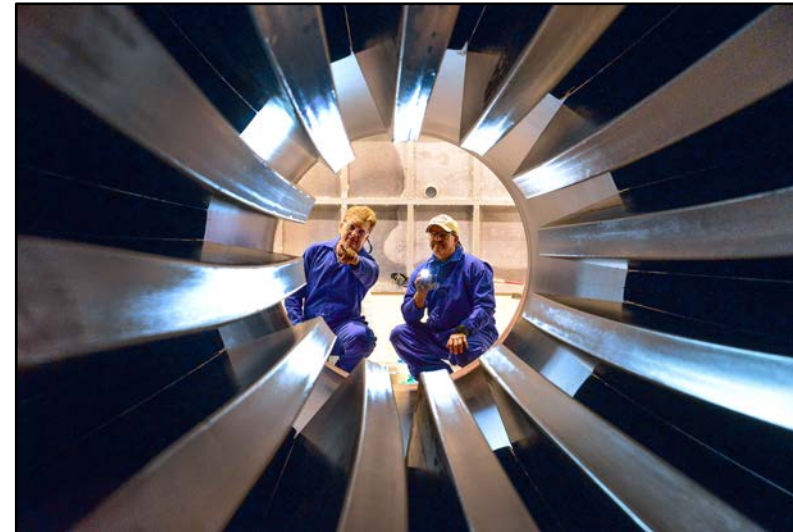
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EM-1 Boosters (Northrop Grumman - Utah)

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- ✓ All Booster Separation Motors are cast and finalized
- ✓ EM-1 Left & Right Hand Booster Production progressing
- ✓ All EM-1 Segment Casting complete (7 out of 10 EM-2 segments cast)
- ✓ Both Aft skirts structural refurbishment complete
- ✓ Both EM-1 Nozzle assemblies and Aft Exit Cones complete
- ✓ Avionics Qualification Testing Complete
- ✓ EM-1 Left Hand aft skirt TVC lower frame installation complete
- ✓ 9 of 10 EM-1 Segments Finalized and in Storage
- Propellant-liner-insulation (PLI) flight rationale complete - December 2018
- EM-1 PLI Waiver signed – 1Q19
- EM-1 Segments Ready to Ship - February 2019



Operators inspect propellant fins



Engineers remove the core after casting the booster case with propellant

EM-1 Engines (Aerojet Rocketdyne – Stennis Space Center)

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- ✓ Held RS-25 Production Re-start Integrated Baseline Review (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 Complete
- ✓ 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*
 - RS-25 Development Test Campaign (First HIP bonded Main Combustion Chamber and Controller Green Runs) - Aug 2018 through Feb 2019 (5 of 10 tests complete)
 - EM-2 (EM-1 contingency engines) Engine Complete
 - E2059 - Nov 2018
 - E2047 - Dec 2018
 - E2063 - Jun 2019
 - E2062 - Jul 2019



Final Engine Adaptation / Software Cert Hot-fire Test



All 4 EM-1 Engines Delivered-in-place



ECU
Dev
Testing



ECU FM1 ATP
Complete



ECU Green Run
Testing Begins



EM-1 Green
Run Testing
Complete



EM-1 RS-25 Engines
Delivered to MAF

Software Test Lab (Marshall Space Flight Center)

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) - June 2018
- Complete GRAS Regression Testing – January 2019
- Complete Release 14 Flight Control Application Software (FCAS) - May 2019

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 (Command and Data Handling (C&DH) & Flight Safety System (FSS) Dry Run) - October 2016
- ✓ Complete Phase 3 (Flt Ctrl & Telemetry (TLM) Dry Run) - June 2017
- Complete Phase 4 (Final Avionics Verif) - January 2019



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

EM-2 SLS Progress

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EM-2 forward and center-forward booster segments



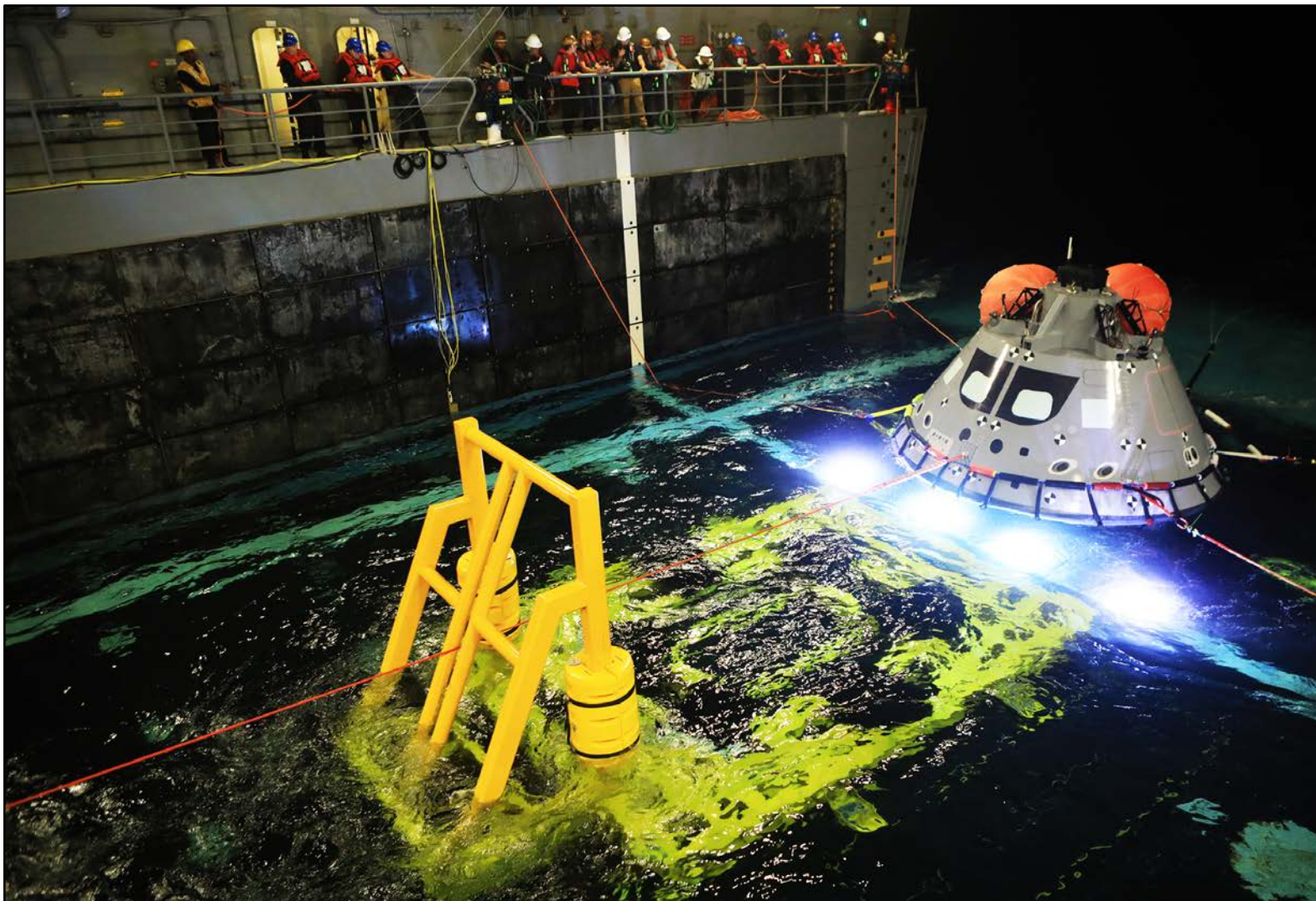
Exploration Upper Stage RL-10 Engine P7001 Injector LO2 Plate



EM-2 Core Stage Engine Section Complete

Exploration Ground Systems Progress

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Umbilical Launch Equipment Testing Facility (LETF) Testing/Mobile Launcher (KSC)

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- ✓ Interim Cryogenic Propulsion Stage Umbilical (ICPSU) installed – March 2018
- ✓ Crew Access Arm (CAA) installed – February 2018
- ✓ LO2 TSMU installed – July 2018
- ✓ LH2 TSMU installed – July 2018
- ✓ Parksite V&V – August 2018
- ✓ ML Fit check at Pad – September 2018
- ✓ ML Roll to VAB – September 2018
- ML/Pad Multi-Element (ME) V&V complete – 2019 CYQ3

EM-2 Development

- ✓ SRR for Facility subsystems completed – July 2018
- Concept study to finalize equipment layout for new & areas impacted by Emergency Egress System (EES) is in work



Crew Access Arm (CAA) Installed



Interim Cryo Propulsion Stage Umbilical (ICPSU)



LO2 Tail Service Mast Umbilical (TSMU)



LH2 TSMU



ML Fit Check at Pad



ML Roll to VAB



ML/Pad multi element V&V

Vehicle Assembly Building (KSC)

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EM-1 Progress

- ✓ All vehicle access platforms have been installed and outfitting is complete
- ✓ VAB High Bay (HB) 3 elevators are complete
- ✓ GSE Handling and Access (H&A) fabrication and installation is complete
- ✓ Fire Alarm/Firex System Acceptance Testing is complete
(During Firex wet flow testing, the measured flow rates did not meet required values in two out of four zones; Follow on work to replace legacy valves (85% complete) and sprinklers to meet new pump pressure and continue mock-up testing with new nozzles)
- ✓ Testing on the Environmental Control System (ECS) for EM-1 complete
 – September 2018
- ME V&V complete

EM-2 Development

- VAB ECS and HB 3/4 design continue to mature
 - ✓ ECS 90% design review completed – July 2018
 - ✓ HB 3/4 60% design review completed – August 2018



CT-2 coming into HB-3



CT-2 parked inside HB-3



All Platforms Installed



Platform Outfitting Complete



Handling and Access install



Fire Protection Systems Complete



ME V&V

Pad 39B (KSC)

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EM-1 Progress

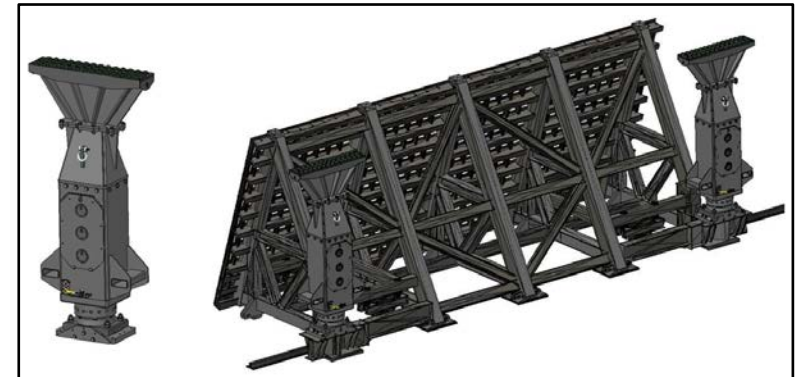
- ✓ Overall Pad B development is nearing completion
- ✓ Ignition Over Pressure and Sound Suppression (IOPSS) Wet Flow Testing complete – December 2017
- ✓ LH2 Storage Tank Fill complete – May 2018
- ✓ Pad Standalone Cryogenic Testing complete – May 2018
- ✓ LO2 Storage Tank Fill complete – July 2018
- ✓ Environmental Control System (ECS) refurbishment complete – April 2018
- ✓ ECS SW Field Testing Complete – August 2018
- ✓ Flame Trench/Flame Deflector Complete – September 2018
- ✓ ECS Pad TRR – October 2018

EM-2 Development

- ✓ Emergency Egress System (EES) Concept study extension to evaluate ML-1 and ML-2 interchangeability complete
- ✓ LH2 Upgrade Construction Award – September 2018
- Converter Compressor Facility (CCF) Design complete, construction planned to start in FY20



Flame Deflector



Flame Deflector with Extensible Columns

Multi-Payload Processing Facility (MPPF) (KSC)

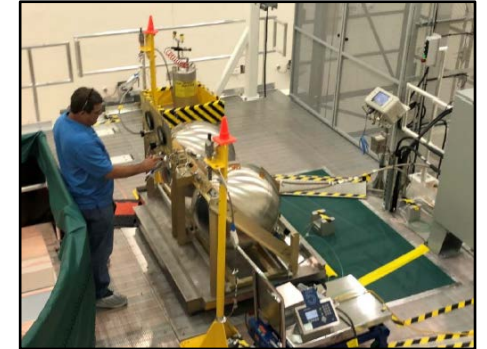
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MPPF standalone V&V activities

- ✓ Crew Module Ammonia Servicing Subsystem (CMASS), Gaseous Nitrogen (GN2), Gaseous Oxygen (GO2), Gaseous Helium (GHe), and Kennedy Complex Control System (KCCS) V&V activities are complete
- ✓ Orion Transportation Pallet (OTP) was received and V&V is complete
- ✓ Ground Cooling System V&V Test Readiness Review completed - February 2018

- Hypergol Servicing/Deservicing V&V testing being split for Fuel and Ox Testing
 - ✓ Cold Flow SCAPE demonstration - July 2018
 - ✓ Hot Flow start - September 2018

- MPPF Ready to support Vehicle Processing – 2019 Q2



Crew Module Hypergol Cold Flow V&V Test Tanks



Hypers SCAPE demo at MPPF



V&V Start



CMASS Haz Testing



Orion Pallet Handling



Hypers Testing



MPPF V&V Complete

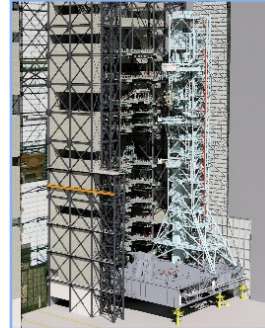
Spaceport Command & Control System (SCCS)

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- ✓ SCCS 4.0.1 - Hazardous Testing & GFAS Development/Test
- SCCS 5.0 – Orion Flight Vehicle Processing & GFAS V&V
- SCCS 6.0 – GFAS Regression, ITCO, WDR and EM-1 Launch



MPPF Hazardous Testing



MEVV @ VAB



MEVV @ Pad

- ✓ Firing Room 2 Hardware Upgrades complete
- ✓ Integration Events (IE) 3 & 4, IE-4 included 500K cps complete
- ✓ SCCS 5.0 Engineering Release 2 – September 2018

SCCS 4.0 Validated Release

SCCS 4.0.1 System Test

SCCS 4.0.1 Validated

SCCS 5.0 Engineering Release

SCCS 5.0 Validated

SCCS 6.0 Engineering Release

SCCS 6.0 Validated

Ground Flight Application Software (GFAS)

GFAS in Firing Room 1 for Cryogenic Simulation



- ✓ HOTH test run for Avionics and COMM on FSW 28c platform completed – July 9-13
- Cross Program initiatives are increasing, yielding positive results (FSW integration, OMRS scripting & pre test, LCC / GLS algorithms, Greenrun / LCD)

GFAS Drop 17

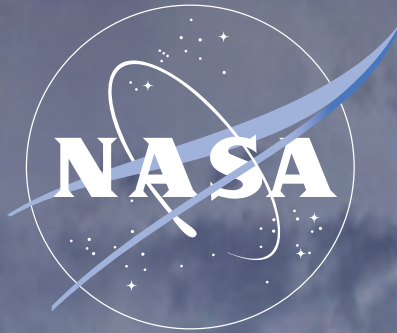
GFAS Drop 22

GFAS (ECLSS/Hypers) V&V Complete

GFAS Ready for ML/Pad ME V&V

GFAS SC Offline Ready (SAR)

GFAS ITCO Ready (SAR)





Acronyms and Abbreviations

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Acronym	Definition	Acronym	Definition	Acronym	Definition
AA	Ascent Abort	FRR	Flight Readiness Review	NDE	Nondestructive Evaluation
AI&T	Assembly, Integration, and Testing	FS	Forward Skirt	O&C	Operations and Checkout
APU	Auxiliary Power Unit	FSS	Flight Safety System	O/D	On Dock
ASEU	Aft Skirt Electrical Umbilical	FSW	Flight Software	OGV	Ogive Panel
ATLO	Assembly, Test, and Launch Operations	FWD	Forward	OMRS	Operations and Maintenance Requirements and Specifications
ATP	Authority to Proceed	GFAS	Ground/Flight Application Software	OMS-E	Orbital Maneuvering System Engine
BFS	Backup Flight System	GFAST	Ground/Flight Application Software Team	OSA	Orion Stage Adapter
C&DH	Command and Data Handling	GHe	Gaseous Helium	OTP	Orion Transportation Pallet
CAA	Crew Access Arm	GLS	Ground Launch Sequencer	PCA	Pressurant Control Assembly
CM	Crew Module	GN2	Gaseous Nitrogen	PCDU	Power Control Distribution Unit
CMA	Crew Module Adapter	GNC	Guidance, Navigation, and Control	PDU	Power Distribution Unit
CMASS	Crew Module Ammonia Servicing Subsystem	GO2	Gaseous Oxygen	PLI	Propellant Liner Insulation
C/O	Check Out	GR&A	Ground Rules and Assumptions	PM	Program Manager
CR	Change Request	GRAS	Green Run Application Software	PPE	Power and Propulsion Element
CS	Core Stage	GRC	Glenn Research Center	PQM	Propellant Qualification Model
CSI	Cross-Program Systems Integration	GSE	Ground Support Equipment	PRA	Probabilistic Risk Assessment
CSM	Crew and Service Module	H&A	Handling and Access	QD	Quick Disconnect
CSS	Consumable Storage System	HB	High Bay	QM	Qualification Motor
CT	Crawler Transporter	HOTH	Houston Orion Test Hardware	RCS	Reaction Control System
CUI	Controlled Unclassified Information	ICPS	Interim Cryogenic Propulsion Stage	SAR	System Acceptance Review
DFAT	Direct Field Acoustics Test	ICPSU	Interim Cryogenic Propulsion Stage Umbilical	SCCS	Spaceport Command and Control System
DVO	Detailed Verification Objectives	IPO	Initial Power On	SCAPE	Self-Contained Atmospheric Protection Ensemble
ECD	Estimated Completion Date	IT	Intertank	SE&I	Systems Engineering and Integration
ECLSS	Environmental Control and Life Support System	ITCO	Integrated Test and Checkout	SIL	System Integration Lab
ECS	Environmental Control System	ITL	Integrated Test Laboratory	SITF	Software Integration Testing Facility
ECU	Engine Controller Unit	JICB	Joint Integrated Control Board	SLS	Space Launch System
EES	Emergency Egress System	JM	Jettison Motor	SM	Service Module
EGS	Exploration Ground Systems	KCCS	Kennedy Complex Control System	SSC	Stennis Space Center
EGSE	Electrical Ground Support Equipment	KSC	Kennedy Space Center	SSPF	Space Station Processing Facility
EM	Exploration Mission	LAS	Launch Abort System	STA	Structural Test Article
EMI/EMC	Electromagnetic Interference and Electromagnetic Compatibility	LCC	Launch Commit Criteria	SW	Software
ES	Engine Section	LETF	Launch Equipment Test Facility	TCU	Thermal Control Unit
ESA	European Space Agency	LH2	Liquid Hydrogen	TLM	Telemetry
ESD	Exploration Systems Development	LN2	Liquid Nitrogen	TPS	Thermal Protection System
ESERP	ESD Safety and Engineering Review Panel	LO2	Liquid Oxygen	TRR	Test Readiness Review
ESM	European Service Module	LOX	Liquid Oxygen	TSMU	Tail Service Mast Umbilical
EUS	Exploration Upper Stage	LVSA	Launch Vehicle Stage Adapter	TVC	Thrust Vector Control
FCAS	Flight Controller Application Software	MAF	Michoud Assembly Facility	ULA	United Launch Alliance
FCV	Flow Control Valve	MEVV	Multi-Element Verification and Validation	V&V	Verification and Validation
FDIR	Fault Detection Isolation& Recovery	ML	Mobile Launcher	VAB	Vehicle Assembly Building
FIL	Fillet Panel	MPPF	Multi-Payload Processing Facility	VAC	Vertical Assembly Center
FM	Flight Model	MPS	Main Propulsion System	WDR	Wet Dress Rehearsal
FMA	Final Mission Analysis	MSFC	Marshall Space Flight Center		
FRAC	Flight Readiness Analysis Cycle	N2	Nitrogen		