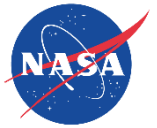

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DEVELOPMENT OF THE EUROPEAN SERVICE MODULE PROPULSION SUBSYSTEM FOR THE MULTI-PURPOSE CREW VEHICLE

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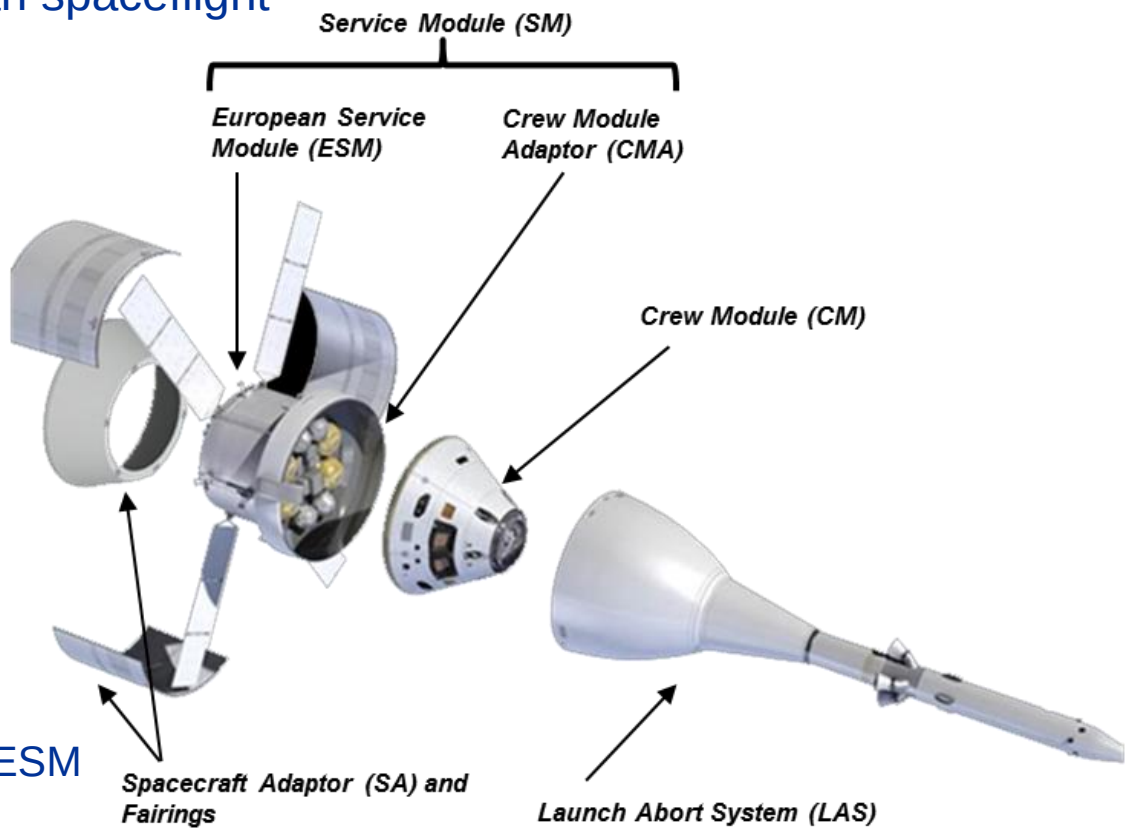
Background

- Orion/MPCV the future of human spaceflight beyond LEO

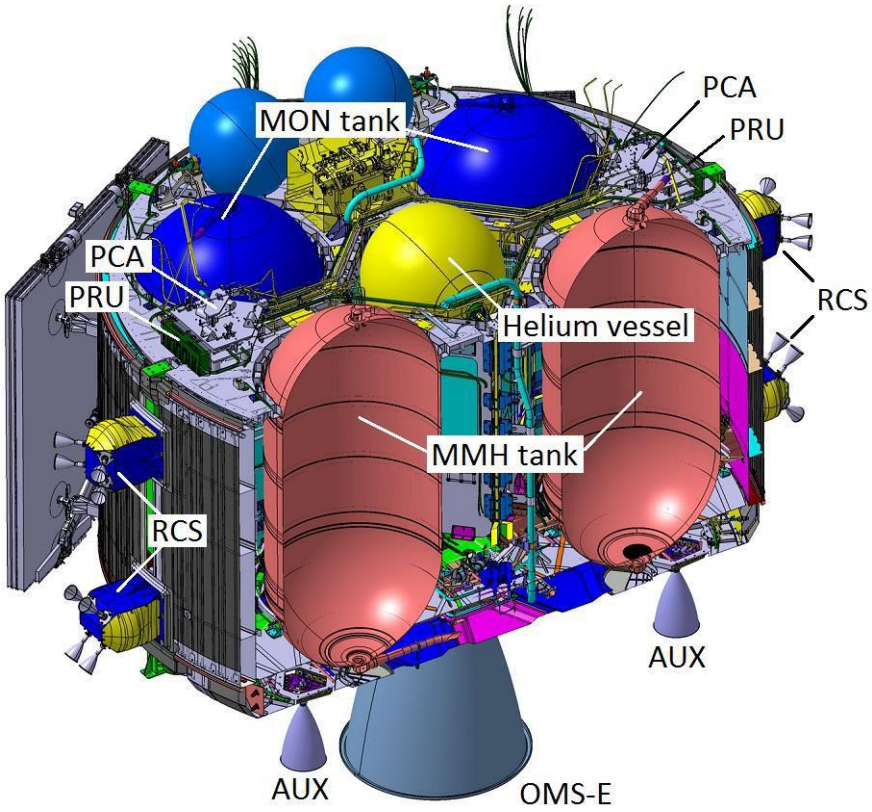
- Major Elements of Orion
  - ESM (Airbus)
  - CMA (Lockheed)
  - CM (Lockheed)
  - SA (Lockheed)
  - LAS (Lockheed)

- Major Milestones
  - May 2011: Study Phase
  - November 2012: Decision for ESM
  - May 2014: System PDR
  - November 2014: PSS PDR
  - February 2016: PSS CDR
  - June 2016: System CDR
  - August 2017: Initiation of PQM Tests



Propulsion Subsystem (PSS) Description

- Pressure-fed, bi-propellant propulsion system
- Uses MMH and NTO (MON-3)
- Usable Propellant: 8,602 kg (18,964 lbm)
- 4 metallic propellant tanks, 2 per propellant type, plumbed serially
- 2 Composite Overwrap Pressure Vessel (COPV) helium bottles, 1 per commodity
- 3 classes of engines, all supplied from common propellant storage
  - 1 Main Engine with Thrust Vector Control (TVC)
  - 8 Auxiliary Engines, one string
  - 24 RCS Engines, 2 redundant strings, 6 pods



PSS Development Approach

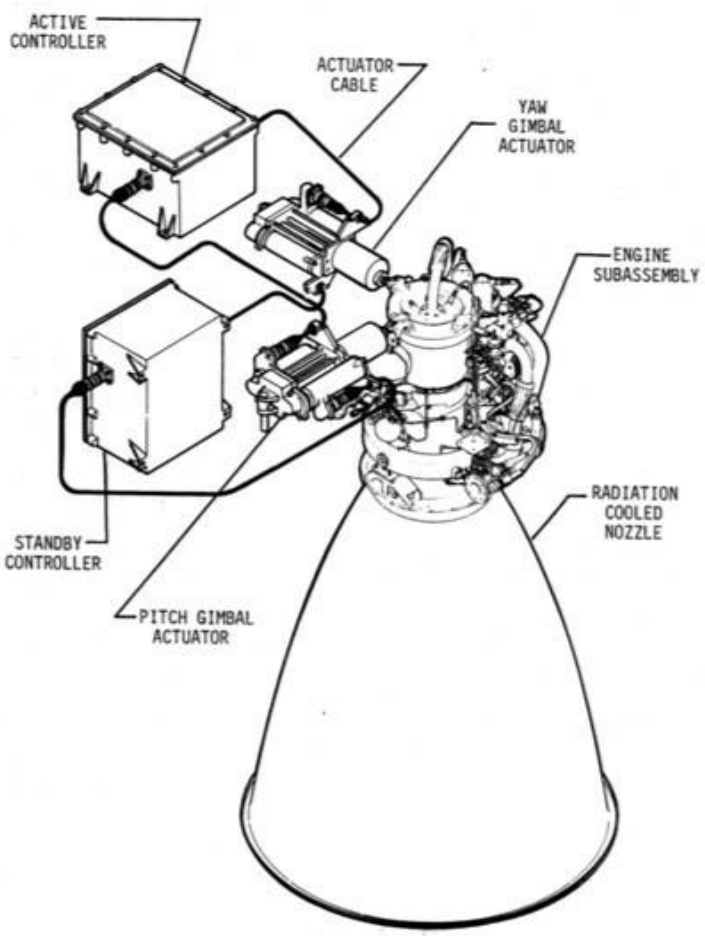
- Hardware Heritage
  - Schedule limitations and budget constraints drove the need for extensive use of heritage hardware designs
  - In some cases flight hardware reuse (from Shuttle) was required, and will be delta-qualified for use on Orion (e.g., Orbital Maneuvering System (OMS) Engine, TVC)
- Primary sources of heritage:
  - ATV
  - Shuttle
  - Orion Crew Module (CM) Propulsion Subsystem (PSS)
  - Ariane 5 Hypergolic Upper Stage (EPS)
- Targeted Development Testing
  - Component development testing was performed to address the highest risk areas of heritage design compliance with Orion requirements
  - Assembly level development testing was performed to understand complex assemblies and component interactions

Orbital Maneuvering System Engine (OMS-E)

- Heritage
  - Direct re-use of assets from Shuttle Orbiters, all assets have varying flight history
- Basic Specifications:
  - Thrust: 6000 lbf
  - Isp (min): 310 sec
  - MR: 1.65
  - Nozzle area ratio: 55:1
- Orion Use
  - Used by Orion for major translational maneuvers
- Design Changes (only as required)
  - Redundant chamber pressure measurement and 2nd fuel injector temperature sensor
  - Heater kit (on TCA nozzle)
  - New harnesses

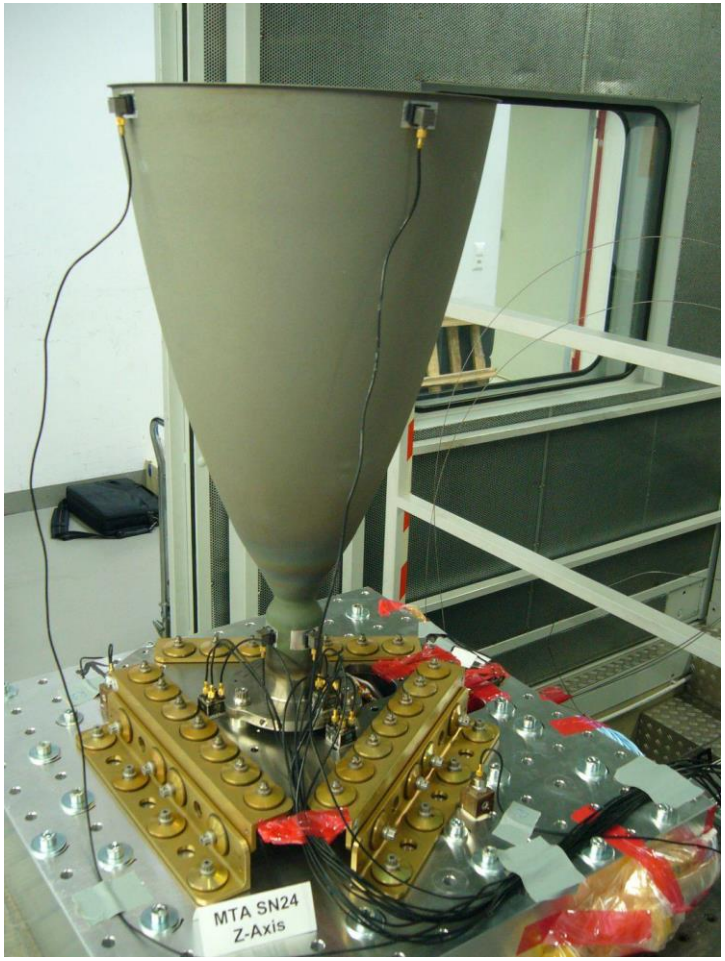
Thrust Vector Control (TVC)

- Heritage
  - Direct re-use of assets from Shuttle Orbiters, all assets have varying flight history
- Orion Use
  - Used by Orion to gimbal the main engine during major translational maneuvers
- Development Testing
  - Random vibration on controller box (lead to card retention design mod)
- Design Changes (only as required)
  - Circuit board retention in controller box (single instance from Shuttle flight history)
  - New, longer harnesses



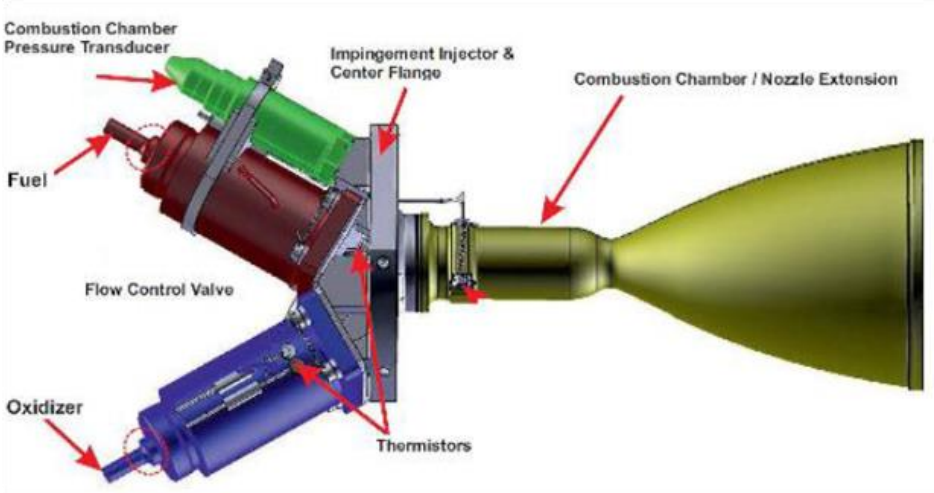
Auxiliary (Aux) Engines

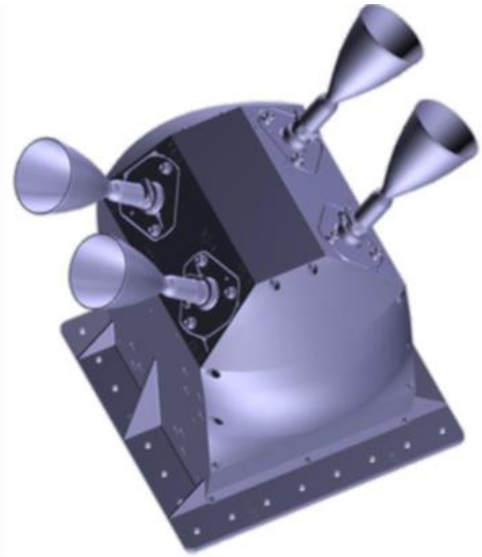
- Basic Specs
  - (8) fixed position engines
  - Thrust: 105 lbf
  - Nozzle area ratio: 164:1
- Orion Use
  - Nominally used for separation maneuvers and mid-course correction maneuvers
  - In contingency scenario (failed main engine), used for major translational maneuvers
    - Drives the need for long continuous duration firing
    - Drives the need for off-pulsing (to steer)
    - Control authority requires 50% duty cycle
- Development Testing
  - Random Vibration (added vibration isolation bracket)
  - Hot fire, duty cycle (changed MR)



Reaction Control System (RCS) Thrusters

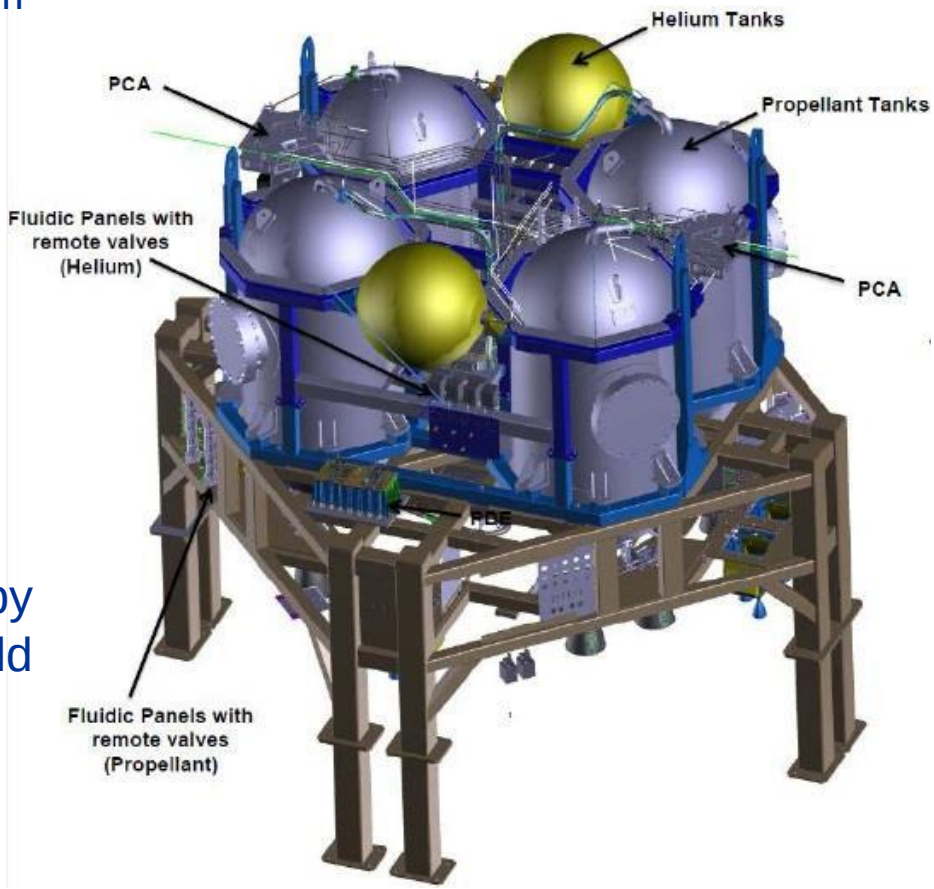
- Basic Specs
  - (24) engines, two redundant strings of 12 engines each
  - Packaged in 6 pods of 4 engines each
- Orion Use
  - Used for attitude control, rendezvous, and proximity operations
- Development Testing
  - Hot fire, 5 Hz command frequency (PT thermal issue)





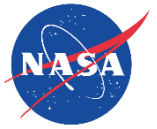
Qualification Testing – Propulsion Qualification Model (PQM)

- System level qualification test to be performed at WSTF in Test Stand 301
  - Sea level test stand for hypergolic system testing
  - Self-pumping diffuser added for OMS-E
- Flight like configuration with some exceptions:
  - Non-flight prop tanks (without PMD's)
  - Single string of RCS thrusters
  - One string of valves per PCA
  - Partial representation of helium cross feed system
- Will complete PSS design qualification by test. Requirements verification that could not be accomplished at a lower level
- Will provide insight into complex system interactions and will also be used for anchoring of analytical models



Summary and Conclusions

- Major design milestones are complete (PDR, CDR). The ESM design meets Orion requirements and is ready for hardware manufacturing and assembly
- Heavy reliance on heritage hardware designs allowed for an expedited design/development schedule within the available budget
- Targeted component and assembly-level development testing were used to buy down the areas of highest risk



Backup

Heritage Designs and Development Testing

Component	Supplier	Heritage	Dev Testing	Test Focus
OMS-E	Aerojet	Shuttle	No	N/A
TVC	Honeywell	Shuttle	**Yes**	Vibe (controller)
Auxiliary Engines	Aerojet	Apollo, ATV, HTV, …	**Yes**	Vibe, Duty Cycle
RCS Engines	Airbus	ATV	**Yes**	Command Freq.
Helium Bottles	Airbus	ATV, Ariane 5 EPS	No	N/A
Helium Filter	Sofrance	Ariane 5 EPS	No	N/A
High Pressure Gas Latch Valves	VACCO	Shuttle	No	N/A
High Pressure Solenoid Valves	VACCO	Shuttle	**Yes**	Higher Op. Press.
Pyro Valves	Cobham	Orion CM	No	N/A
Propellant Tanks	Airbus	OST23	No	N/A
Tank PMD's	Airbus	ATV, OST1, OST2	**Yes**	Vibe (dry)
BDRV	RDI	Orion CM	**Yes**	Design Scaling
MLIV	VACCO	Orion CM	No	N/A
ABIV	Airbus	ATV	No	N/A
RBIV	Airbus	ATV	No	N/A
BRV	Airbus	ATV	No	N/A
ABPF	VACCO	ATV	No	N/A
PDE	Airbus	ATV	No	N/A
PRU	Airbus	**None**	No	N/A