



TO THE MOON, MARS AND BEYOND: PNEUMATIC GROUND SYSTEMS FOR ML-2

Kennedy Space Center (KSC) Student Showcase Presentation

7-27-2021

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- ◆ **Introduction**
 - Education & Experience
 - Assigned Organization
 - Pneumatics Discipline
- ◆ **Artemis Program**
 - Program Overview
 - Exploration Ground Systems (EGS)
 - Mobile Launcher Configurations
- ◆ **Pathways Project**
 - PAS Prototype
 - Pneumatic System Design
 - Pneumatic System Analysis
 - PVS Certification Analysis/Volume Calculations
 - Conclusion
- ◆ **Final Remarks**
 - Acknowledgments
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Figure 1. Mobile Launcher Roll Back to VAB



♦ Education

- The University of Texas Rio Grande Valley (UTRGV)
- B.S. in Mechanical Engineering
- Graduation in December 2021

♦ Experience

- **DOE Internship at Savannah River Site (SRS) Environmental Station** June-July 2018
 - Teleoperated VEX Robotics prototype hardware to address management of hazardous nuclear materials
 - C++ PID Controller for robotic arm mobility
- **Thermodynamics Research Assistant at UTRGV** Aug 2019 – May 2020
 - Excel and Python analytical models for Thermodynamics System
 - Fabrications of thruster nozzles and Data Acquisition Systems for a Compressed Air System
- **OSTEM Internship at John C. Stennis Space Center (SSC)** Aug 2020 – Dec 2020
 - Rocket Propulsion Testing and Analysis Intern
 - Private Liquid/Hybrid Rocket Engine Market Database
 - Automation of Analytical Prediction Model for A-1 Test Stand propellant inlet conditions



Figure 2. Freshman John Ortiz proud to be accepted into UTRGV's ME program.



- ♦ KSC Pathways Student (Engineering) Trainee Interns are assigned to the **Human Resources Directorate (BA)** and Matrixed to the **Engineering Directorate (NE)**
- ♦ John Ortiz is matrixed to the Environmental and Life Support Systems Branch, NE-XF
- ♦ **Engineering Directorate (NE):**
 - **Exploration Systems and Operations Division (NE-X)**
 - Exploration Ground Systems (EGS) program success
 - **Environmental and Life Support Systems Branch (NE-XF)**
 - *Environmental Control and Life Support Systems (ECLSS)*
 - ***Pneumatics***
 - *Ground Cooling Subsystems (GCS)*
 - *Environmental Control Subsystems (ECS)*
 - *Purge Vent and Drain (PVD) systems*
 - *Crew Module Ammonia Servicing Subsystems (CMASS)*
 - *Pressure Vessels and Pressurized Systems (PVS)*

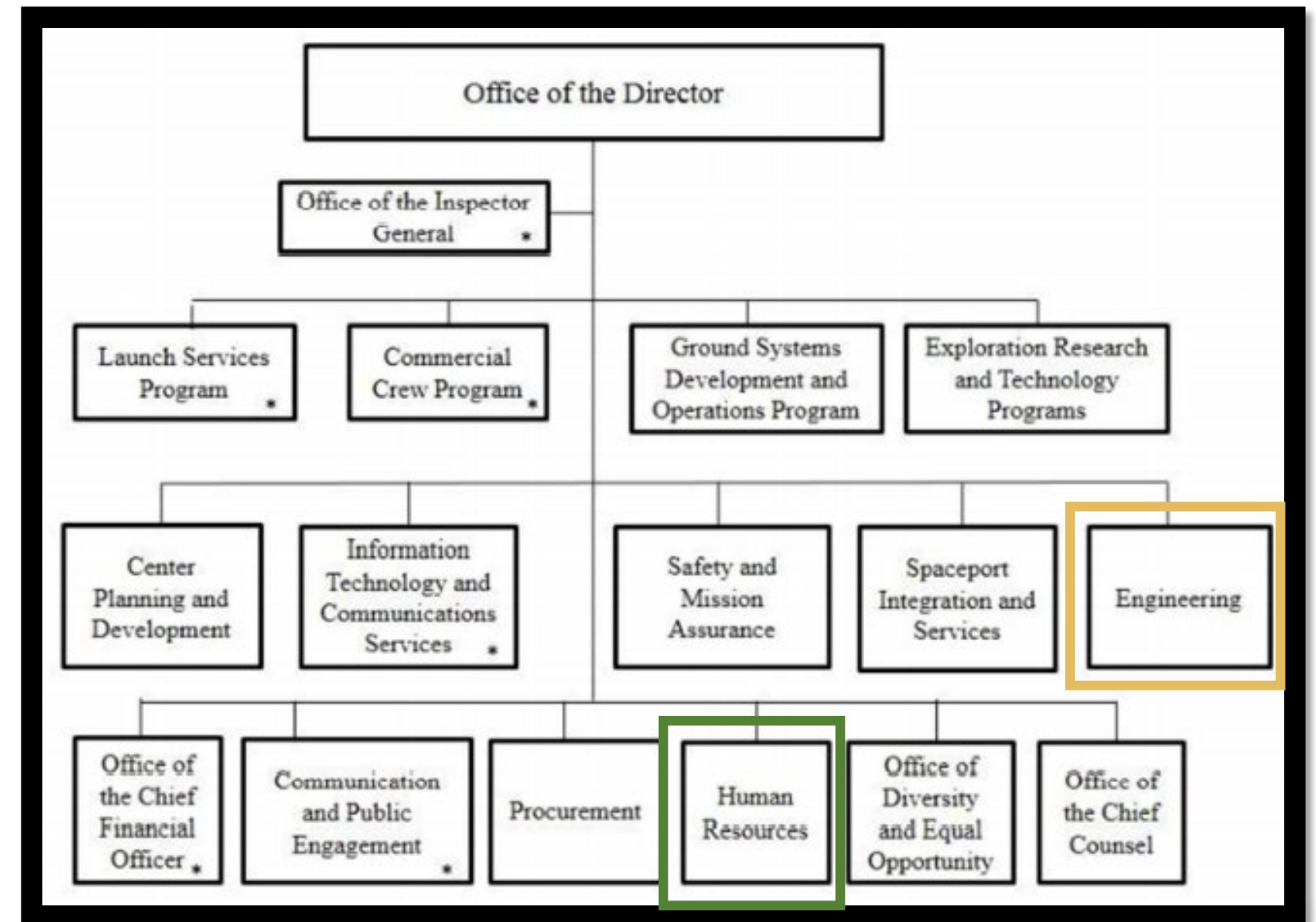


Figure 3. KSC Organizational Chart (see Ref. 1)

- ♦ Branch of Fluid Mechanics concern with the mechanics and properties of gases and its application to engineering systems.
- Applications of Pneumatics in the Aerospace systems:
 - Flight Hardware –
 - *Reaction Control Systems*
 - *Rocket Pressure Fed Systems*
 - Ground Operations –
 - *Valve Actuation*
 - *Inert Environment (Purge)*
 - *Tube Drying/Cleaning*
- **NE-XF Pneumatics Engineering** provides design & operation expertise to support EGS. Commodities used at KSC systems:
 - *Gaseous Helium (GHe)*
 - *Gaseous Oxygen (GO2)*
 - *Gaseous Nitrogen (GN2)*
 - *Breathing Air (BAIR)*
 - Support other subsystems:
 - LH2, LO2, Ground Main Propulsion System (GMPS), etc



Figure 4. MPPF Facility Pneumatics System

♦ Lunar Exploration Program

- Prepare for the humanity's next giant leap – Human exploration of Mars

♦ Artemis main goals:

- Early Human Landing
 - First woman and first person of color will land in 2024
 - Space Exploration Leadership
- Sustainable Lunar Exploration
 - Commercial Partnerships
 - Reliable Lunar Exploration Infrastructure

♦ Exploration Ground Systems (EGS)

- Based at KSC with the mission to integrate, process, launch and recover the Space Launch System (SLS) rocket and the space capsule, Orion while supporting operations and maintenance of unique KSC systems necessary for the sustainability of the **Artemis Program**



Figure 5. Artemis Program Identity



- ♦ Space Launch System (SLS) rocket
 - Most powerful and capable NASA rocket for deep space missions
 - Design to evolve into increasingly more powerful configurations

- ♦ Mobile Launcher
 - Ground support structure that will be used to **assemble, processes and launch** the SLS rocket
 - There is currently two visions of Mobile for the Artemis program, Mobile Launcher 1 (**ML-1**) and Mobile Launcher 2 (**ML-2**)

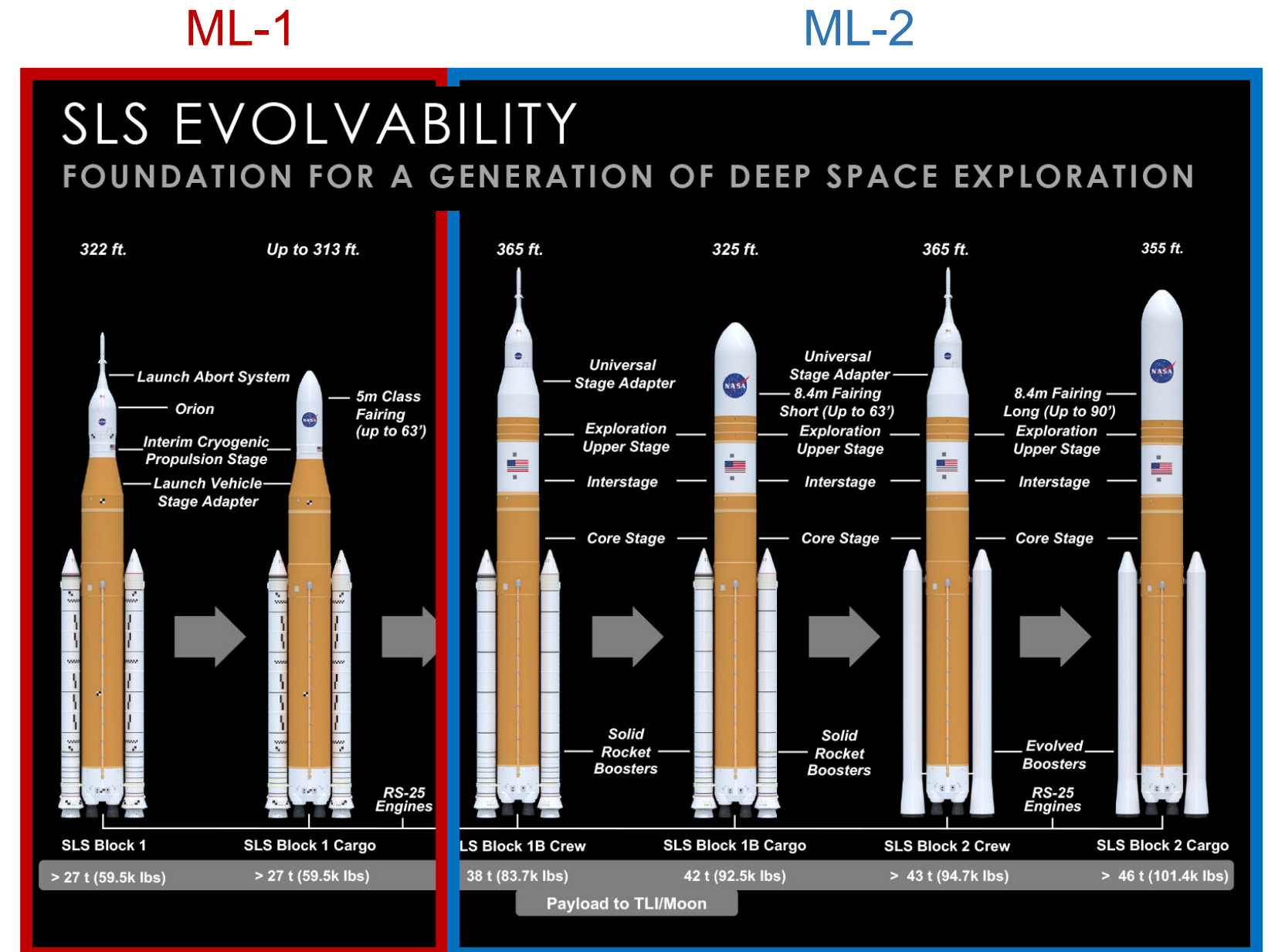


Figure 6. SLS Evolution (see Ref. 2)

◆ Changes to ML-2 compared to ML-1:

1. ML-2 Crew Access Arm and Orion Service Module Umbilical are on a higher level
2. ML-2 Exploration Upper Stage (EUS) umbilical replaces the Interim Cryogenic Propulsion Stage (ICPS) umbilical
3. Resized Vehicle Stabilizer is located at a higher level
4. Updated structural connections for taller and heavier SLS Block 1B configuration
5. Base structural connections are updated similarly

◆ NE-XF Pneumatic Systems on-board ML-1 that required modifications for ML-2:

- **GN2 Subsystem**
 - Crew Module (CM) Backshell Purge Panel
- **Breathing Air subsystem**
 - Cabin Air Supply Panel Purge Panel

New System for ML-2

- **Payload Accommodation Sub-system (PAS)**

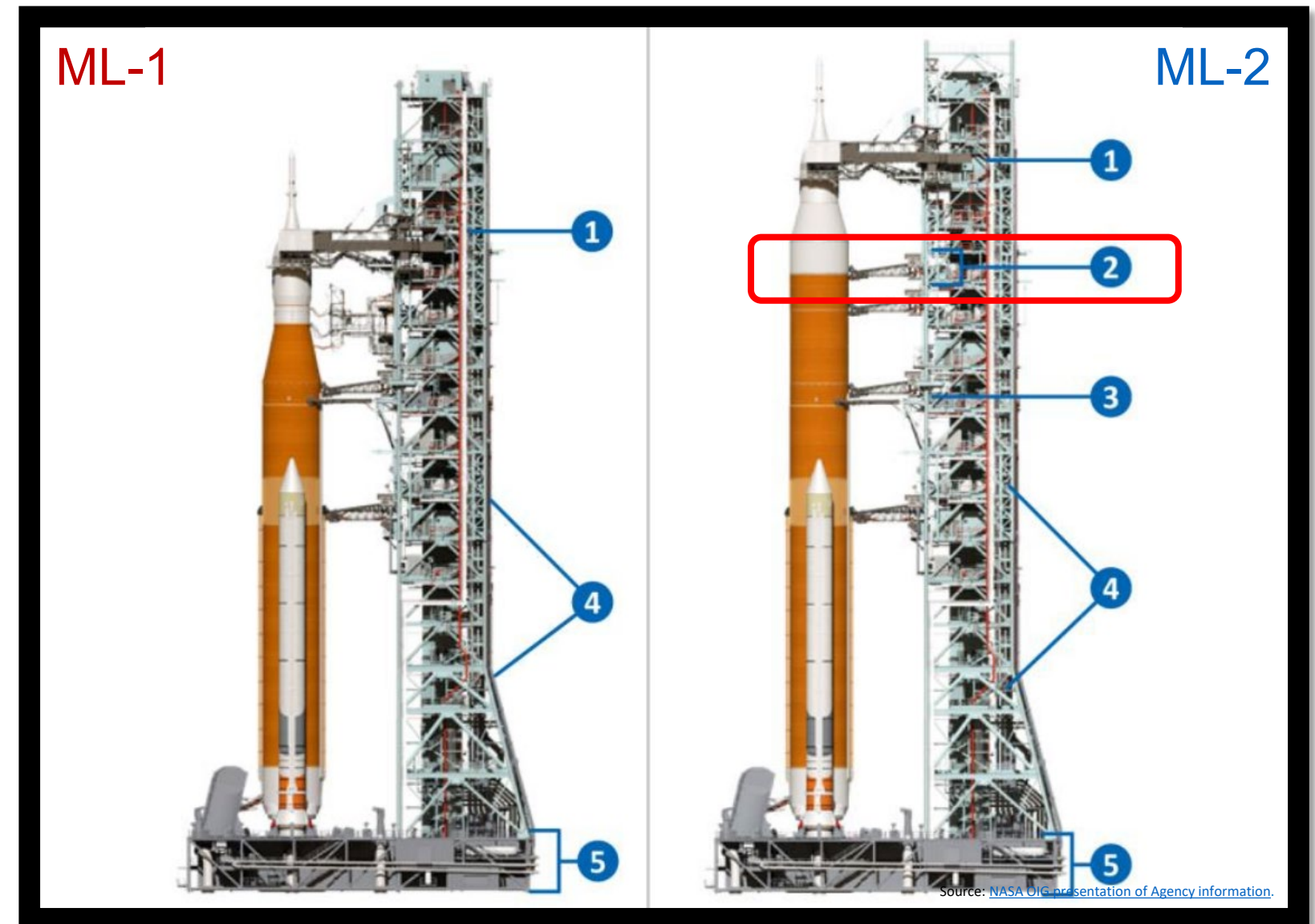


Figure 7. Comparison Between ML-1 and ML-2

♦ PAS

- PAS provides high purity, temperature- and flow rate-controlled GN2 purge to the payload through the EUS Umbilical that interfaces ML-2 with SLS Block 1B

♦ PAS Prototype

- A prototype is required to reduce the PAS system design, development and integration risk for ML-2

♦ PAS Prototype Objectives:

- The PAS prototype is a **temporary test configuration** that will test:
 1. The integration and capability of the PAS system major components
 2. That the system can deliver high purity levels GN2
 3. That the flow controller can control the flow of GN2 over the operating flow range
 4. That the heater capability can control the GN2 temperature across the PAS temperature range requirement

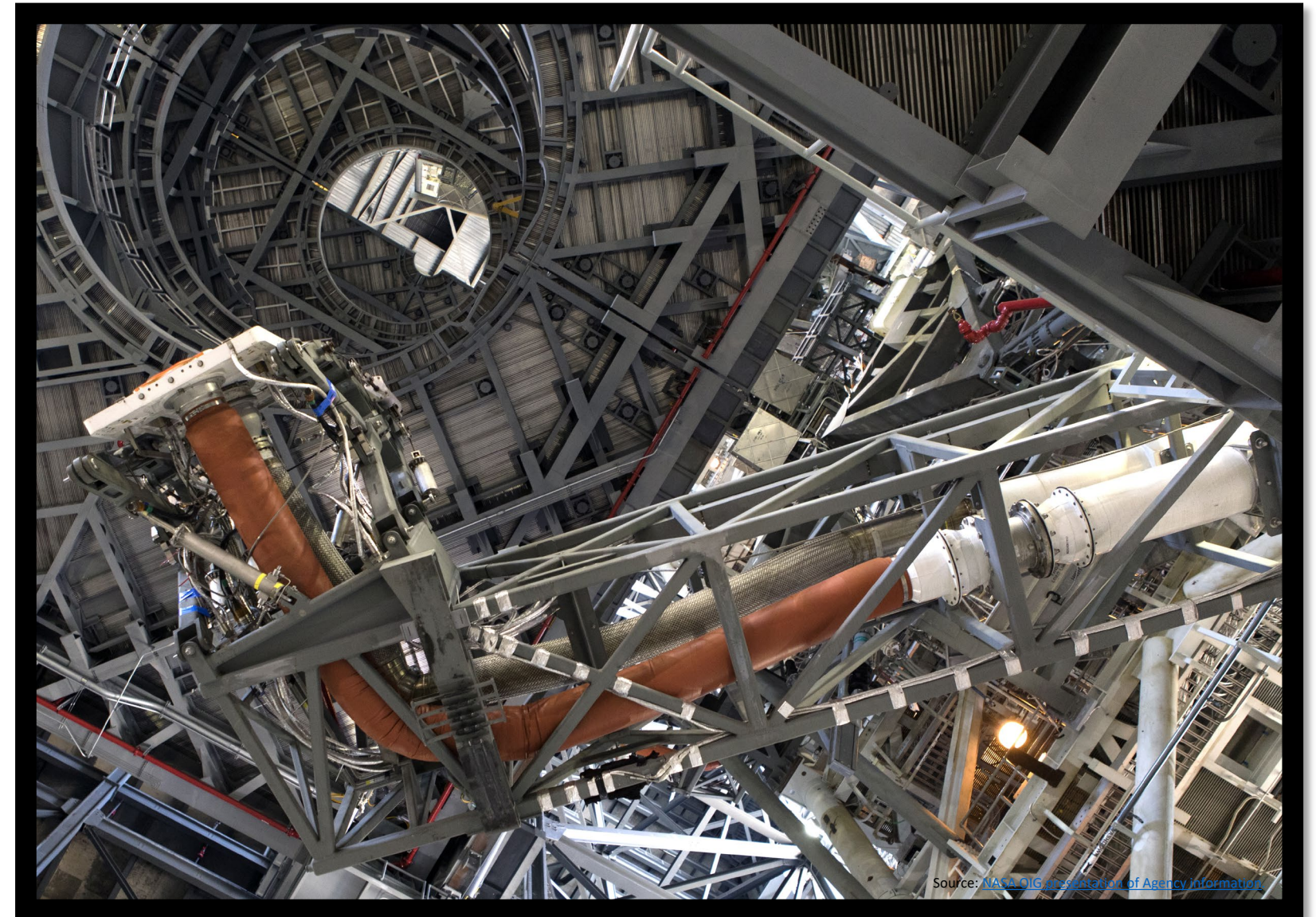


Figure 8. ML-1 Core Stage Inter-tank Umbilical (CSITU)



- ◆ Design Standards and Specification
 - ASME B31.3 – Process Piping Code
 - ASME BPVC.VIII.1 – Boiler and Pressure Vessel Code
 - Compliance with all NASA and KSC requirements:
 - [NASA-STD 8719.17](#) – NASA Requirements for Ground-Based PVS
 - [KSC-DE-512](#) – SM Ground Systems Development Standard
 - [KSC-F-124](#) – Specifications for Flared Tube Fittings
 - [KSC-GP-435](#) – Fluid Fitting Engineering Standards
 - [KSC-GP-435](#) – Engineering Drawing Practices Volume I
 - [KSC-STD-Z-0005](#) – Pneumatic Ground Systems Development Standard

- ◆ Component Evaluation
 - All components are verifying to meet Pressure Vessel and Pressurized Systems (PVS) requirements, including:
 - Component Design Pressure
 - Component Temperature Rating
 - System Pressure at component location
 - System Temperature at component location
 - Component Material Compatibility
 - Design Standards

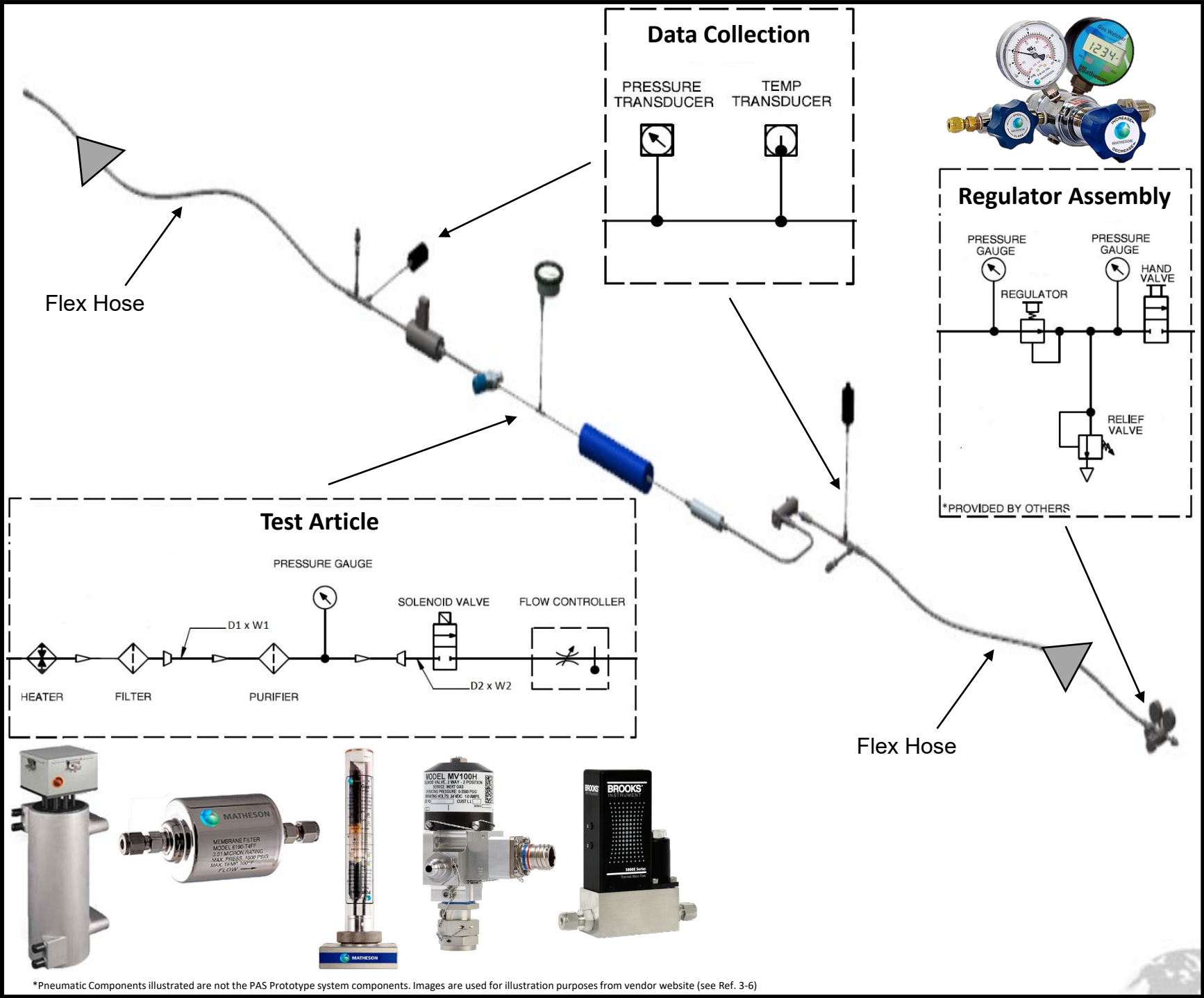


Figure 9. PAS Prototype Configuration Schematic

♦ Analysis Objective

- Identify configuration capabilities
- Study operational and failure scenarios

♦ Fundamental Principles

- Conservation Equations
 - Continuity
 - Momentum
 - Energy
- Equation of State
- Mach Number

♦ Analysis Challenges

- Compressible Flow mechanism
- Heat Transfer mechanism
- Real Gas Properties

♦ Applied Flow Technology (AFT) Arrow Software

- Fluid Dynamics Simulation Tool for compressible flow systems at steady state
- We use a KSC standardized methodology.
- Reduce complexity through abstraction. Boundary conditions:
 1. Commodity composition
 2. Component characteristics
 3. Heat Rates

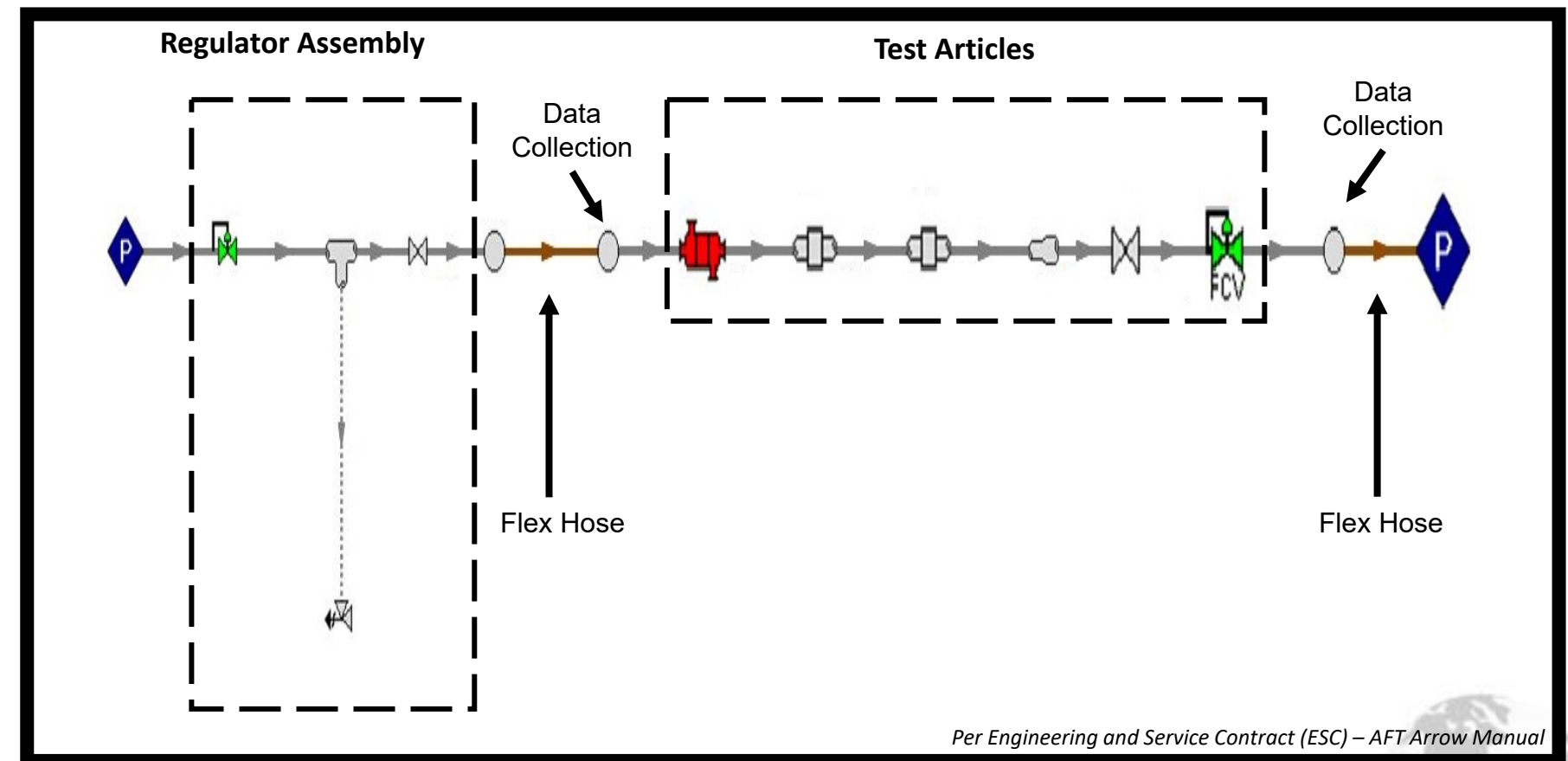


Figure 10. PAS Prototype AFT Arrow Model

♦ PVS Relief Valve for Regulator Failure Mode

– Flow Type Across Regulator Test, where:

- P_c : Critical Regulator Outlet Pressure
- P_i : Regulator Inlet Pressure
- P_o : Regulator Outlet Pressure
- γ : Specific Heat Transfer ratio (For GN2 is 1.4)

$$P_c = P_i \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma}{\gamma - 1}}; \quad \text{Since } P_c > P_o; \quad \longrightarrow \quad \text{Critical Flow}$$

– Q , Regulator Critical Flow Rate:

$$Q = 16.05 * C_v P_i \sqrt{\frac{1 - \frac{2}{\gamma + 1}}{S_g T_i Z_i}} = \mathbf{91.56 SCFM}$$

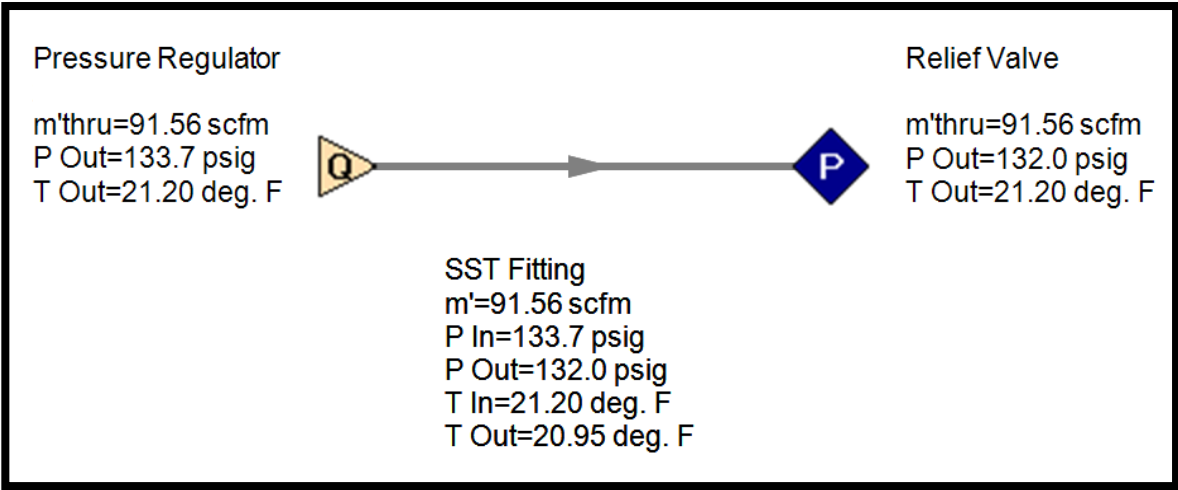
- Model as an **isentropic process** is an overestimate due to heat transfer. Thus, Q , can be interpret as worst-case scenario with fully open regulator failure mode.

– Relief Valve Flow Capacity, Q_{RV} , according to manufacturer's specifications.

Relief Valve Set Pressure (PSIG)	Corresponding Flow Capacity (SCFM)
130	114
132	115.6
135	118

♦ PVS Regulator/Relief Valve Pressure Drop

– AFT Model of High Delivery Pressure Regulator Assembly



- Pressure Drop Percentage:

Find Number	Set Pressure (PSIG)	Relief Valve Flow Capacity (SCFM)	Maximum Regulator Flow Rate (SCFM)	Pressure Drop (% of relief valve set pressure)
N/a	132	115.6	91.56	1.16

♦ Technical Lessons Learned

- Earned experience designing pneumatic systems per ASME B31.3, ASME BPVC VIII,
- Model and analysis pneumatic systems operational and failure modes.
- Prepared Engineering Products for peer engineering reviews
- Learned to interpreted pneumatics system and component drawings.

♦ Professional Lessons Learned

- Assigned project priorities and execute assignments in order of mission importance
- Learned to communicated with component manufactures effectively to qualify pneumatic components documentation

♦ Future Work

- Deliver other critical NE-XF engineering products, such as:
 - PVS Certification Report for Breathing Air Panel
 - Vendor component qualification review
- Work on-site!



Figure 11. Astronaut Neil Armstrong at U.S. Space and Rocket Center

♦ Environmental and Life Support Systems Branch, NE-XF:

- Christian J. Nunez Velez – Payload Accommodation Systems Lead Design Engineer
- Ruben Jaca – Pneumatics Lead Design Engineer
- Stephen M. Anthony – Environmental and Life Support Systems Branch Chief

♦ Integration Office, BA-A:

- Mai L. Miller – Pathways Program Coordinator
- David M. Wilson – Supervisor

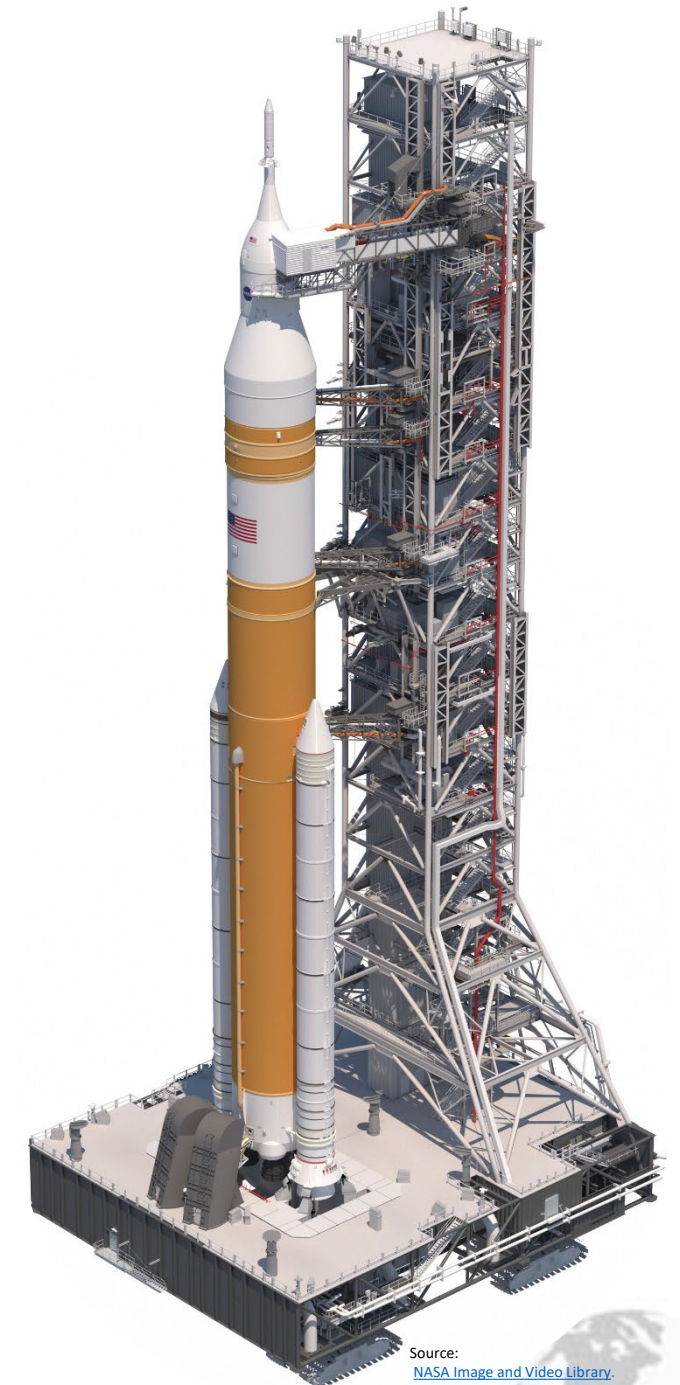
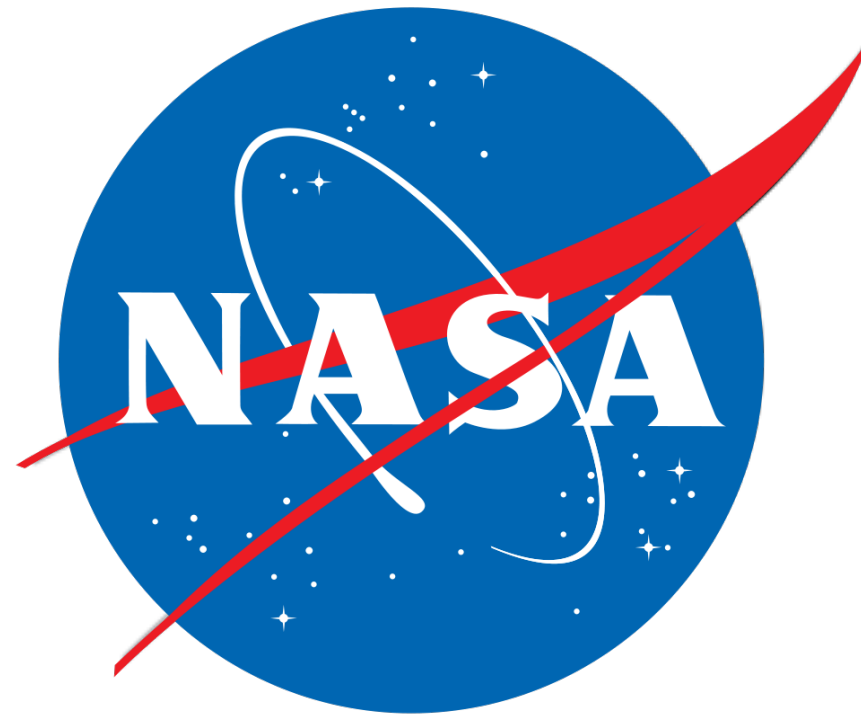


Figure 12. SLS Block 1B on ML

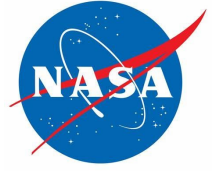
Q & A



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References & Acronyms



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♦ **Acronyms:**

- A-1** – Name of Rocket Test Stand in SSC
- AFT** – Applied Flow Technology
- BA** – Human Resources Directorate
- BAIR** – Breathing Air
- BPVC** – Boiler and Pressure Vessel Code
- CLPS** – Commercial Lunar Payload Services
- CMASS** – Crew Module Ammonia Servicing Subsystem
- CMS** – Configuration Management System
- CSITU** – Core Stage Inter-tank Umbilical
- DOE** – Department of Energy
- D#** – Diameter dimension
- ECLSS** - Environmental Control and Life Support Systems
- ECS** – Environmental Control Subsystems
- EGS** – Exploration Ground Systems
- ESC** – Engineering Service Contract
- EUS** – Exploration Upper Stage
- GCS** – Ground Cooling Subsystems

- GHe** – Gaseous Helium
- GMPS** – Ground Main Propulsion System
- GN2** – Gaseous Nitrogen
- GO2** – Gaseous Oxygen
- GSE** – Grounds Support Equipment
- HLS** – Human Landing System
- ICPS** – Interim Cryogenic Propulsion Stage
- KSC** – John F. Kennedy Space Center
- ME** – Mechanical Engineering
- ML** – Mobile Launcher
- ML-2** – Mobile Launcher 2
- MPPF** – Multi-Payload Processing Facility
- NASA** – National Aeronautics and Space Administration
- NE** – Engineering Directorate
- NE-X** – Exploration Systems and Operations Division
- NE-XF** – Environmental Systems and Operations Division
- OSTEM** – Office of STEM
- PAS** – Payload Accommodation Sub-system
- PLS** – Programmable Logic Computer
- PSIG** – Pounds Per Square Inch (Gage)
- PVD** – Purge Vent and Drain (PVD)
- PVS** – Pressure Vessels and Pressurized Subsystems
- SCFM** – Standard Cubic Feet Per Minute
- SLS** – Space Launch Systems
- SRS** – Savannah River Site
- SSC** – John C. Stennis Space Center
- STEM** – Science, Technology, Engineering and Mathematics
- TLI** – Trans-lunar Injection
- UTRGV** – The University of Texas Rio Grande Valley
- VAB** – Vehicle Assembly Building
- W#** – Thickness dimension

