Propulsion and Human Landing Systems:
Marshall Space Flight Center's Expertise

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WARNING: Propulsion Biased Presentation

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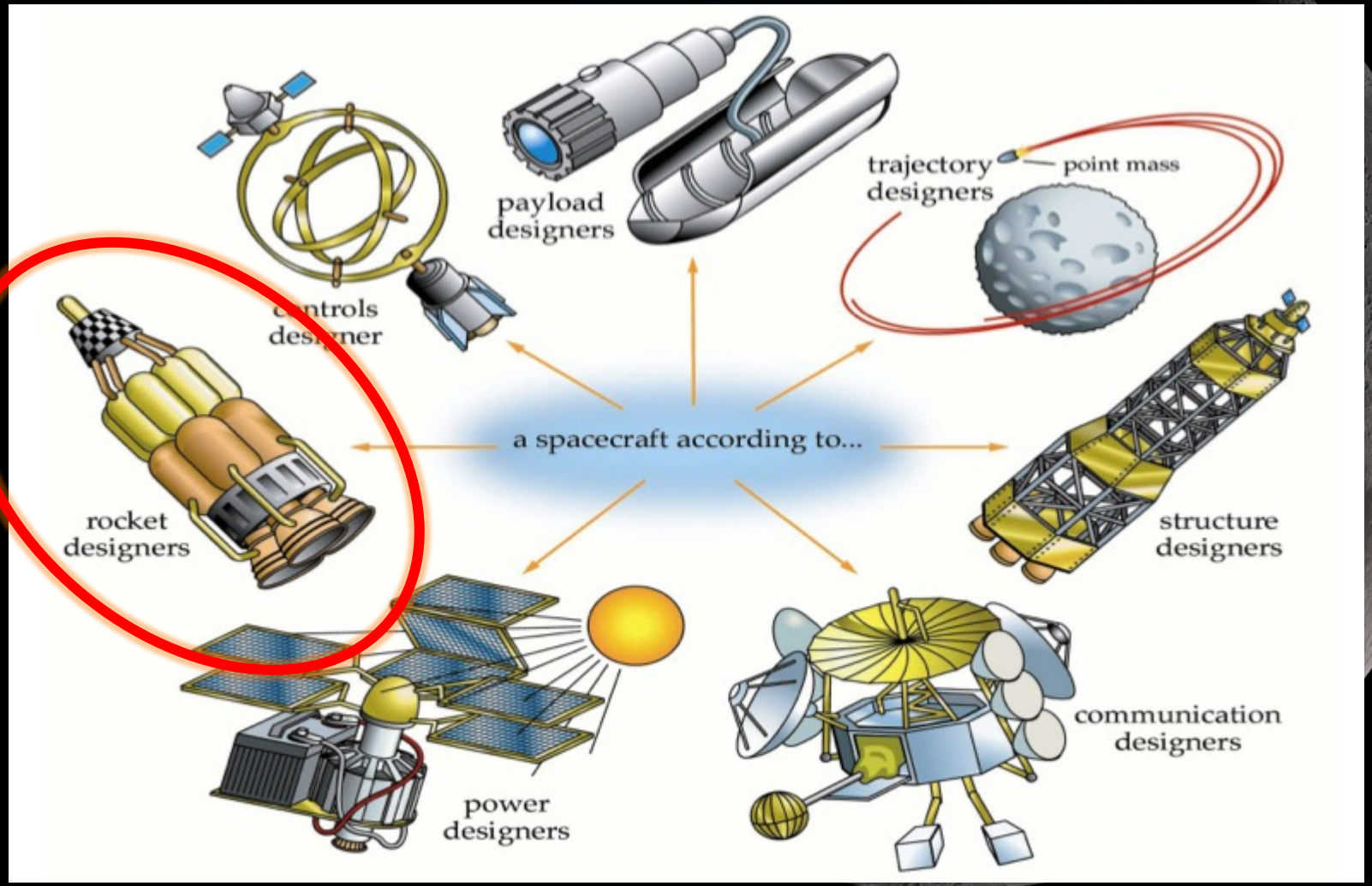

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Vacuum Raptor Cold Start Test – August 2023

Video Credit: SpaceX

BE-7 TCA Hotfire Test – March 2023

Video Credit: Blue Origin

Needless to say… I have the best job in the world

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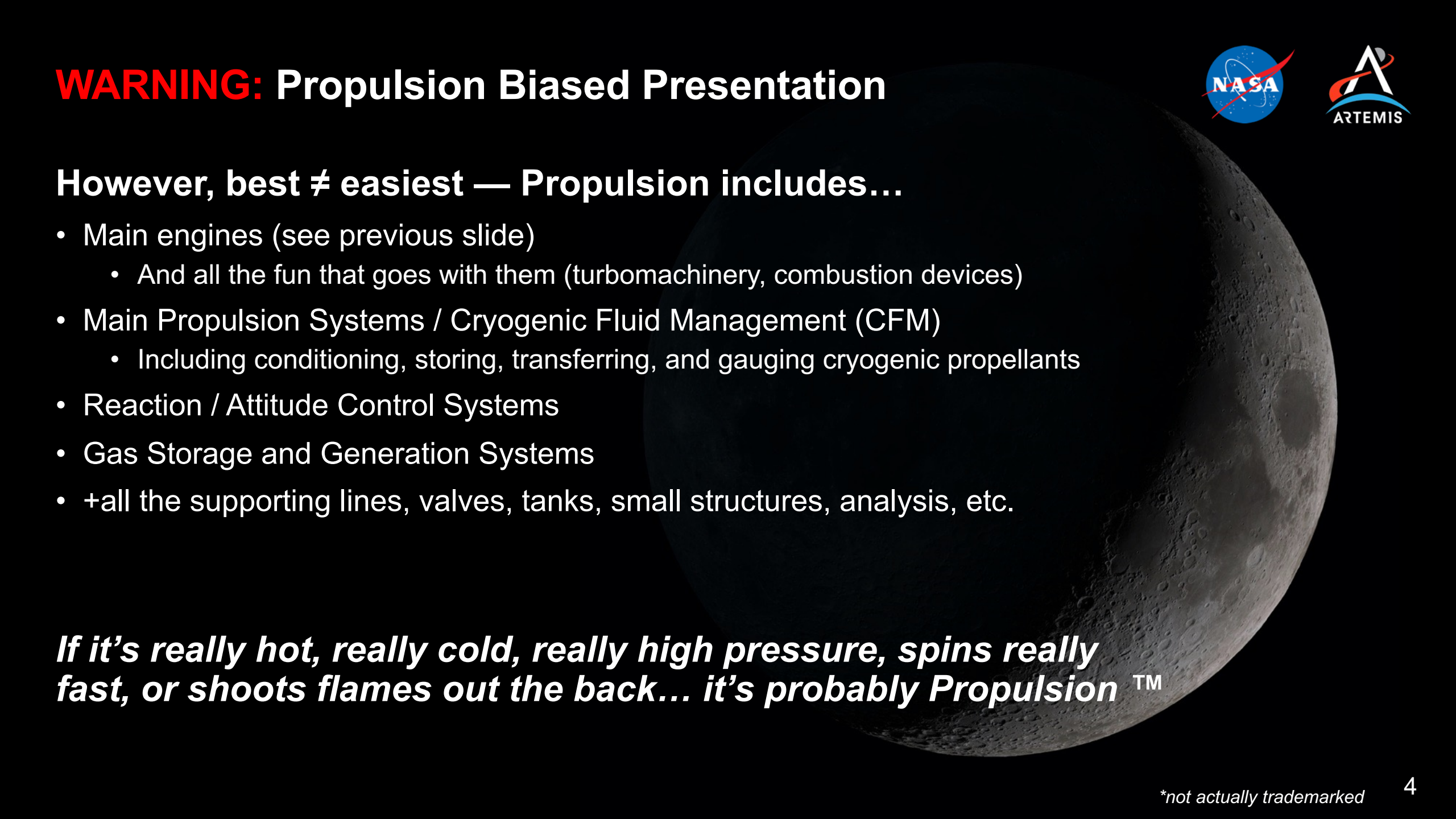


However, best ≠ easiest — Propulsion includes…

- Main engines (see previous slide)
  - And all the fun that goes with them (turbomachinery, combustion devices)
- Main Propulsion Systems / Cryogenic Fluid Management (CFM)
  - Including conditioning, storing, transferring, and gauging cryogenic propellants
- Reaction / Attitude Control Systems
- Gas Storage and Generation Systems
- +all the supporting lines, valves, tanks, small structures, analysis, etc.

If it's really hot, really cold, really high pressure, spins really fast, or shoots flames out the back… it's probably Propulsion ™

**not actually trademarked*

Human Landing System (HLS)

Objective – With SLS and Orion, return U.S. astronauts to the lunar surface for a sustained campaign of exploration and utilization

Goals (HLS-PLAN-001)

- Create a sustainable path to rapidly and safely get humans back to the moon
- U.S. Industry-led design, development, manufacture, and operation of lunar human landing systems
- Strengthen and utilize subject matter expertise of the NASA workforce critical to developing human-rated lander capabilities

Bottom Line: Get the moon and stay there with U.S. Industry

STARSHIP

Human Landing System (HLS)

NASA is working with SpaceX to develop its Starship Human Landing System for use on:

- Artemis III - the mission that will put the next two Americans on the surface of the Moon
- Artemis IV - which meets an extended set of requirements such as docking with Gateway for crew transfer, more mass to the surface, and longer mission durations

SpaceX will perform an uncrewed demonstration mission prior to the crewed Artemis III mission.

Image Credit: SpaceX

BLUE MOON

Human Landing System (HLS)

NASA is working with Blue Origin to develop a human landing system for use on:

- Artemis V – meets NASA's extended set of requirements such as docking with Gateway for crew transfer, more mass to the surface, and longer mission durations

Blue Origin will perform an uncrewed demonstration mission prior to the crewed Artemis V mission.

The team's approach consists of: **Blue Origin's** Blue Moon lander and **Lockheed Martin's** Cislunar Transporter along with partners:

- **Draper**
- **Boeing**
- **Astrobotic**
- **Honeybee Robotics**

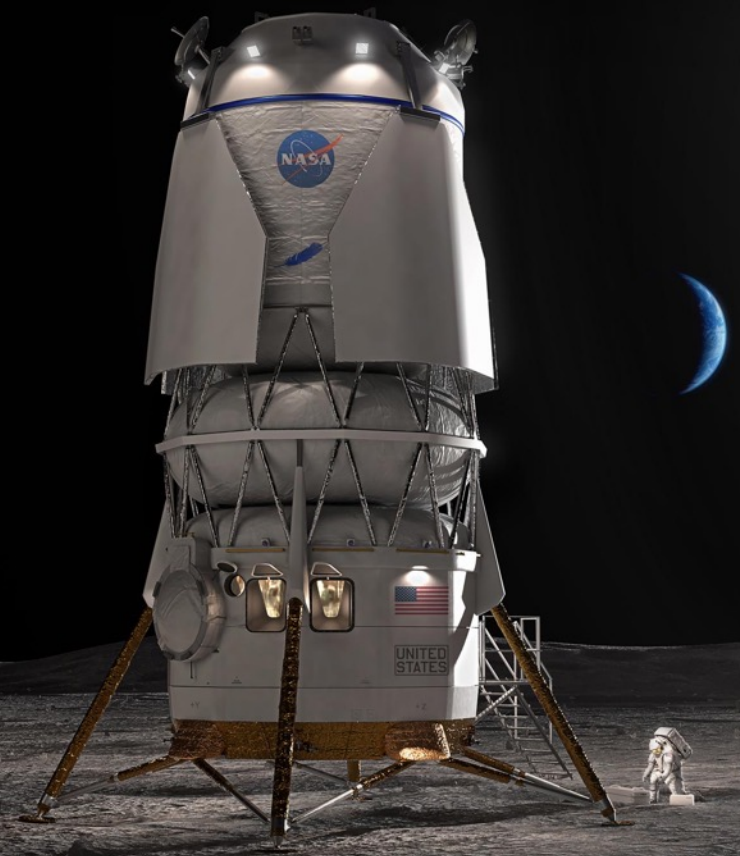


Image Credit: Blue Origin

How do we get from today…

… to here?

NASA Swim Lanes

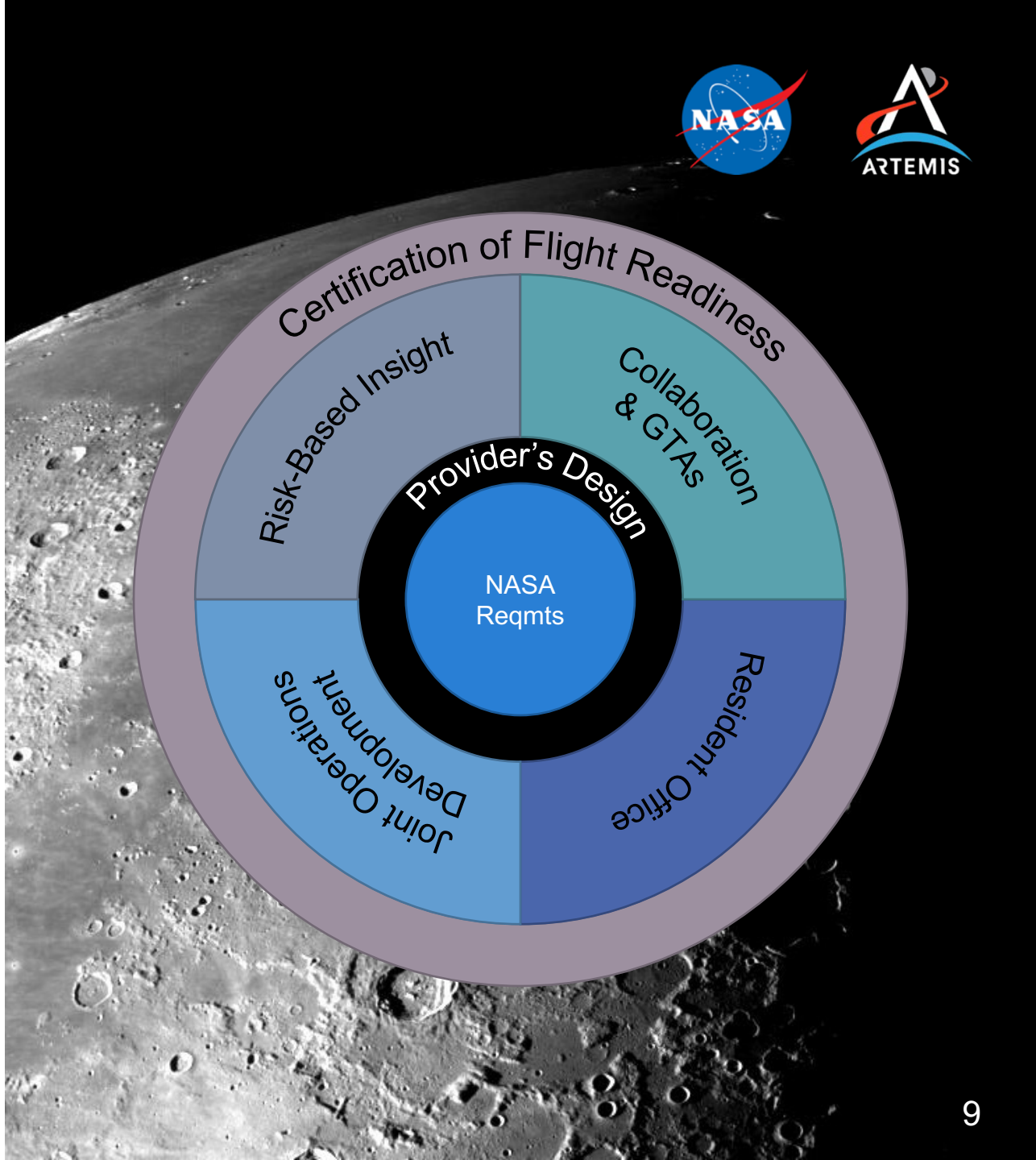
Insight

- Risk based focusing on targeted areas of program concern
- Ensures HLS resources are applied efficiently, and that Providers are not overly burdened by excessive insight activity in low risk areas

Collaboration

- Personnel that are assigned to work with the Provider and part of their team
- Accomplish tasks that are specified by the Provider, and deliverable to the Provider as in-line work

NASA maintains ultimate authority on certification of flight readiness.



Insight and Collaboration: A Sandwich Analogy

Mission: Serve astronauts a tasty sandwich

Oversight:

- Contractor A (Prime) shall integrate the elements per NASA Specification 999 and deliver to NASA to serve.
- Contractor B shall supply plain white Wonderbread per NASA Specification 123
- Contractor C shall supply oven-roasted sliced turkey per NASA Specification 456 … etc.
- NASA ensures compliance to all specifications and owns the sandwich and design

Insight and Collaboration: A Sandwich Analogy

Mission: Serve astronauts a tasty sandwich

Insight and Collaboration:

- Contractor D shall provide a tasty sandwich as a service and owns the sandwich design
- Sandwich design shall meet NASA / industry standards:
  - NASA-STD-5019 – *How to avoid bread fracture and crumbling for zero-g consumption*
  - SMC-S-016 – *Testing requirements for meat and cheese sandwiches and sub-components*
  - NASA-HMTA-123 – *Astronaut taste preferences and guidelines for sub-sandwiches*
- NASA ensures compliance to standards on a risk-driven basis (**Insight**)
  - *Ex: Contractor D proposes a change to rye bread—NASA experience says this is a high risk (see NASA-STD-5019)*
- NASA provides sandwich experts as needed to perform in-line work (**Collaboration**)
- NASA approves sandwich design certification and consumption readiness (**Insight**)

How do you make Insight and Collaboration work?

Start with robust historical experience supporting **good people** and **good capabilities**

As part of the NASA-wide HLS team, Marshall Space Flight Center (MSFC) **history, people, and capabilities** help move us towards the Moon

MSFC People and Capabilities

- **Propulsion Engineering (People):**
  - Liquid Systems Design, Development, and Integration
  - Propulsion Structural, Thermal and Fluids Analysis
  - Solid Propulsion Systems
  - Thrust Vector Control
  - Advanced Propulsion Development
  - Support many programs: ISS, CCP, SLS, HLS, Draco, MAV...

- **Manufacturing and Test (Capabilities):**
  - Test stands for any individual component or subsystem
  - Hydrogen Cold Flow Facility
  - Test Stand 300 – Vacuum Test Facility
  - Advanced materials and manufacturing labs
  - Space Env. Effects and Lunar Env. Testing
  - Docking and Rendezvous Testing
  - Structural and Dynamics Testing
  - In-Space Cryogenic Prop Transfer Development

Rotating Detonation Rocket Engine (RDRE) Testing at MSFC Test Stand 115

MSFC Exploration Systems Test Facility 9' Vacuum Chamber, CFM Testing Facility

MSFC Propulsion Industry Collaboration

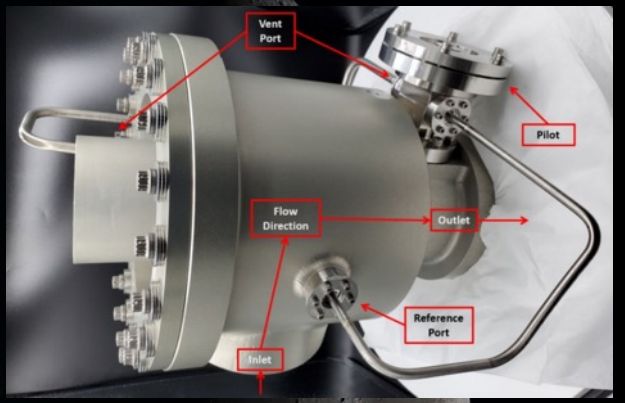
Working together to develop key technologies and analyze difficult technical challenges to ensure successful lunar exploration missions

Engine Systems and RCS

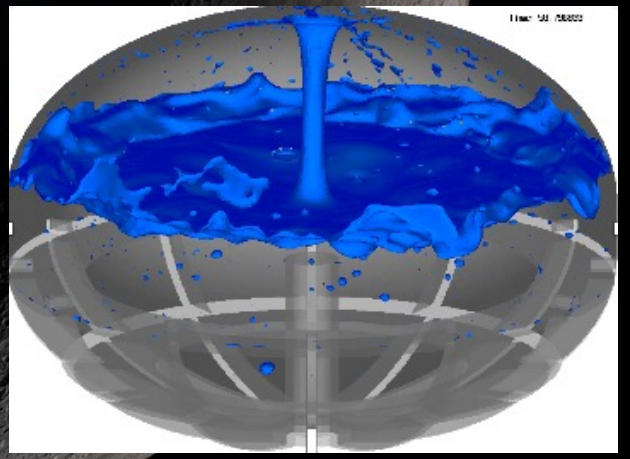
- Turbomachinery and Combustion Devices expertise sharing
- Transient and steady state engine performance modeling
- Plume Surface Interaction (PSI) lessons learned and modeling assistance
- Thrust Vector Control (TVC) verification and certification lessons learned
- Reaction Control Systems (RCS) design, development, and test lessons learned

Cryogenic Fluid Management and Prop Transfer

- Cryogenic valve leakage analysis and testing, and low leakage valve design
- Thermal analysis of cryogenic propulsion systems
- Lessons learned from previous CFM projects at MSFC, GRC, and KSC
- CFM modeling leveraging extensive NASA experience and expertise
- Models of propellant transfer operations
- STMD CFM Portfolio Projects – Tipping Point flight tests & cryocooler development



NASA MSFC Internal Low Leakage Relief Valve (LLRV) Development Article



NASA MSFC ER42 CFD Simulation of Tank Slosh

HLS Propulsion Insight

Leveraging the best of NASA's propulsion and fluids technical community to understand Commercial Provider designs and processes and inform Program stakeholders

Starts with a great team—led by MSFC with support across NASA centers

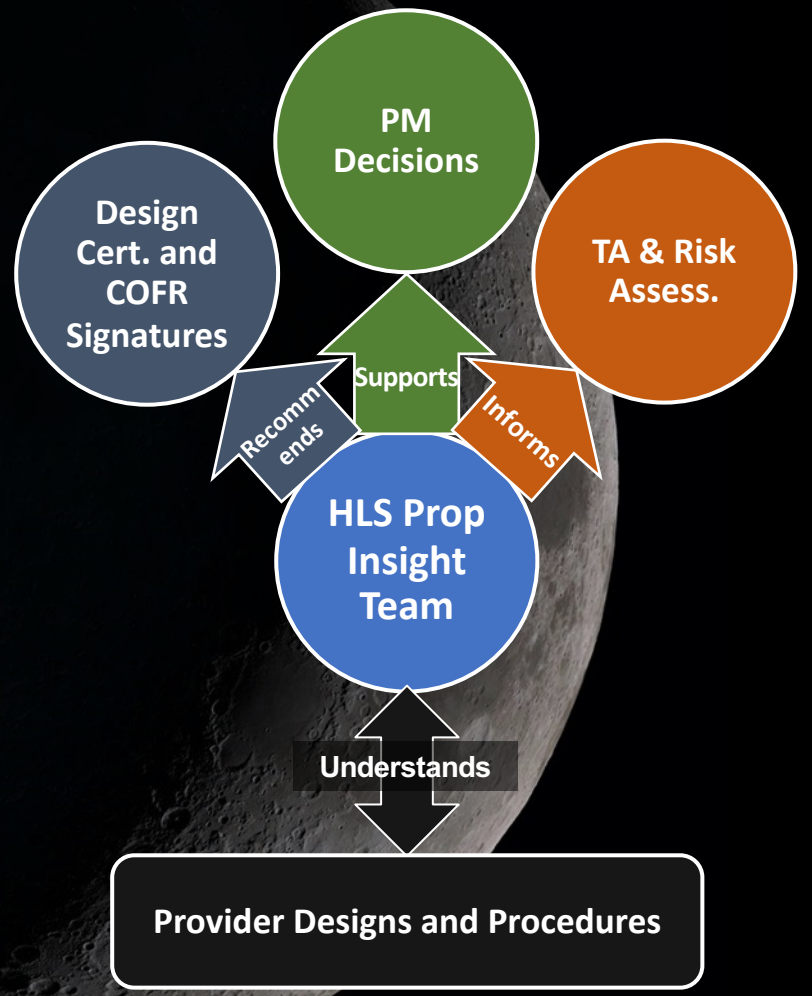
- Deeply technical and disciplined team of engineers committed to the lunar mission

Focused insight justified by risk to understand provider designs

- Use risk-based analysis to justify deeper insight in targeted areas
- e.g., Engines, CFM

Use the understanding to inform the Program by:

- Providing expert propulsion insight and analysis to support Program Management (PM) and Technical Authority (TA) risk assessments and real-time mission support
- Providing expert propulsion design, certification, and flight hardware reviews to support Design Certification and Certification of Flight Readiness (COFR)



To summarize, NASA has:

- **Goals** – land on the Moon and stay
- **Partners** – U.S. industry designing and building vehicles
- **Methods** – insight and collaboration with partner operation
- **People** – deep technical bench committed to the lunar mission
- **Capabilities** – extensive manufacturing, test, and analysis

What's next?

Human Landing System Plans for 2024

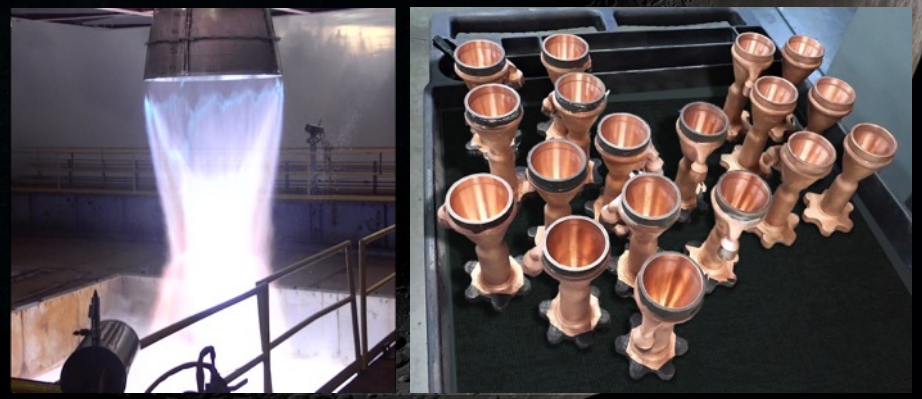
SpaceX Starship HLS

- Additional flight tests
- Pad(s) development
- Start large cargo lander work
- Interface work with Orion & Suits

Blue Origin Blue Moon HLS

- Preliminary Design Review
- Additional engine testing
- Start large cargo lander work
- Interface work with Gateway & Suits

Second Integrated Flight Test – November 2023



BE-4 Hotfire Test – February 2024
Blue Moon GH2/GOX RCS Thrusters

Artemis I

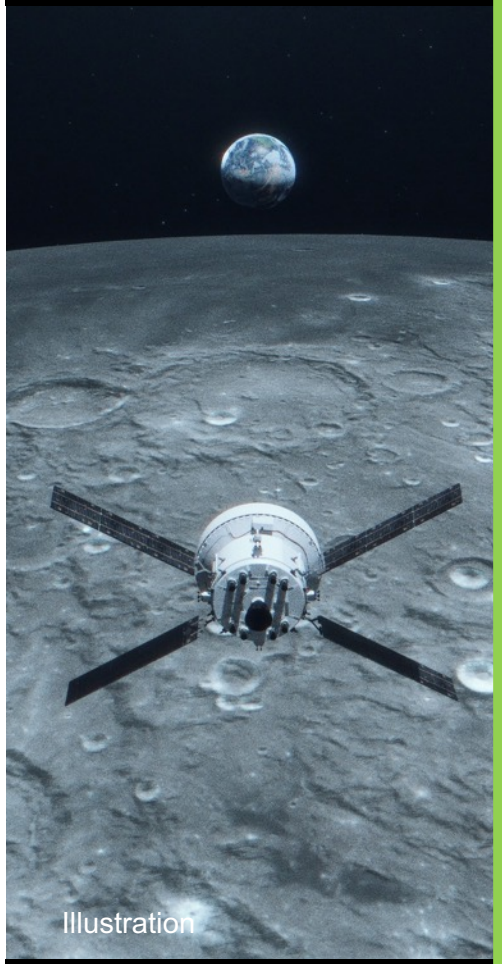
Uncrewed flight test

COMPLETE

SLS, Orion, EGS

Artemis II

Crewed flight test



SLS, Orion, EGS

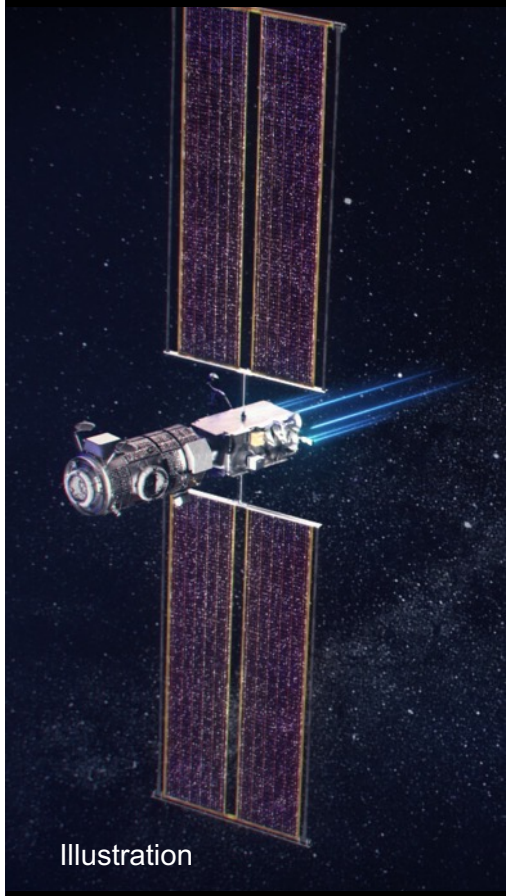
Artemis III

Crewed surface expedition

SLS, Orion, EGS, HLS, EHP

Artemis IV

Gateway assembly, crewed sustaining lander expedition



SLS, Orion, EGS, HLS, EHP, Gateway *(PPE/HALO, I-HAB)*

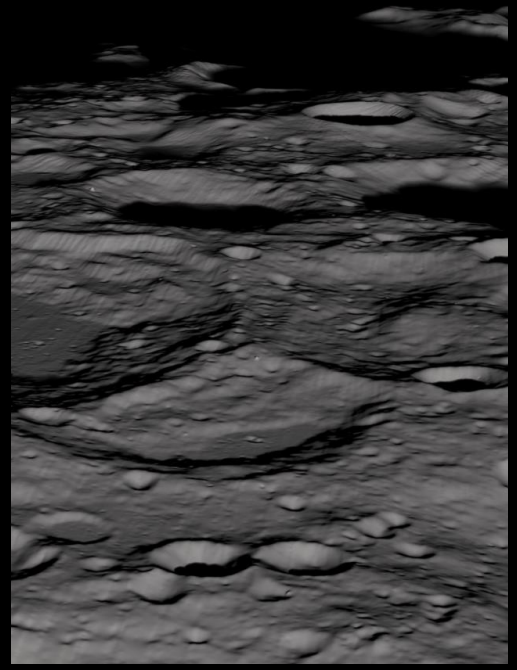
Artemis V

Crewed mobile surface exploration, Gateway expansion

SLS, Orion, EGS, HLS, EHP, LTV, Gateway (*ESPRIT, Canadarm3*)

HLS Uncrewed Demo

SpaceX Starship



Artemis III

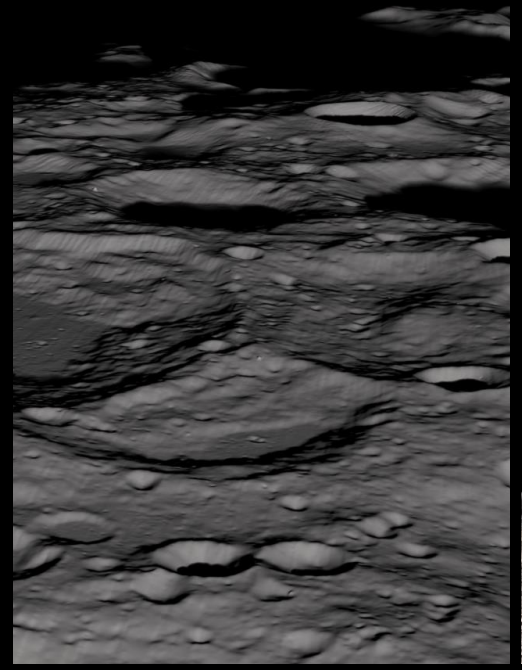
SpaceX Starship

Artemis IV

SpaceX Starship

HLS Uncrewed Demo

Blue Origin
Blue Moon



Artemis V

Blue Origin
Blue Moon


Follow the missions
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