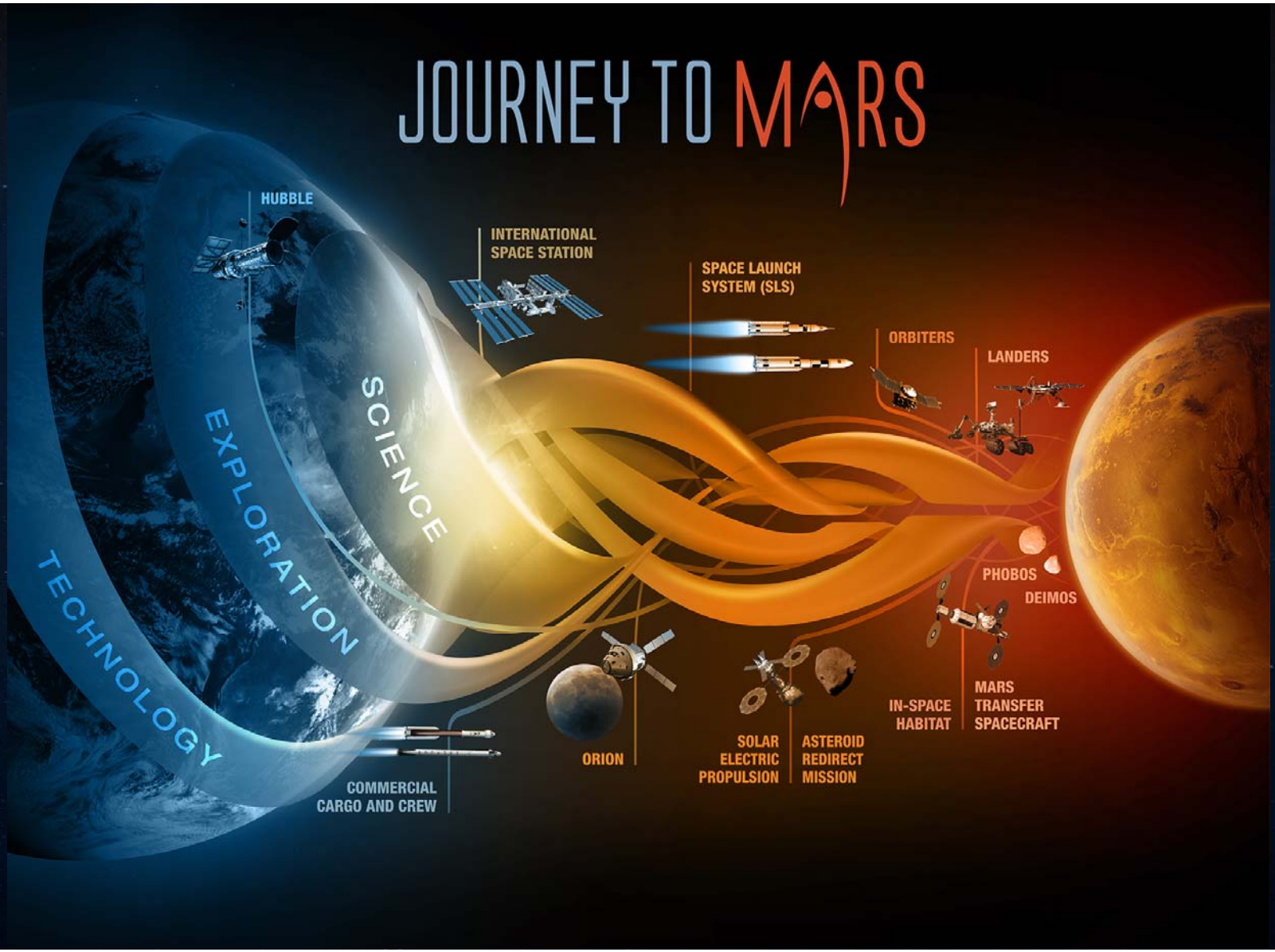
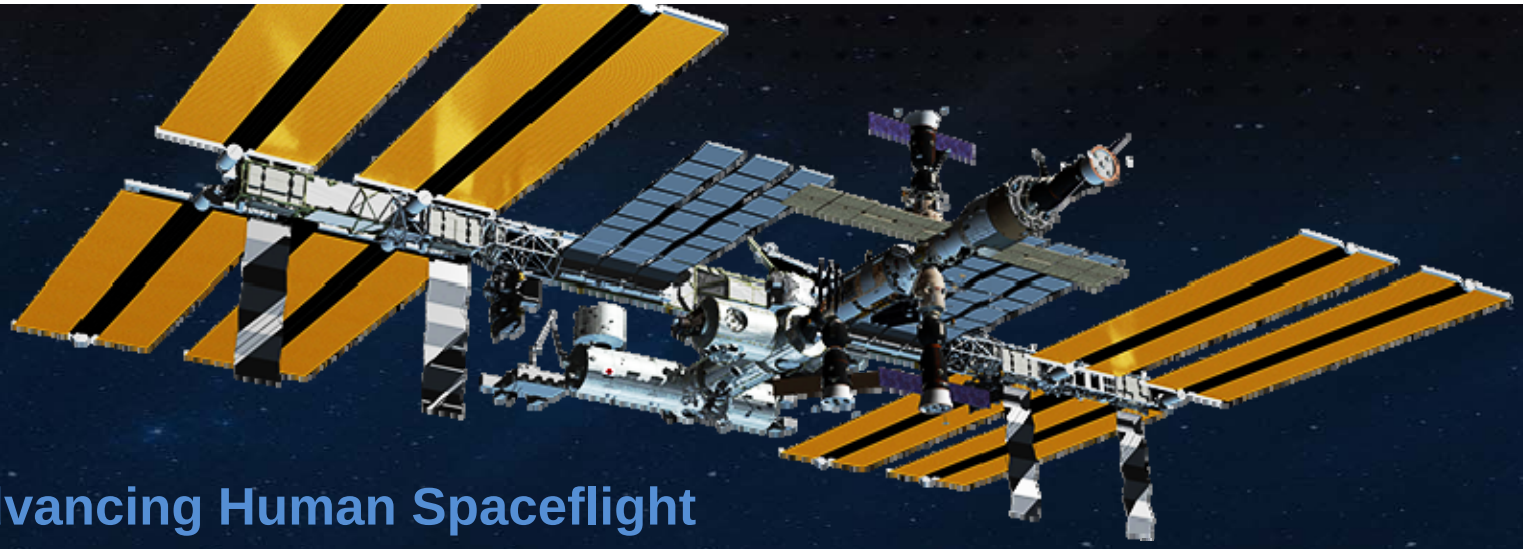
COMMERCIAL CREW PROGRAM

Rick Russell

June 22, 2015


JOURNEY TO MARS
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
IN-SPACE HABITAT
MARS TRANSFER SPACECRAFT
ORION
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
COMMERCIAL CARGO AND CREW



Advancing Human Spaceflight

The vision of commercial human spaceflight to low-Earth orbit is a robust, vibrant enterprise with many providers and a wide range of private and public users. A successful human space transportation system will strengthen the International Space Station Program, allow NASA to focus on deep-space exploration, potentially reduce the cost of human access to space and significantly contribute to the national economy. NASA's Commercial Crew Program serves two purposes:

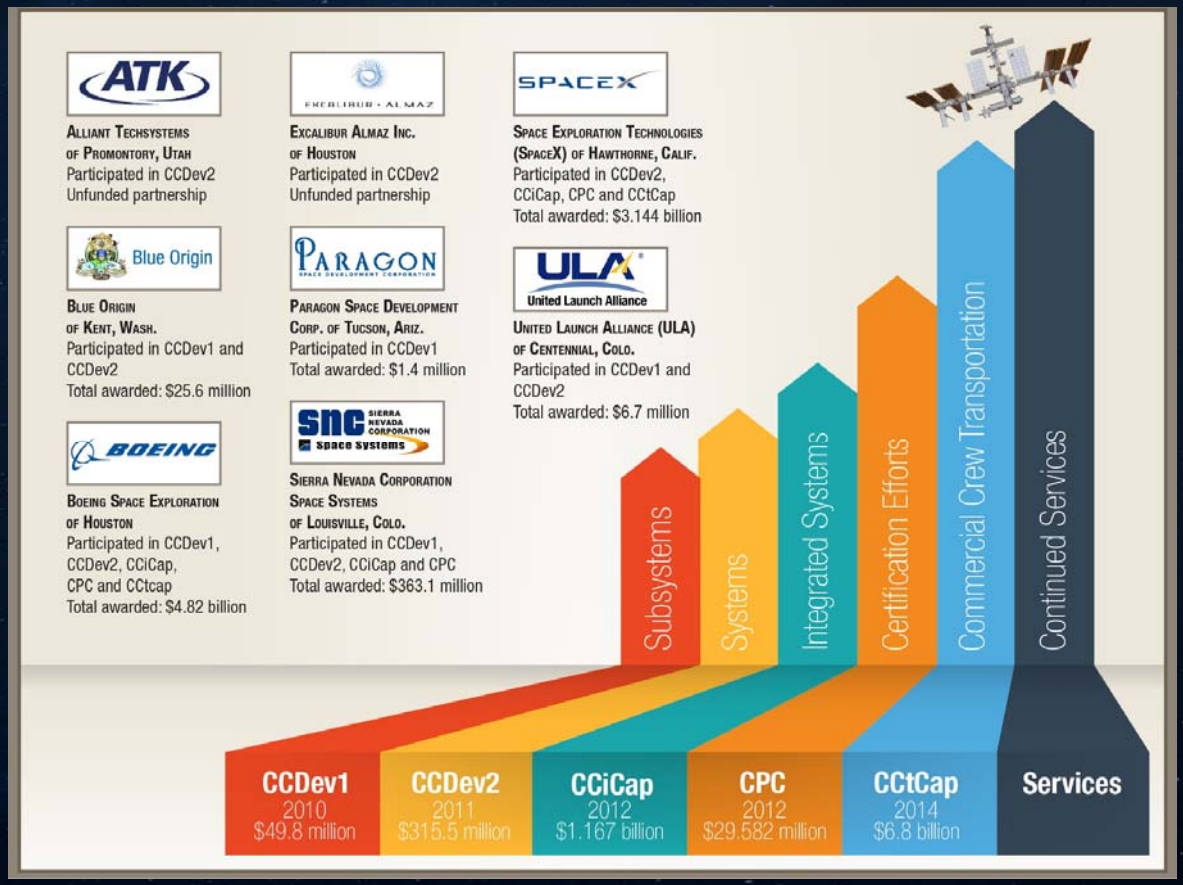
Public Purpose

Support the development of non-NASA markets for commercial human transportation services to and from low-Earth orbit.

NASA Purpose

Safe transport of NASA and NASA-sponsored astronauts to and from the station.

COMMERCIAL CREW EVOLUTION



PUBLIC PURPOSE

Development Work Through Space Act Agreements

Invest in System, Subsystem and Integrated Capabilities:

- Overall spacecraft and launch vehicle
- Launch abort systems
- Environmental control and life support development
- Launch vehicle emergency detection systems
- Thermal protection systems
- Rocket motor development and testing
- Parachute testing
- Pressure vessel testing
- Integrated system development
- Ground, orbital and recovery operations
- Significant development milestones
- Began the partnership with the FAA

PUBLIC PURPOSE

Development Work Through Space Act Agreements

Blue Origin (CCDev2):

- Pusher Escape In-Flight Escape Demonstration Data Review
- Flight Demonstration of BE-3 Engine
- Flight Demo of Subscale Propellant Tank Assembly

Boeing (CCiCap):

- All milestones complete

Sierra Nevada Corporation (CCiCap):

- ETA Flight Testing #2
- Design Analysis Cycle-6 Closeout Review

SpaceX (CCiCap):

- Pad Abort Test
- Dragon Primary Structure Qualification – Hatch Open Test
- Delta Crew Vehicle Critical Design Review
- In-Flight Abort Test

NASA PURPOSE

The Path to NASA Certification and Flights

Certification Products Contracts (CPC):

- Enabled NASA and industry to have a dialogue on what would be required for certification
- Promoted the delivery, technical interchange and NASA disposition of early lifecycle certification products with Boeing, Sierra Nevada Corporation and SpaceX

Commercial Crew Transportation Capability (CCtCap):

- Built with industry to advance American human spaceflight and support both the public and NASA's needs
- Lays the foundation for NASA to acquire commercially provided crew transportation services to and from the International Space Station from Boeing and SpaceX

NASA PURPOSE

The Path to NASA Certification and Flights

CCtCap contracts were awarded to Boeing and SpaceX for the final development and certification of integrated crew transportation systems. Under the contracts, there are 10 required milestones.

NASA's Certification Milestones:

- Certification Baseline Review
- Design Certification Review
- Flight Test Readiness Review
- Operational Readiness Review
- Certification Review

NASA's Mission Milestones:

- Vehicle Baseline Review
- Mission Integration Review
- Mission Certification Review
- Flight Readiness Review
- Post Flight Review

Boeing and SpaceX also proposed their own interim development milestones and activities.

BOEING

SPACEX

NASA PURPOSE

The Path to NASA Certification and Flights

Boeing's Progress:

- More than 150 pieces of hardware are inside the modernized Orbital Processing Facility 3 at NASA's Kennedy Space Center.
- Human-rating of Space Launch Complex-41 at Cape Canaveral Air Force Station is underway. Boeing and United Launch Alliance broke ground on the crew access tower in February 2015. Segments of the tower are being built near the launch pad and installed in between Atlas V launches.
- NASA astronauts continue to conduct testing in Boeing's CST-100 mock-up and flight simulator in Houston.
- The CST-100 crew and service modules will be mated in mid-2015 for testing.
- The Atlas V vehicles are being readied for flight tests.
- Boeing will conduct a pad abort test in early 2017, followed by unmanned and manned flight tests to the station in 2017.

NASA PURPOSE

The Path to NASA Certification and Flights

SpaceX's Progress:

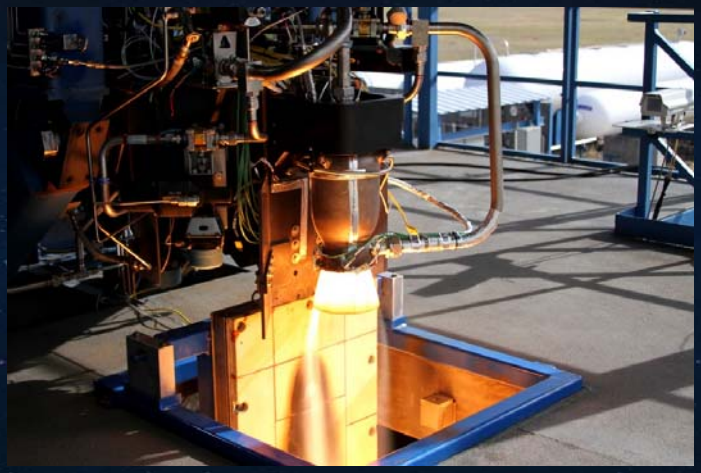
- SpaceX is modifying Launch Pad 39A at NASA's Kennedy Space Center. A 300-foot-long horizontal hangar is being built at the base of the pad to process the Crew Dragon spacecraft and Falcon 9 rocket.
- NASA astronauts continue to conduct tests in the Crew Dragon spacecraft in Hawthorne, California.
- SpaceX conducted a pad abort test from Space Launch Complex 40 at Cape Canaveral Air Force Station in May 2015.
- An in-flight abort test is targeted for later 2015 from Vandenberg Air Force Base in California.
- An unmanned flight test of the Crew Dragon and Falcon 9 system is planned for late 2016, followed by a manned flight test in early 2017.

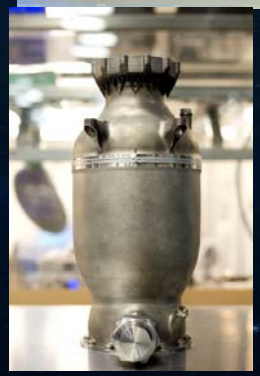
Additive Manufacturing Applications SpaceX

- SpaceX has been evaluating the benefits of additive manufacturing and developing flight hardware
- On January 6, 2014 a Falcon 9 rocket launched with a 3D printed Main Oxidizer Valve (MOV) Body in one of the nine Merlin 1D engines.
- The original MOV was made from a cast part. The new printed part was determined to have superior strength, ductility, and fracture resistance, with a lower variability in materials properties.

Additive Manufacturing Applications SpaceX

- In partnership with NASA's Commercial Crew Program, SpaceX produced SuperDraco engine chambers for the Crew Dragon spacecraft.
- A successful hot fire was performed in late 2013 using a 3-D printed chamber developed entirely in-house.
- SuperDraco engines will be used for both the launch escape system, producing up to 120,000 pounds of axial thrust. The engines also will be part of the company's planned propulsive landing system.
- Eight SuperDraco engines were successfully fired during the company's recent Pad Abort Test.





Additive Manufacturing - Path to Certification

Current NASA Standards for Manned Space Hardware:

- NASA-STD-6016 – Standard Materials and Processes Requirement for Spacecraft
- NASA-STD-5012 – Strength and Life Assessment Requirements for Liquid-Fueled Space Propulsion System Engines
- NASA-STD-5019 – Fracture Control Requirements for Spaceflight Hardware

- These NASA Standards utilize both NASA internal and industry standards, none which are specific for Additive Manufacturing
  - AWS D17.1 Fusion Welding for Aerospace Applications
  - SAE AMS 2175 Classification and Inspection of Castings
  - SAE AMS 4985 Ti-6-4 Investment Castings
  - All of these documents call for a conservable collection of “applicable documents”

Additive Manufacturing standards are currently very limited

- Universal challenge – not just NASA
- Standard development being done mainly by ASTM Committee F42 on Additive Manufacturing
- Other standard organizations are also working on AM Standards
  - SAE AMS, AWS etc.

NASA has a current need for Additive Manufacturing standards

- NASA needs to develop requirements to balance AM opportunities and risks
- **NASA’s goal is to certify the Boeing and SpaceX commercial crew transportation systems in 2017**

Additive Manufacturing - NASA Approach

Develop a Center-level requirements document:

- Allows for a more timely release
- Allows for a wider review cycle
  - NASA Centers
  - NESC
  - Partners (SpaceX, Aerojet-Rocketdyne, Lockheed Martin)
  - Industry (GE, Honeywell)
  - Certifying Agencies (FAA, USAF)
- Current plan is to revise as needed/levy as required
- Will watch progress of standards organizations and other certifying agencies
- Will incorporate AM requirements at an appropriate level in agency specifications

Key topics in draft AM requirements

- Tailoring
- Governing Standards
- AM Design
- Part Classification
- Structural Assessment
- Fracture Control
- Qualification Testing
- Part Development Plans
- Process Controls
- Material Properties
- Finishing, Cleaning, Repair Allowances
- Part Inspection and Acceptance

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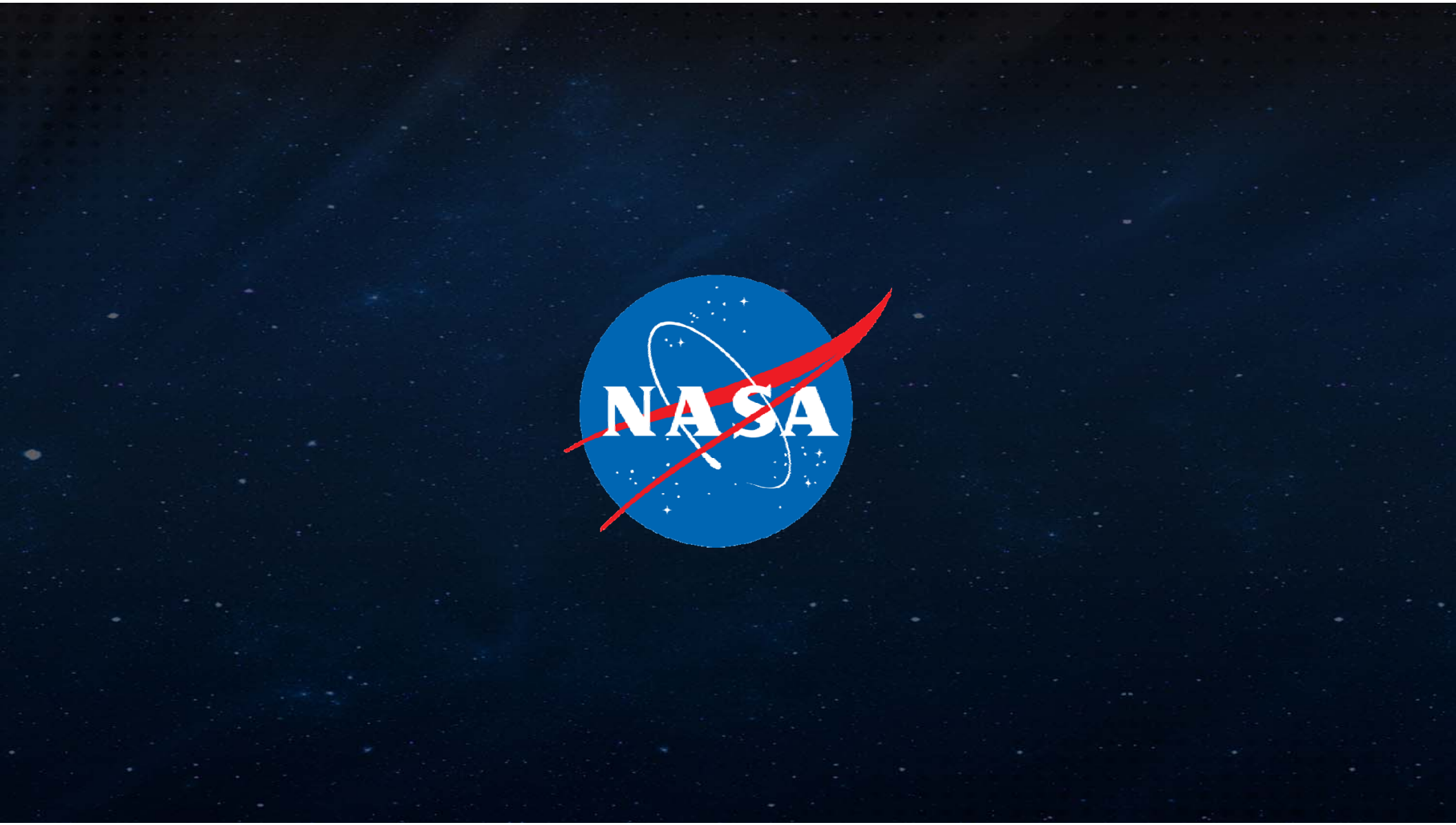
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