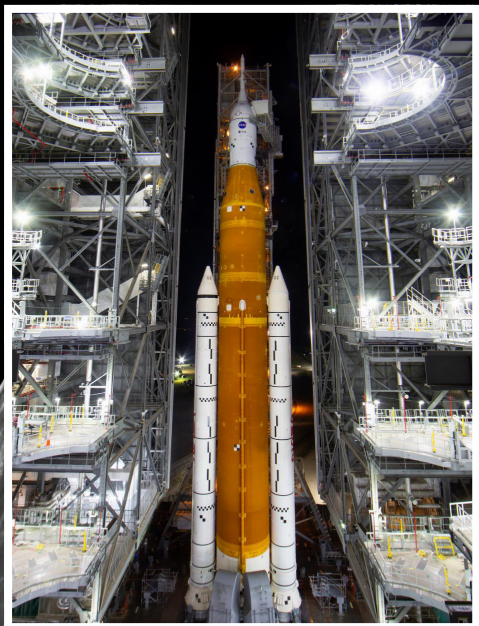
National Aeronautics and Space Administration



Heavy Lifting

A Lesson in Engineering

engineering is out of this world

Next Generation Science Standards

MS-PS2 – Motion and Stability: Forces and Interactions

STANDARD: MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of an object.

DISCIPLINARY CORE IDEA: MS-PS2.A. The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.

CROSS-CUTTING CONCEPTS: Cause and Effect, Systems and Models, Influence of Science

MS-ETS1 – Engineering Design

STANDARD: MS-ET1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

STANDARD: MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

DISCIPLINARY CORE IDEA: ETS1.B. A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.

DISCIPLINARY CORE IDEA: ETS1.C. Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.

CROSS-CUTTING CONCEPTS: Engineering and Technology on Society and the Natural World

Common Core State Standards – Mathematics

MP.2 – Reason Abstractly and Quantitatively

6.EE.A.2. Write, read and evaluate expressions in which letters stand for numbers.

7.EE.B.4. Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities.

Artemis

With NASA's Artemis campaign, we are exploring the Moon for scientific discovery, technology advancement, and to learn how to live and work on another world as we prepare for human missions to Mars. We will collaborate with commercial and international partners and establish the first long-term presence on the Moon.

America's Rocket for Deep Space Exploration

NASA's SLS (Space Launch System) is a super heavy-lift rocket that provides the foundation for human exploration beyond Earth orbit. With its unprecedented capabilities, SLS is the only rocket that can send NASA's Orion spacecraft, four astronauts, and large cargo directly to the Moon on a single mission.

Offering more payload mass, volume, and departure energy than any other single rocket, SLS can support a range of mission objectives, while reducing mission complexity. The SLS rocket is designed to be evolvable, which makes it possible to increase its capability to fly more types of missions, including human missions to the Moon and Mars and robotic scientific missions to the Moon, Mars, and the outer planets.

SLS is designed for deep space missions and will send Orion or other cargo to the Moon, which is nearly 1,000 times farther than where NASA's International Space Station resides in low Earth orbit. The high-performance rocket provides the power to help Orion reach a speed of 24,500 mph—the speed needed to send it to the Moon.

The Power to Explore Beyond Earth's Orbit

To fulfill America's future needs for deep space missions, SLS will evolve into increasingly more powerful configurations.
SLS is designed for deep space missions and will send Orion or other cargo to the Moon, which is nearly 1,000 times farther than where NASA's International Space Station resides in low Earth orbit. The high-performance rocket provides the power to help Orion reach a speed of 24,500 mph—the speed needed to send it to the Moon.

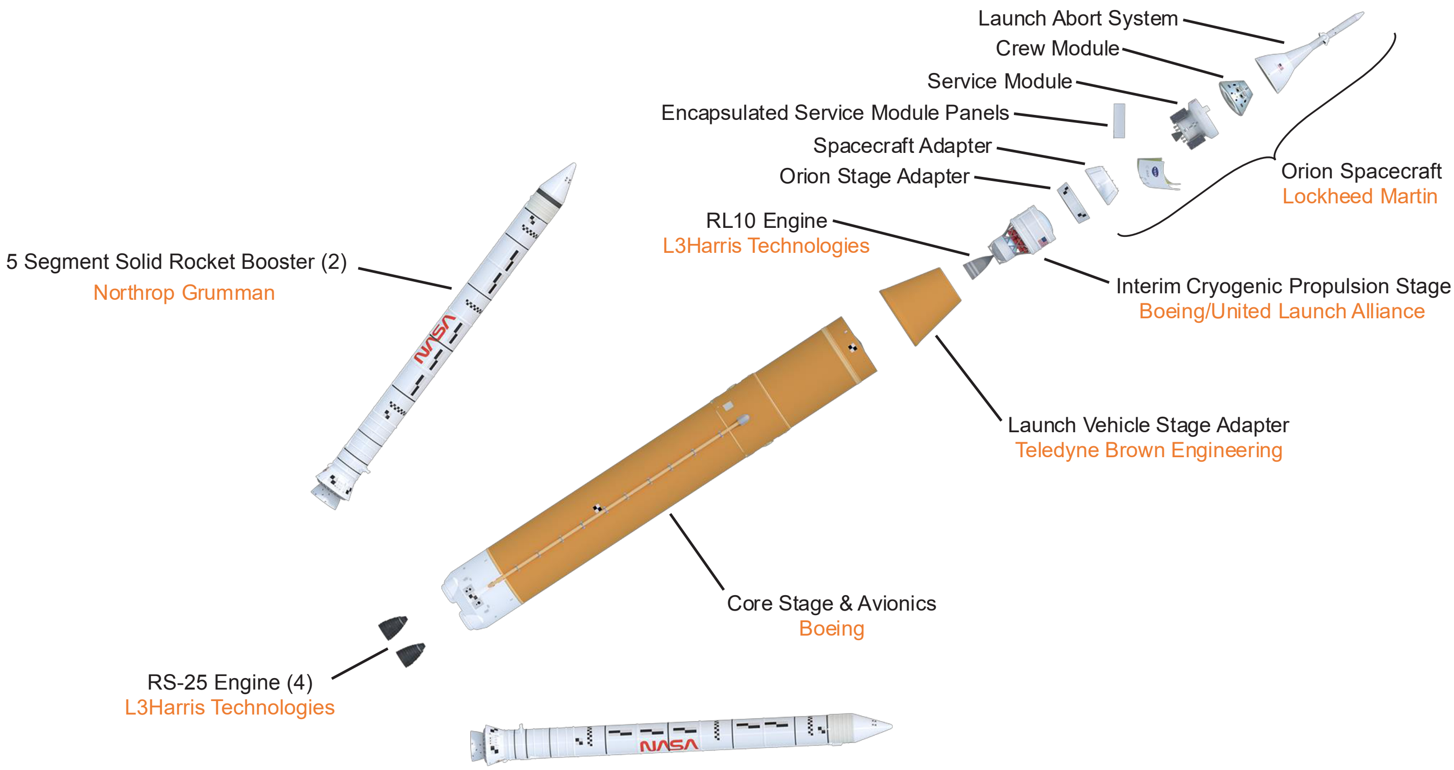
The first SLS variant, called Block 1, can send more than 27 metric tons (t) or 59,500 pounds (lbs.) to the Moon. It is powered by twin five-segment solid rocket boosters and four RS-25 liquid propellant engines generating 8.8 million lbs. After reaching space, the interim cryogenic propulsion stage (ICPS) helps send Orion on to the Moon. Like Artemis I, the SLS rockets that will power Artemis II and III will use the Block 1 configuration.

The next planned evolution of the SLS, the Block 1B crew vehicle, will use a new, more powerful upper stage to enable more ambitious missions. The Block 1B rocket can, in a single launch, carry the Orion spacecraft along with large cargos needed to support a long-term presence on the Moon.

The Block 1B rocket can send 38 t (84,000 lbs.) to deep space, including Orion and its crew. Launching with cargo only, SLS has a large volume payload fairing to send larger exploration systems to the Moon and Mars or robotic science probes on solar system exploration missions.

The final SLS configuration, Block 2, will provide 9.4 million lbs. of launch thrust, compared to the Block 1's 8.8 million lbs. and will be the workhorse vehicle for sending cargo to the Moon, Mars, and other deep space destinations. SLS Block 2 will be designed to lift up to 46 t (101,000 lbs.) to deep space. An evolvable design provides the nation with a rocket able to pioneer new human and robotic spaceflight missions.

Block 1 – Initial SLS Configuration



Artemis I

Artemis I was the first in a series of increasingly complex missions to build a long-term human presence at the Moon that will enable future crewed missions to Mars. Artemis I launched Nov. 16, 2022, from NASA's Kennedy Space Center in Florida. The Orion spacecraft splashed down off the coast of California Dec. 11, 2022.

The primary goals for Artemis I were to demonstrate Orion's systems in a spaceflight environment and ensure a safe re-entry, descent, splashdown, and recovery prior to the first flight with crew.

The Artemis I test flight was a success and proved that SLS was ready for crewed flight.

Artemis I Launch

Core Stage

The SLS core stage is the tallest stage NASA has ever built. Towering 212 feet with a diameter of 27.6 feet, it stores cryogenic liquid hydrogen and liquid oxygen and all the systems that will feed the stage's four RS-25 engines. It also houses the flight computers and much of the avionics needed to control the rocket's flight. The core stage is designed to operate for approximately 500 seconds before reaching low Earth orbit and separating from the upper stage and NASA's Orion spacecraft.

Boeing, the prime contractor for the SLS core stage, uses state-of-the-art manufacturing equipment, including a friction-stir welding tool that is the largest of its kind in the world, to build the stage at NASA's Michoud Assembly Facility in New Orleans. The SLS avionics computer software is being developed at NASA's Marshall Space Flight Center in Huntsville, Alabama.

SLS Core Stage with RS-25 Engines

RS-25 Engines

NASA's SLS (Space Launch System) core stage is powered by RS-25 engines that combine proven performance with advanced engineering and technology. The SLS rocket has four RS-25 engines fueled by liquid hydrogen and liquid oxygen. The four engines provide about 2 million lbs. of thrust for the eight-minute climb to Earth orbit.

The SLS Program began with an inventory of 16 RS-25 flight engines – built by L3Harris Technologies – transferred from the shuttle program. During the Space Shuttle Program, the RS-25 underwent several design updates to improve service life, durability, reliability, safety, and performance. SLS takes advantage of that technology investment and experience and builds on it using contemporary technologies and processes to improve manufacturability, affordability, and performance.

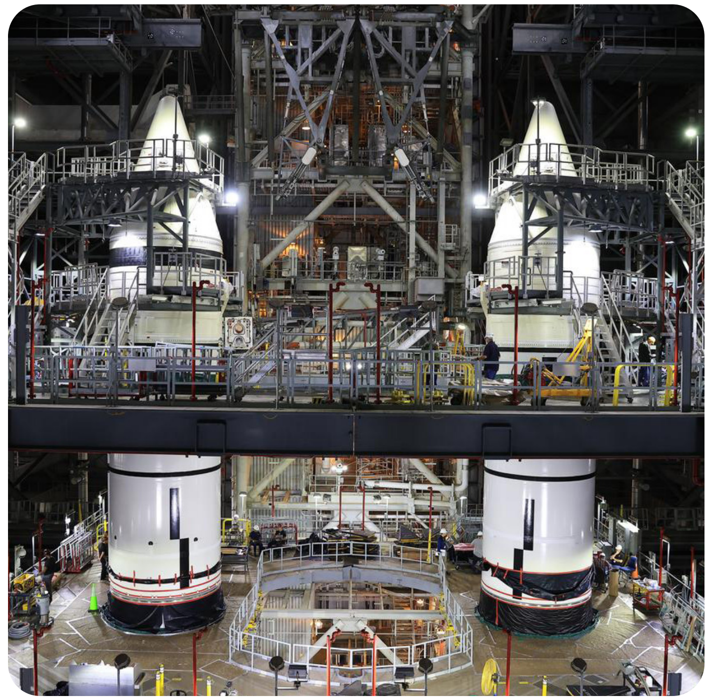
L3Harris is producing 24 new RS-25 engines. The new engines will use a simplified design, new manufacturing technologies, new inspection technologies, and processes that reduce handling and support labor, hardware defects, and production time.

Boosters

The SLS boosters, manufactured by prime contractor Northrop Grumman and based on the space shuttle solid rocket boosters, are the largest, most powerful solid propellant boosters ever built for flight. Each 5-segment booster is 177 ft. tall, 12 ft. in diameter, and weighs 1.6 million lbs. when filled with solid propellant.

Burning approximately six tons of propellant every second, each booster generates more thrust than 14 four engine jumbo commercial airliners. Together, the twin SLS boosters provide more than 75 percent of the total SLS thrust at launch.

The boosters are the first SLS element stacked on the mobile launcher. On the launch pad, the boosters carry the entire weight of the fueled SLS rocket. After launch, the boosters operate for about two minutes before separating from the core stage and landing in the Atlantic Ocean.

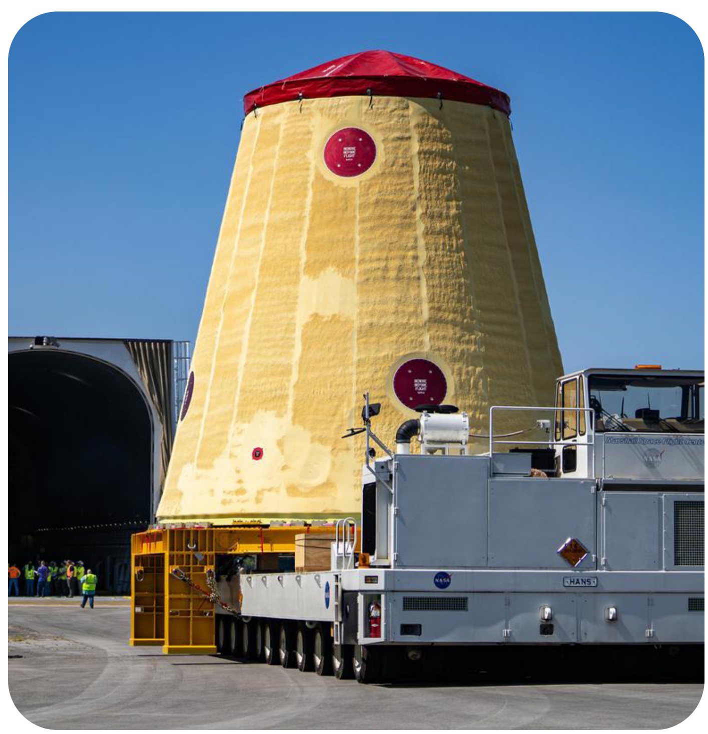


Stacking of Artemis II Booster Nose Cones

Launch Vehicle Stage Adapter

The cone-shaped launch vehicle stage adapter connects the interim cryogenic propulsion stage to the SLS core stage for the first three Artemis flights. Prime contractor Teledyne Brown Engineering manufactures this stage using self-reacting friction-stir welding tools at NASA's Marshall Space Flight Center in Huntsville, Alabama.

During launch and ascent, the adapter provides structural support and protects avionics and electrical devices within the interim cryogenic propulsion stage from extreme vibrations and acoustic conditions. Approximately 500 seconds into flight, a frangible joint assembly at the top of the adapter instantaneously separates the launch vehicle stage adapter and core stage from the upper part of the rocket.

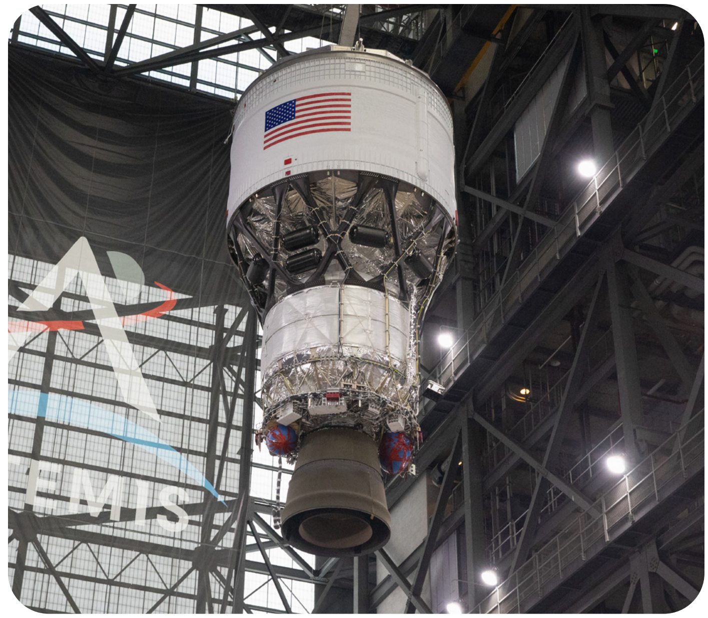


Launch Vehicle Stage Adapter

Interim Cryogenic Propulsion Stage

The SLS cryogenic propulsion stage is an in-space rocket stage that provides propulsion to the Orion spacecraft during the first three Artemis missions. Measuring 45 ft. tall and 16.7 ft. in diameter, this stage provides in-space propulsion after the SLS solid rocket boosters and core stage are jettisoned. The propulsion is provided by the RL10 engine, which uses a liquid hydrogen/liquid oxygen-based system.

Built by Boeing and United Launch Alliance, the interim cryogenic propulsion stage is a modified Delta Cryogenic Second Stage – a proven upper stage used on United Launch Alliance's Delta IV family of launch vehicles.



Interim Cryogenic Propulsion Stage

Orion Stage Adapter

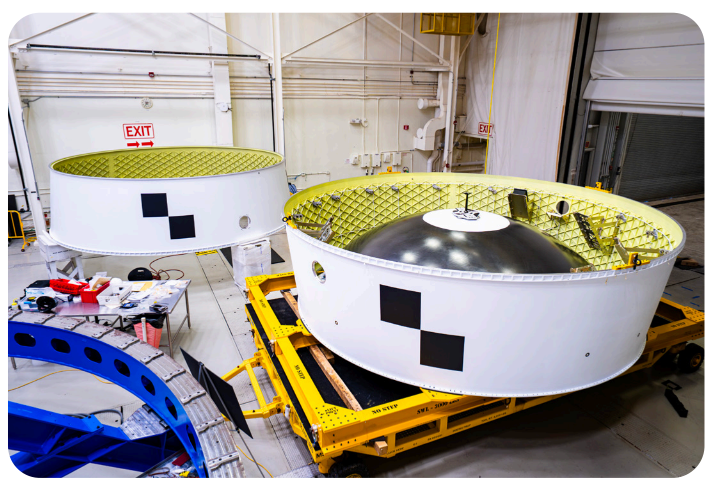
The Orion stage adapter, built by NASA's Marshall Space Flight Center in Huntsville, Alabama, connects the SLS rocket's interim cryogenic propulsion stage to NASA's Orion spacecraft. The small ring structure is the topmost portion of the SLS rocket. A diaphragm within the adapter provides a barrier and protects Orion from gases generated during launch, such as hydrogen.

The adapter can also carry small payloads, called CubeSats, to deep space.

The Orion stage adapter can potentially accommodate up to 17 CubeSats in a combination of 6U and 12U sizes (one unit, or U, is 10 cm x 10 cm x 10 cm). The actual number of CubeSats manifested on a flight depends on several factors, including mission parameters and CubeSat weight.

The SLS Program provides a comprehensive secondary payload deployment system for CubeSats, including mounting brackets for commercial off-the-shelf dispensers, cable harnesses, a vibration isolation system, and an avionics unit.

CubeSats can play a key role in the Artemis missions by gathering data and demonstrating potential technologies that reduce risk, increase effectiveness, and improve the design of robotic and human space exploration missions.



Orion Stage Adapter

Payload Volume	516 ft³ (14.6 m³)	8,118 ft³ (230 m³)	10,100 ft³ (286 m³)**	21,930 ft³ (621 m³)	10,100 ft³ (286 m³)**	34,910 ft³ (989 m³)

Maximum Thrust	8.8 M lbs.	8.8 M lbs.	8.84 M lbs.	8.84 M lbs.	9.44 M lbs.	9.44 M lbs.

Heavy Lifting Rocket Activity

Objective

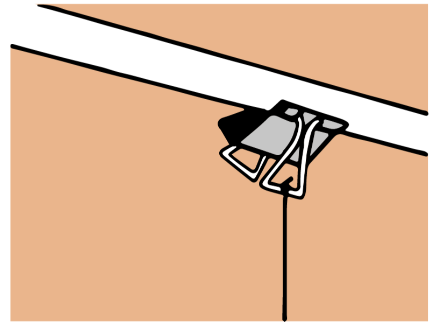
Students construct balloon-powered rockets to launch the greatest payload possible.

Description

Student teams receive identical parts with which to construct their rockets. Drinking straws guide balloon rockets up strings suspended from the ceiling. Teams compete to launch the greatest number of paper clips to space (the ceiling).

Materials

- Large binder clips (one per launch pad)
- Fishing line or smooth string
- Long balloons (see below about sources)
- Bathroom size (3 oz.) cup
- 2 straight (non-bendable) drinking straws
- 50 small paper clips
- Sandwich size plastic bag
- Masking tape
- Balloon hand pumps (optional)
- Wooden spring-type clothespins (optional)



Binder clip attached to ceiling grid.

Management

Prepare your classroom by setting up "launch pads" consisting of pieces of fishing line or string suspended from the ceiling (one line per team of students). If your classroom has a suspended ceiling, use binder clips or clothespins to attach to the metal frame supporting the ceiling tiles. Tie the fishing line to the clip or pins. Make sure the line is long enough to reach the floor. Provide open working space around each launch pad.

Explain how the straw is used for guiding the rockets. The fishing line or string is fed through the straw and one or more balloons are attached to the straw with masking tape. When the balloon is released, the straw will ride up the line. Stress that it is very important for students to hold the lower end of the line to the floor. If there is slack in the line or if the lower end of the line is free, the rocket will waffle about and not reach the ceiling. If you have balloon pumps, demonstrate how they are used to inflate the balloons.

Avoid providing too much information for the students. This is an exercise in creativity, skill, and problem solving. Simply explain the activity, how to use the straws for stability, and tell them that they can use any or all of the parts in their supply kits to build and fly their rockets. The supply kits contain three balloons. Remind students that they only get three balloons.

Some different ways students may devise to carry the paper clip "payloads." The plastic bag can be used, too. Let teams come up with their own ideas.

Balloon Sources

Many party supply stores carry variety packs that may include long balloons. Ask if they will special order packs of long balloons for you. The balloons become cylinders 5 inches in diameter and 24 inches long when inflated. They are sometimes called 524 (5 by 24 inches) airships. Find manufacturers and distributors by searching "524 balloons" on the Internet.

524 Airship

Background

SLS will send heavy payloads such as habitats and human spacecraft to the Moon and eventually to Mars. It can also send very large science missions like robotic landers or satellites to planets throughout our solar system. Raising heavy payloads to orbit is challenging. Rockets require powerful engines and massive amounts of fuel. NASA's SLS will be able to accomplish the job. It is the only rocket that can send NASA's Orion spacecraft, four astronauts, and large cargo directly to the Moon on a single mission.

Procedure

1. Divide your students into teams of three or four. Explain the project to them.

   "NASA is looking for creative ideas for launching heavy payloads into orbit. Payloads will be parts and supplies; large aperture telescopes; and spacecraft that will carry humans to the Moon and Mars, and possibly transport large fuel tanks to be used to power deep space rockets. You are challenged to build the most efficient heavy-lift rocket from the same set of materials for each team. The team that is able to lift the heaviest payload into space (the ceiling) is the winner."

2. Provide each team with an identical kit of materials. Tell them that any or all of the materials can be used for their rockets.

3. Review the launching procedure. Explain how the straw guides the rocket up the fishing line or string and that the line must be held snug to the floor for the launch. Remind the teams that they only get three balloons. They can launch as many times as they want but should try to increase the number of paper clips they can successfully lift.

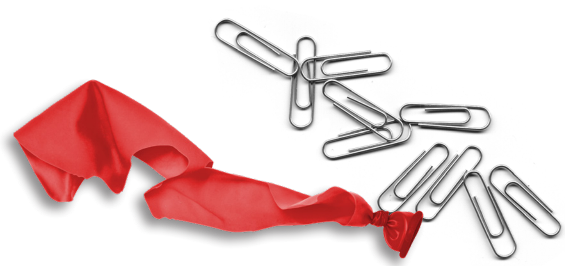
   NOTE: 1 paper clip = 2 g

4. Draw a chart on the board for teams to record their results.

Tips

1. If you wish to do so, provide one extra balloon to each team as a replacement in case of a mishap (pop!) or as a fourth rocket for their cluster. Make a small coupon for the extra balloon and put it in the parts bag. The coupons will help you keep track of which teams have already requested an extra balloon.

2. Occasionally, a balloon will have a tiny pinhole that will prevent it from being inflated or from holding air very long. Keep a small supply of replacement balloons.



Heavy-Lift Rocket Mission Report

Name:
Team Name:
Team Members:

Describe your rocket.

Flight Test	Mass Lifted (g)
1	
2	
3	
4	
5	

How did you change your rocket to make it carry more mass?

Make a sketch of your best rocket.

What other ways could you change your rocket to improve it?

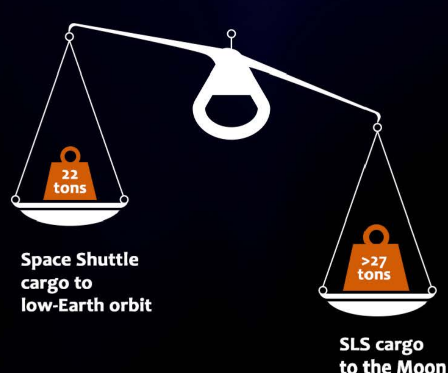
National Aeronautics and
Space Administration

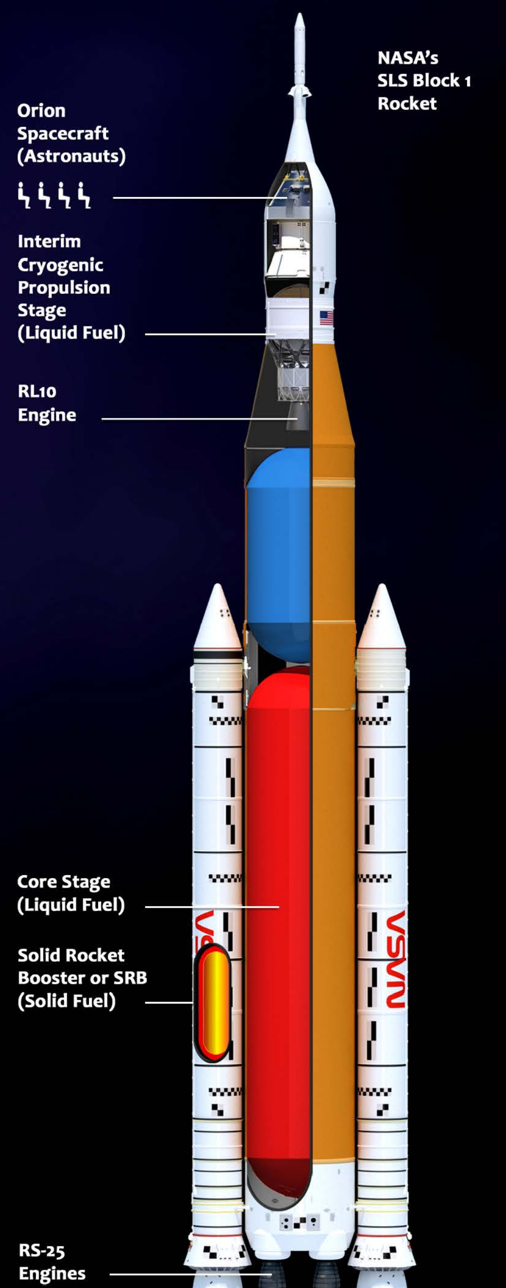
MEET THE ROCKET

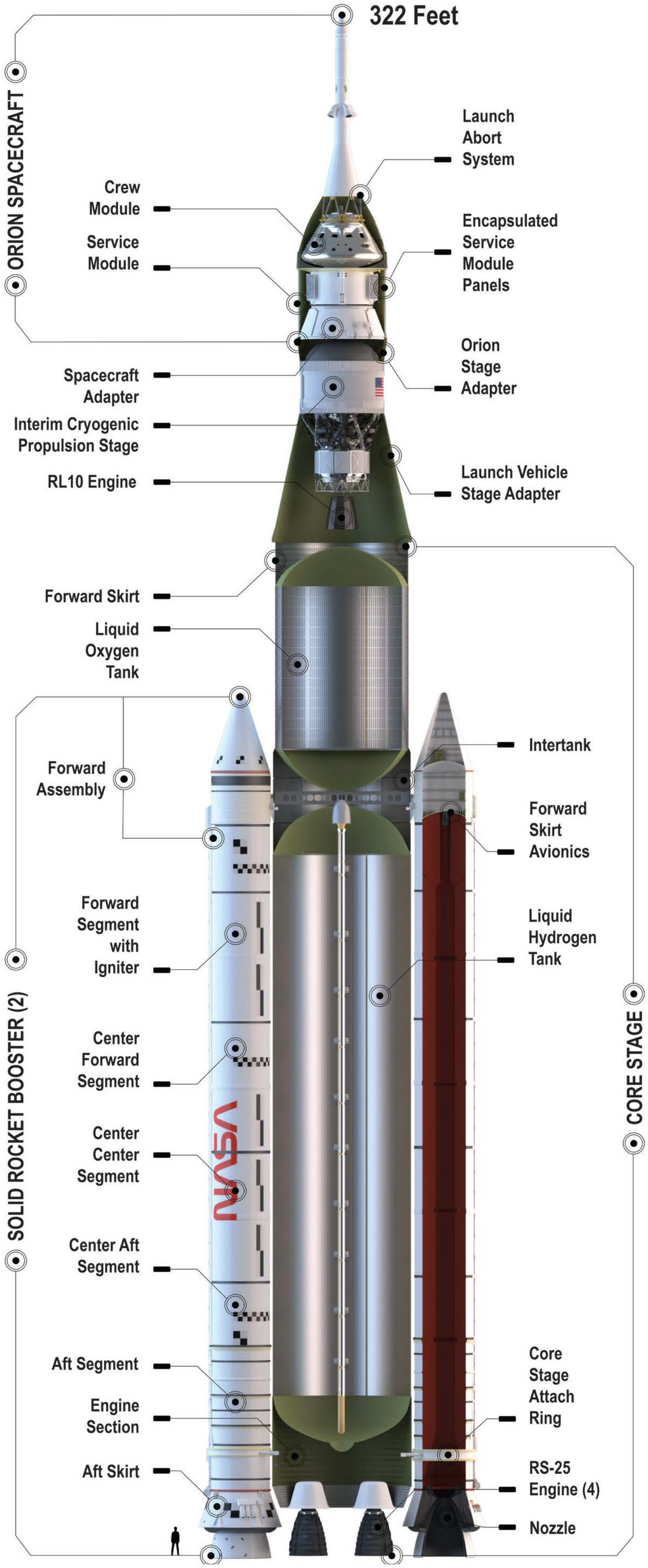
If you wonder how NASA's SLS (Space Launch System) compares to earlier generations of NASA launch vehicles:

SLS produces 13% more thrust at launch than the space shuttle and 17% more than Saturn V during liftoff and ascent.

SLS launches more cargo to the Moon than the space shuttle could send to low-Earth orbit.






322 Feet
ORION SPACECRAFT
Launch Abort System
Crew Module
Service Module
Encapsulated Service Module Panels
Orion Stage Adapter
Spacecraft Adapter
Interim Cryogenic Propulsion Stage
RL10 Engine
Launch Vehicle Stage Adapter
Forward Skirt
Liquid Oxygen Tank
Intertank
Forward Assembly
Forward Skirt Avionics
Forward Segment with Igniter
Liquid Hydrogen Tank
CORE STAGE
SOLID ROCKET BOOSTER (2)
Center Forward Segment
Center Center Segment
Center Aft Segment
Aft Segment
Core Stage Attach Ring
Engine Section
Aft Skirt
RS-25 Engine (4)
Nozzle
NASA

National Aeronautics and Space Administration

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www.nasa.gov

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