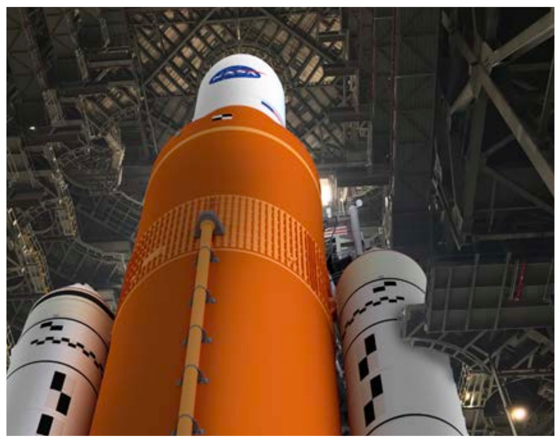
National Aeronautics and Space Administration

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.

Space Launch System

America's Rocket for Deep Space Exploration

NASA's Space Launch System, or SLS, is an advanced launch vehicle that provides the foundation for human exploration beyond Earth's orbit. With its unprecedented power and capabilities, SLS is the only rocket that can send Orion, astronauts, and large cargo to the Moon on a single mission.

Offering more payload mass, volume capability, and energy to speed missions through space than any current launch vehicle, SLS is designed to be flexible and evolvable and will open new possibilities for payloads, including robotic scientific missions to places like the Moon, Mars, Saturn, and Jupiter.

The Power to Explore Beyond Earth's Orbit

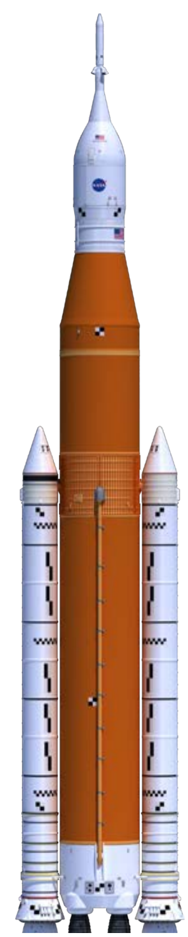
To meet America's future needs for deep space missions, SLS will evolve into increasingly more powerful configurations. SLS is designed for deep space missions and will send Orion or other cargo to the Moon, which is nearly 1,000 times farther than where the space station resides in low-Earth orbit. The rocket will provide the power to help Orion reach a speed of at least 24,500 mph, which is needed to break out of low-Earth orbit and travel to the Moon. That speed is about 7,000 mph faster than the space station travels around Earth.

Every SLS configuration uses the core stage with four RS-25 engines. The first SLS vehicle, called Block 1, can send more than 26 metric tons (t) [57,000 pounds (lb.)] to orbits beyond the Moon. It will be powered by twin five-segment solid rocket boosters and four RS-25 liquid propellant engines generating 8.8 million pounds of thrust. After reaching space, the Interim Cryogenic Propulsion Stage (ICPS) sends Orion on to the Moon.

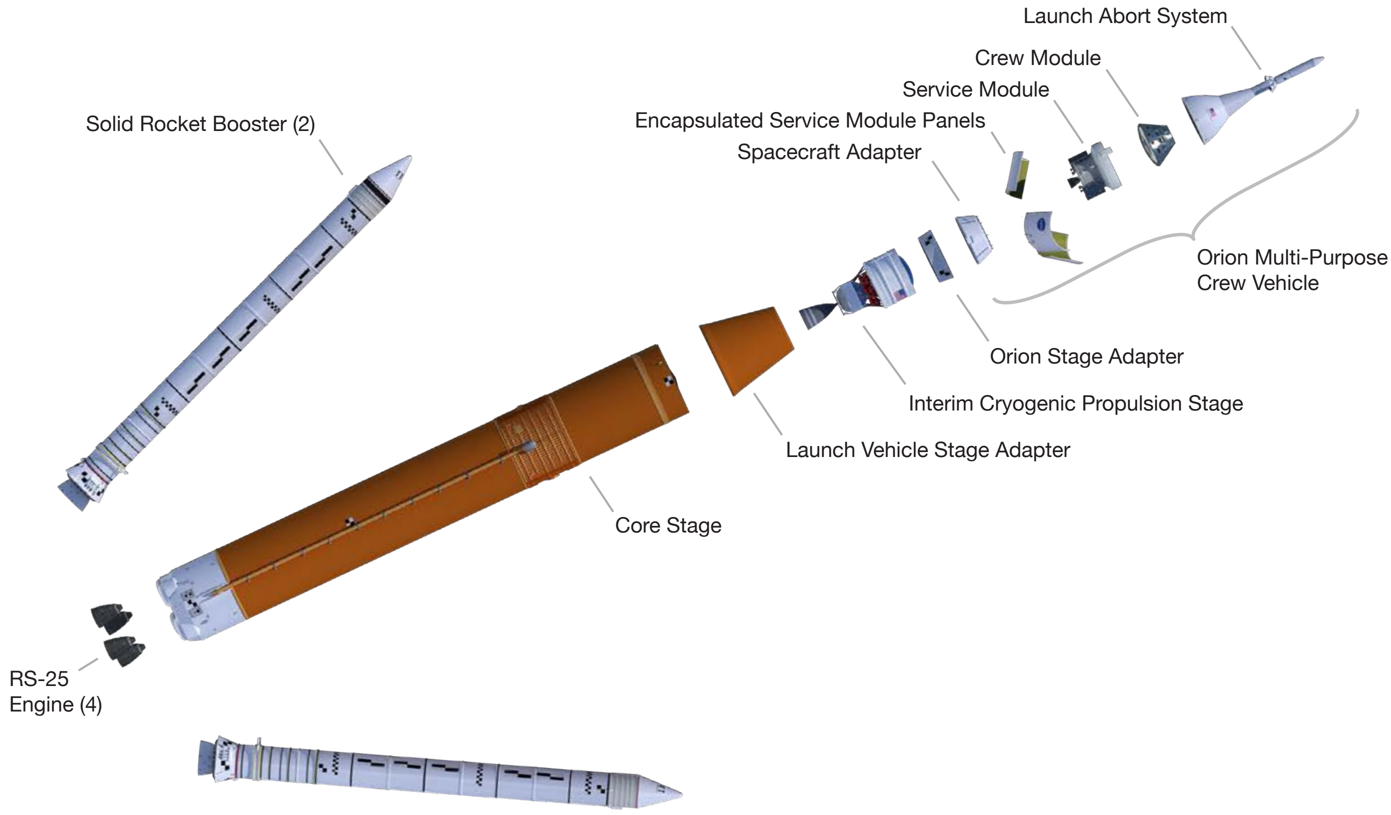
The next planned evolution of the SLS, the Block 1B crew vehicle, will use a new, more powerful Exploration Upper Stage (EUS) to enable more ambitious missions. The Block 1B vehicle can, in a single launch, carry the Orion crew vehicle along with exploration systems like a deep space habitat module.

The Block 1B crew vehicle can send approximately 37 t (81,000 lb.) to deep space including Orion and its crew. Launching with cargo only, SLS has a large volume payload fairing to send larger exploration systems or science spacecraft on solar system exploration missions.

The next SLS configuration, Block 2, will provide 11.9 million pounds of thrust 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 more than 45 t (99,000 lb.) to deep space. An evolvable design provides the nation with a rocket able to pioneer new human spaceflight missions.



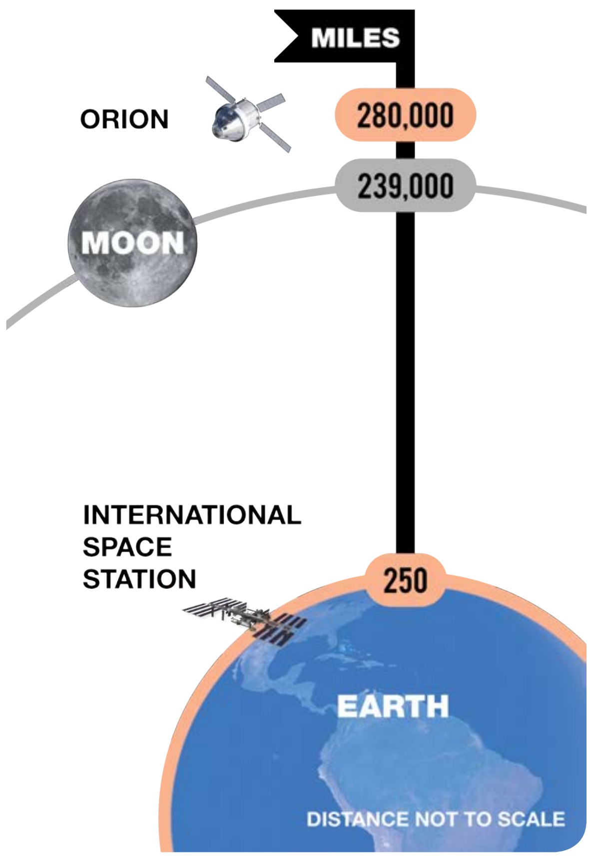
Block 1 – Initial SLS Configuration



Space Launch System Missions

Exploration Mission-1 (EM-1), the first integrated flight of SLS and Orion, uses the Block 1 configuration, which stands 322 feet, taller than the Statue of Liberty, and weighs 5.75 million pounds. SLS will produce 8.8 million pounds of maximum thrust, 15 percent more thrust than the Saturn V rocket.

For EM-1, Block 1 will launch an uncrewed Orion spacecraft to an orbit 40,000 miles beyond the Moon, or 280,000 miles from Earth. This mission will demonstrate the integrated system performance of SLS, Orion, and Exploration Ground Systems teams prior to a crewed flight to send Orion to lunar orbit. SLS will also carry 13 small satellites, each about the size of a shoebox, to be deployed in deep space.



For Exploration Mission-1, Orion will travel 280,000 miles from Earth—farther in deep space than any spacecraft built for humans has ever ventured.

Core Stage

The Boeing Company, in Huntsville, Alabama, is building the SLS core stage, including the avionics that will control the vehicle during flight. Towering more than 200 feet with a diameter of 27.6 feet, the core stage will store 730,000 gallons of super-cooled liquid hydrogen and liquid oxygen that will fuel the RS-25 engines.

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

SLS Liquid Oxygen Tank (top) and Liquid Hydrogen Tank (bottom)

RS-25 Engines

Propulsion for the SLS core stage will be provided by four RS-25 engines. Aerojet Rocketdyne of Sacramento, California, is upgrading an inventory of 16 RS-25 shuttle engines to SLS performance requirements, including a new engine controller, nozzle insulation, and required operation at 512,000 pounds of thrust. During the flight, the four engines provide around 2 million pounds of thrust.

The engines for EM-1 are built, tested, and ready for attachment to the core stage. After the engines are installed and the core stage is fully assembled, NASA's barge Pegasus will transport the entire stage to Stennis Space Center near Bay St. Louis, Mississippi, for testing. Then, Pegasus will take the core stage to Kennedy Space Center in Florida where it will be prepared for launch. Aerojet Rocketdyne has started development testing of new, advanced components to make the engines more affordable for future missions.

Boosters

Two shuttle-derived solid rocket boosters will be used for the initial flights of the SLS. To provide the additional power needed for the rocket, the prime contractor for the boosters, Northrop Grumman, of Redondo Beach, California, has modified the original shuttle's configuration of four propellant segments to a five-segment version. The design includes new avionics, propellant design, and case insulation and eliminates the recovery parachutes.

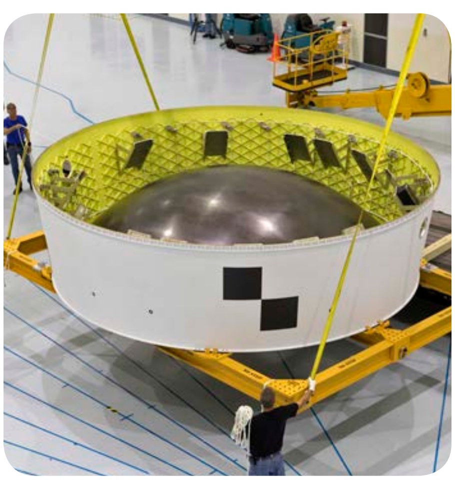
At the Utah facility, Northrop Grumman has cast all booster segments needed for EM-1. At Kennedy Space Center, engineers are refurbishing and upgrading space shuttle booster components to meet SLS requirements. Trains will carry booster segments from Utah to Kennedy where they will be stacked with other booster components. The boosters' avionics systems are being tested at Kennedy and Marshall.

Exploration Mission-1 Booster Aft Segment

Spacecraft and Payload Adapter, Fairings, and In-Space Stage

The Orion stage adapter will connect Orion to the ICPS on the SLS Block 1 vehicle and is the place where the small satellites will ride to space. Teledyne Brown Engineering of Huntsville, Alabama, has built the launch vehicle stage adapter (LVSA) that will connect SLS's core stage to the upper part of the rocket.

The initial capability to propel Orion out of Earth's orbit for Block 1 will come from the ICPS, based on the Delta Cryogenic Second Stage used successfully on United Launch Alliance's Delta IV family of rockets. It uses one RL10 engine made by Aerojet Rockedyne. The engine is powered by liquid hydrogen and liquid oxygen and generates 24,750 pounds of thrust.



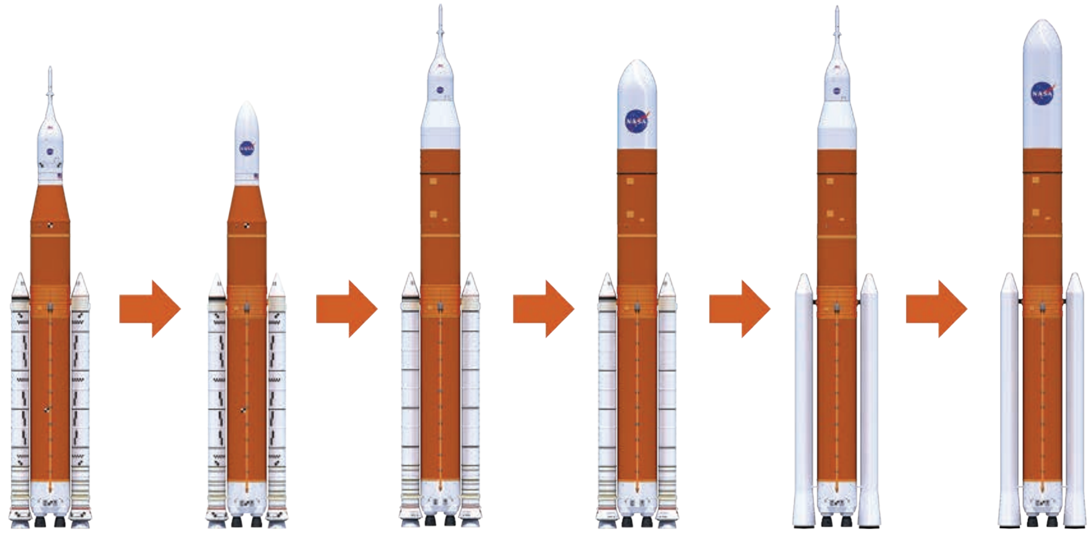
Orion Stage Adapter

Launch Vehicle Stage Adapter

Interim Cryogenic Propulsion Stage

Payload to TLI/Moon	> 26 t (57k lbs)	> 26 t (57k lbs)	34-37 t (74k–81k lbs)	37-40 t (81k–88k lbs)	> 45 t (99k lbs)	> 45 t (99k lbs)
Payload Volume	N/A*	9,030 ft³ (256m³)*	10,100 ft³ (286m³)*	18,970 ft³ (537 m³)	10,100 ft³ (286 m³)*	34,910 ft³ (988 m³)
	SLS Block 1 Crew	SLS Block 1 Cargo	SLS Block 1B Crew	SLS Block 1B Cargo	SLS Block 2 Crew	SLS Block 2 Cargo
Maximum Thrust	8.8M lbs	8.8M lbs	8.8M lbs	8.8M lbs	11.9M lbs	11.9M lbs

* Not including Orion/ Service Module volume



SLS Evolution

NASA has designed the Space Launch System as the foundation for a generation of human exploration missions to deep space, including missions to the Moon and Mars. SLS will leave low-Earth orbit and send the Orion spacecraft, its astronaut crew and cargo to deep space. To do this, SLS has to have enough power to perform a maneuver kown as trans-lunar injection, or TLI. This maneuver accelerates the spacecraft from its orbit around Earth onto a trajectory toward the Moon. The ability to send more mass to the Moon on a single mission makes exploration simpler and safer.

Heavy Lifting Rocket Activity

Objective

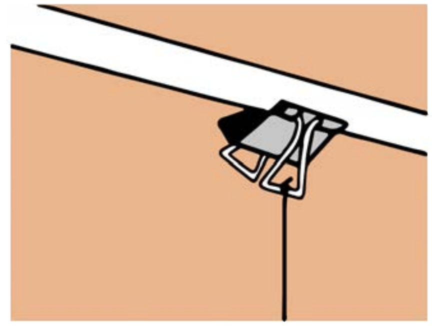
Students construct balloon-powered rockets to launch the greatest payload possible.

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 will be the largest and most powerful rocket ever built.

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?

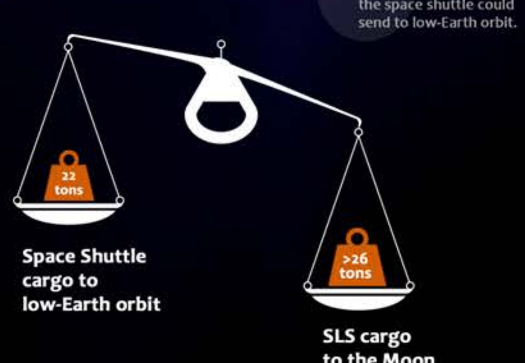
What other ways could you change your rocket to improve it?

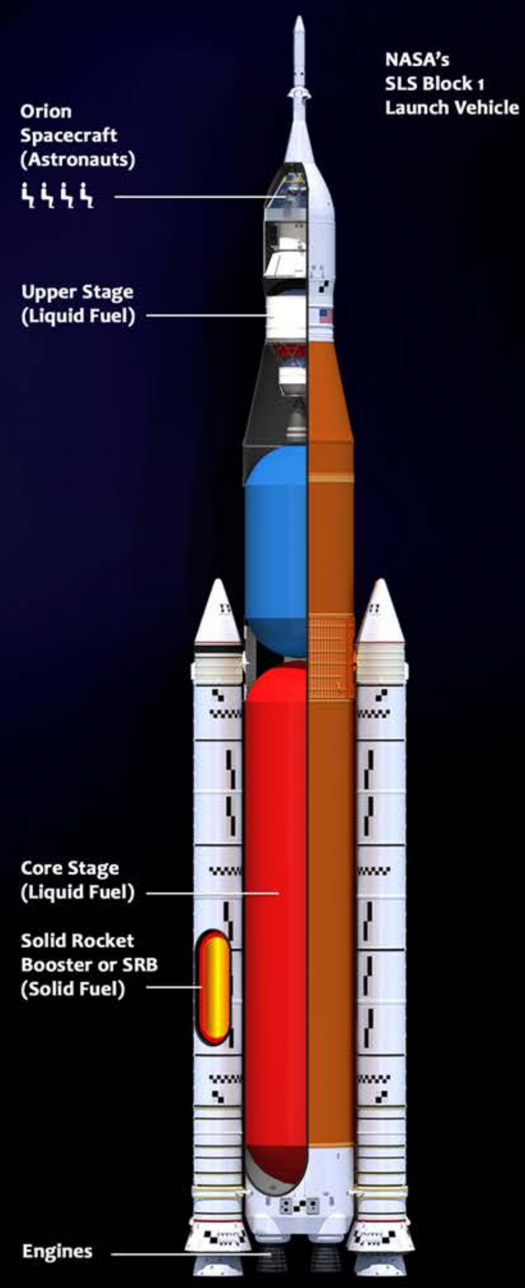
Make a sketch of your best rocket.

National Aeronautics and Space Administration

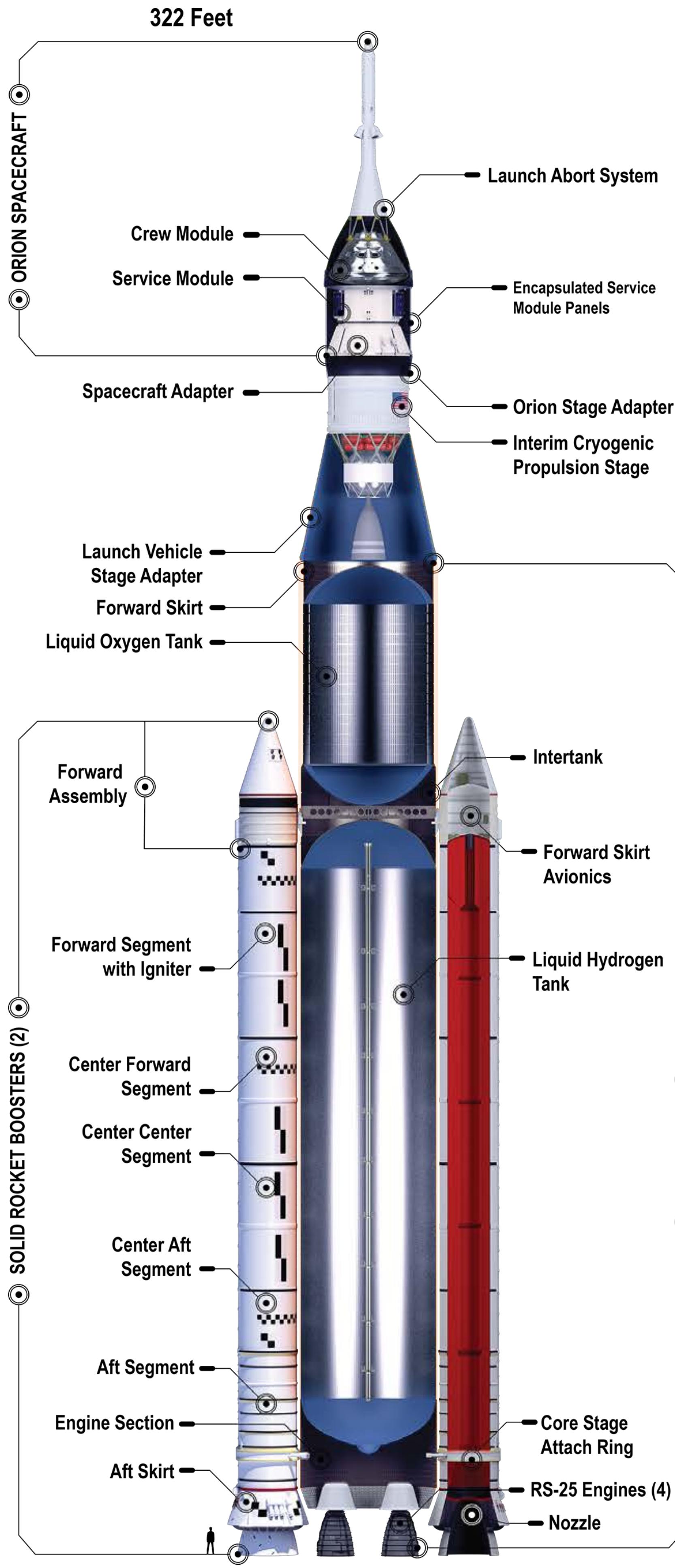
MEET THE ROCKET

If you wonder how NASA's Space Launch System, or SLS, compares to earlier generations of NASA launch vehicles...





www.nasa.gov/sls #NASASLS



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