Space Launch System

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The **Space Launch System** (**SLS**) is an American Space Shuttle-derived heavy expendable launch vehicle being designed by NASA. It follows the cancellation of the Constellation program, and is to replace the retired Space Shuttle. The NASA Authorization Act of 2010 envisions the transformation of the Constellation program's Ares I and Ares V vehicle designs into a single launch vehicle usable for both crew and cargo, similar to the Ares IV. SLS will be the world's most powerful rocket with 20% more thrust than Saturn V and a comparable payload capacity.[9][10][11]

The SLS launch vehicle is to be upgraded over time with more powerful versions. Its initial Block 1 version is to lift a payload of 70 metric tons to low Earth orbit (LEO), which will be increased with the debut of Block 1B and the Exploration Upper Stage.[12] Block 2 will replace the initial Shuttle-derived boosters with advanced boosters and is planned to have a LEO capability of more than 130 metric tons to meet the congressional requirement.[13] These upgrades will allow the SLS to lift astronauts and hardware to various beyond-LEO destinations: on a circumlunar trajectory as part of Exploration Mission 1 with Block 1, to a near-Earth asteroid in Exploration Mission 2 with Block 1B, and to Mars with Block 2. The SLS will launch the Orion Crew and Service Module and may support trips to the International Space Station if necessary. SLS will use the ground operations and launch facilities at NASA's Kennedy Space Center, Florida.

During the joint Senate-NASA presentation in September 2011, it was stated that the SLS program has a projected development cost of $18 billion through 2017, with $10 billion for the SLS rocket, $6 billion for the Orion Multi-Purpose Crew Vehicle and $2 billion for upgrades to the launch pad and other facilities at Kennedy Space Center.[14][15]

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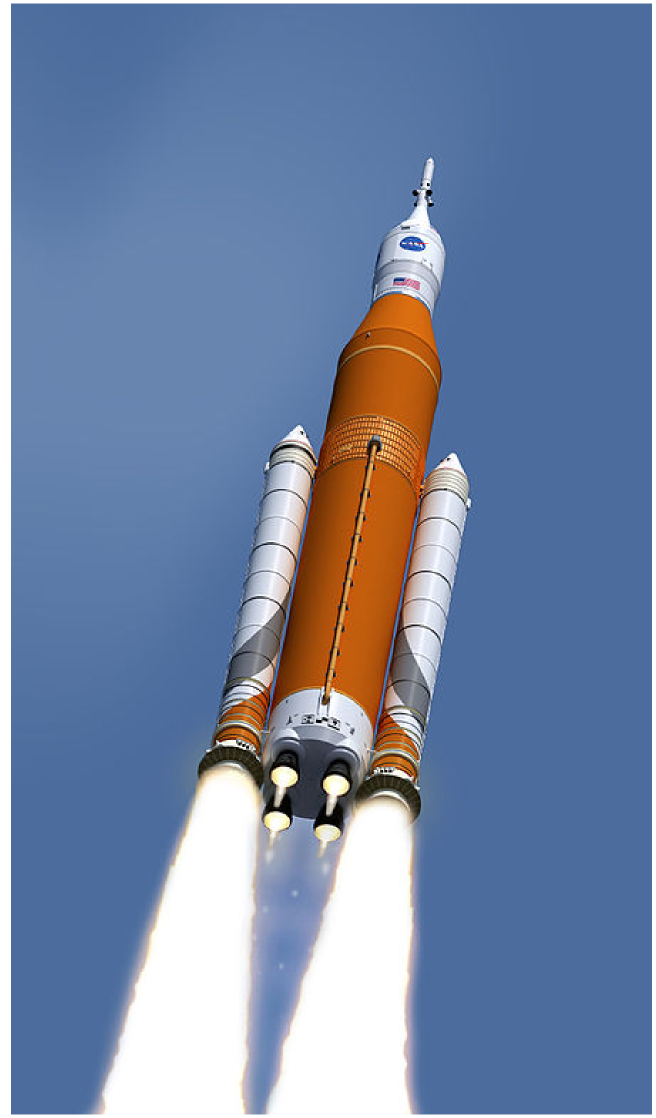
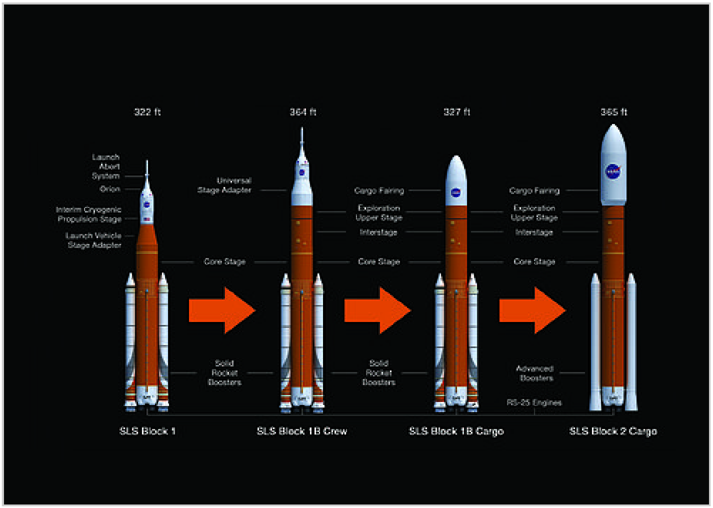


Artist's rendering of the SLS Block 1 launching with Orion.

Contents

Function	Launch vehicle
Manufacturer	Boeing, United Launch Alliance, Orbital ATK, Aerojet Rocketdyne
Country of origin	United States
Project cost	US$7 billion (2014-2018, 2014 estimate),[1] to 35 billion (until 2025, 2011 estimate)[2][3]
Cost per launch	US$500 million (2012, planned)[4] to 5 billion[5][6]
Size	
Diameter	27 ft 7 in (8.4 m) (core stage)
Stages	2
Capacity	
Payload to LEO	150,000 to 290,000 lb (70,000 to 130,000 kg)
Associated rockets	
Family	Shuttle-Derived Launch Vehicles
Launch history	
Status	Undergoing development
Launch sites	LC-39B, Kennedy Space Center
First flight	No later than November 2018[7]
Notable payloads	Orion MPCV, Europa Multiple-Flyby Mission, Uranus orbiter and probe
Boosters (Block 1)	

Design and development



Space Launch System's planned upgrade path

On September 14, 2011, NASA announced its design selection for the new launch system, declaring that it, in combination with the Orion spacecraft,[16] would take the agency's astronauts farther into space than ever before and provide the cornerstone for future US human space exploration efforts.[17][18][19]

Three versions of the launch vehicle are planned: Block 1, Block 1B, and Block 2. Each will use the same core stage with four main engines, but Block 1B will feature a more powerful second stage called the Exploration Upper Stage (EUS), and Block 2 will combine the EUS with upgraded boosters. Block 1 has a baseline LEO payload capacity of 70 metric tons (77 short tons) and Block 1B has a baseline of 105 metric tons (116 short tons). The proposed Block 2 will have lift capacity of 130 metric tons (140 short tons), which is similar to that of the Saturn V.[13][20] Some sources state this would make the SLS the most capable heavy lift vehicle built;[21][22] although the Saturn V lifted approximately 140 metric tons to LEO in the Apollo 17 mission.[9][23]

During the development of the SLS a number of different configurations were considered, including a Block 0 with three main engines,[24] a Block 1A variant which would have upgraded the vehicle's boosters instead of its second stage,[24] and a Block 2 with five main

Boosters (Block 1)	
Nº boosters	2 five-segment Solid Rocket Boosters
Thrust	3,600,000 lbf (16,000 kN)
Total thrust	7,200,000 lbf (32,000 kN)
Specific impulse	269 seconds (2.64 km/s) (vacuum)
Burn time	124 seconds
Fuel	PBAN, APCP
First Stage (Block 1, 1B, 2) - Core Stage	
Diameter	27 ft 7 in (8.4 m)
Empty mass	187,990 lb (85,270 kg)
Gross mass	2,159,322 lb (979,452 kg)
Engines	4 RS-25D/E[8]
Thrust	1,670,000 lbf (7,440 kN)
Specific impulse	363 seconds (3.56 km/s) (sea level), 452 seconds (4.43 km/s) (vacuum)
Fuel	LH_2/LOX
Second Stage (Block 1) - ICPS	
Length	44 ft 11 in (13.7 m)
Diameter	16 ft 5 in (5 m)
Empty mass	7,690 lb (3,490 kg)
Gross mass	67,700 lb (30,710 kg)
Engines	1 RL10B-2
Thrust	24,800 lbf (110.1 kN)
Specific impulse	462 seconds (4.53 km/s)

engines and a different second stage, the Earth Departure Stage, with up to three J-2X engines.[25] In February 2015, it was reported that NASA evaluations showed "over performance" versus the baseline payload for Block 1 and Block 1B configurations.[26]

On July 31, 2013 the SLS passed the Preliminary Design Review (PDR). The review encompassed all aspects of the SLS' design, not only the rocket and boosters but also ground support and logistical arrangements.[27] On August 7, 2014 the SLS passed a milestone known as Key Decision Point C and entered full-scale development, with an estimated launch date of November 2018.[28]

impulse	
Burn time	1125 seconds
Fuel	LH_2/LOX
Second Stage (Block 1B, Block 2) - Exploration Upper Stage	
Diameter	27 ft 7 in (8.4 m)
Engines	4 RL10
Thrust	99,000 lbf (440 kN)
Fuel	LH_2/LOX

Vehicle description

Core stage

The core stage will be 8.4 meters (28 ft) in diameter and utilize four RS-25 engines.[8][24] Initial flights will use modified RS-25D engines left over from the Space Shuttle program;[29] later flights are expected to switch to a cheaper version of the engine not intended for reuse.[30] The stage's structure will consist of a modified Space Shuttle External Tank with the aft section adapted to accept the rocket's Main Propulsion System (MPS) and the top converted to host an interstage structure.[21][31] It will be fabricated at the Michoud Assembly Facility.[32]

The core stage will be common across all currently planned evolutions of the SLS. Initial planning included studies of a smaller Block 0 configuration with three RS-25 engines,[33][34] which was eliminated to avoid the need to substantially redesign the core stage for more powerful variants.[24] Likewise, while early Block 2 plans included five RS-25 engines on the core,[25] it was later baselined with four engines.[26]

In 2015, NASA announce that following a Design Review Phase, the SLS core stage would be the same rust color as the iconic STS "orange tank."

Boosters

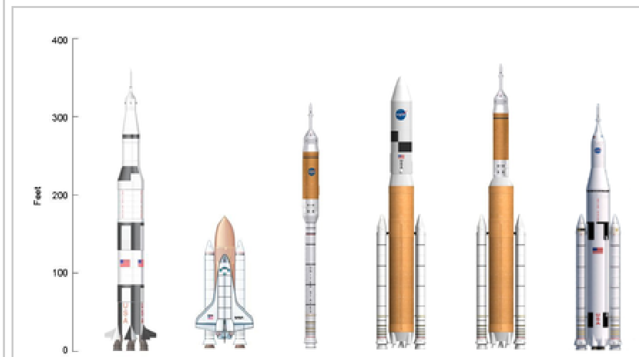
Shuttle-derived solid rocket boosters

Rendering of the SLS Block 1 with its older black-and-white paint scheme, showing the large core stage, two 5-segment SRBs, and the smaller upper stage.

Blocks 1 and 1B of the SLS will use two five-segment Solid Rocket Boosters (SRBs), which are based on the four-segment Space Shuttle Solid Rocket Boosters. Modifications for the SLS included the addition of a center booster segment, new avionics, and new insulation which eliminates the Shuttle SRB's asbestos and is 860 kg (1,900 lb) lighter. The five-segment SRBs provide approximately 25% more total impulse than the Shuttle SRB and will not be recovered after use.[35][36]

Artist's rendering of a Block 1 SLS

Orbital ATK (formerly Alliant Techsystems) has completed four full-scale, full-duration static fire tests of the five-segment SRB. Development Motor 1 (DM-1) was tested on September 10, 2009; DM-2 was tested on August 31, 2010, and DM-3 on September 8, 2011. The DM-2 motor was cooled to a core temperature of 40 °F (4 °C), and DM-3 was heated to above 90 °F (32 °C). These tests validated motor performance at extreme temperatures.[37][38][39] Qualification Motor 1 (QM-1) was tested on March 10, 2015.[40]



Comparison of the Saturn V, Space Shuttle, Ares I, Ares V, Ares IV and SLS Block I

Advanced boosters

For Block 2, NASA plans to switch from Shuttle-derived five-segment SRBs to advanced boosters.[41] This will occur after development of the Exploration Upper Stage for Block 1B. Early plans would have developed advanced boosters before an updated second stage; this configuration was called Block 1A. By 2012 NASA planned to select these new boosters through an Advanced Booster Competition which was to be held in 2015.[8][42] Several companies proposed boosters for this competition:

- Aerojet, in partnership with Teledyne Brown, offered a booster powered by three AJ1E6 engines, which would be a newly developed LOX/RP-1 oxidizer-rich staged combustion engine. Each AJ1E6 engine would produce 4,900 kN (1,100,000 lbf) thrust using a single turbopump to supply dual combustion chambers.[43] On February 14, 2013, NASA awarded Aerojet a $23.3 million, 30-month contract to build a 2,400 kN (550,000 lbf) main injector and thrust chamber.[44]
- ATK proposed an advanced SRB nicknamed "Dark Knight". This booster would switch from a steel case to one made of lighter composite material, use a more energetic propellant, and reduce the number of segments from five to four.[45] It would deliver over

20,000 kN (4,500,000 lbf) maximum thrust and weigh 790,000 kg (1,750,000 lb) at ignition. According to ATK, the advanced booster would be 40% less expensive than the Shuttle-derived five-segment SRB. It is uncertain if the booster will allow SLS to deliver the mandated 130 t to LEO without the addition of a fifth engine to the core stage,[26] as a 2013 analysis indicated a maximum capacity of 113 t with the baselined four-engine core.[46]

- Pratt & Whitney Rocketdyne and Dynetics proposed a liquid-fueled booster named "Pyrios".[47] The booster would use two F-1B engines which together would deliver a maximum thrust of 16,000 kN (3,600,000 lbf) total, and be able to continuously throttle down to a minimum of 12,000 kN (2,600,000 lbf). The F-1B would be derived from the F-1 engine, which powered the first stage of the Saturn V. It would have been easier to assemble, with fewer parts and a simplified design,[48] while providing improved efficiency and a thrust increase of 110 kN (25,000 lbf).[49] Estimates in 2012 indicated that the Pyrios booster could increase Block 2 low-Earth orbit payload to 150 t, 20 t more than the baseline.[50]

Christopher Crumbly, manager of NASA's SLS advanced development office in January 2013 commented on the booster competition, "The F-1 has great advantages because it is a gas generator and has a very simple cycle. The oxygen-rich staged combustion cycle [Aerojet's engine] has great advantages because it has a higher specific impulse. The Russians have been flying ox[ygen]-rich for a long time. Either one can work. The solids [of ATK] can work."[51]

Later analysis showed the Block 1A configuration would result in high acceleration which would be unsuitable for Orion and could require a costly redesign of the Block 1 core.[52] In 2014, NASA confirmed the development of Block 1B instead of Block 1A and called off the 2015 booster competition.[26][53] In February 2015, it was reported that SLS is expected to fly with the five-segment SRB until at least the late 2020s, and modifications to Launch Pad 39B, its flame trench, and SLS's Mobile Launcher Platform were evaluated based on SLS launching with solid-fuel boosters.[26]

Upper stage

Interim Cryogenic Propulsion Stage

Block 1, scheduled to fly Exploration Mission 1 (EM-1) by November 2018,[7] will use the Interim Cryogenic Propulsion Stage (ICPS). This stage will be a modified Delta IV 5-meter Delta Cryogenic Second Stage (DCSS),[54] and will be powered by a single RL10B-2. Block 1 will be capable of lifting 70 t in this configuration, however the ICPS will be considered part of the payload and be placed into an initial 1,800 km by -93 km suborbital trajectory to ensure safe disposal of the core stage. ICPS will perform an orbital insertion burn at apogee, and then a translunar injection burn to send the uncrewed Orion on a circumlunar excursion.[55]

Exploration Upper Stage

The Exploration Upper Stage (EUS) is scheduled to debut on Exploration Mission 2 (EM-2). It is expected to be used by Block 1B and Block 2 and, like the core stage, will be 8.4 meters in diameter. The EUS would be powered by four RL10 engines,[56] and would complete the SLS ascent phase and then re-ignite to send its payload to destinations beyond low-Earth orbit, similar to the role performed by the Saturn V's 3rd stage, the J-2 powered S-IVB.[57]

Other upper stages

- The Earth Departure Stage, powered by J-2X engines,[58][59] was to be the upper stage of the Block 2 SLS had NASA decided to develop Block 1A instead of Block 1B and the EUS.[57]
- An additional beyond-LEO engine for interplanetary travel from Earth orbit to Mars orbit, and back, is being studied as of 2013 at Marshall Space Flight Center with a focus on nuclear thermal rocket (NTR) engines.[60] In historical ground testing, NTRs proved to be at least twice as efficient as the most advanced chemical engines, allowing quicker transfer time and increased cargo capacity. The shorter flight duration, estimated at 3–4 months with NTR engines,[61] compared to 8–9 months using chemical engines,[62] would reduce crew exposure to potentially harmful and difficult to shield cosmic rays.[63][64][65][66] NTR engines, such as the Pewee of Project Rover, were selected in the Mars Design Reference Architecture (DRA).[64][67][68][69]
- In 2013, NASA and Boeing analyzed the performance of several second stage options. The analysis was based on a second stage usable propellant load of 105 metric tons, except for the Block 1 and ICPS, which will carry 27.1 metric tons. The ICPS upper stage and upper stages using four RL10 engines and two MB60 engines and one J-2X engine were studied.[70] In 2014, NASA also considered using the European Vinci instead of the RL10. The Vinci offers the same specific impulse but with 64% greater thrust, which would allow for a reduction of one or two of the four second stage engines for the same performance for a lower cost.[71][72]


An RL10 engine, like the one pictured above, will be used as the second stage engine in both the ICPS and EUS upper stages.

Robotic exploration missions to Jupiter's water-ice moon Europa are increasingly seen as well suited to the lift capabilities of the Block 1B SLS.[73]

Fabrication

In mid-November 2014, construction of the first SLS began using the new welding system at NASA's Michoud Assembly Facility, where major rocket parts will be assembled.[74]

The SLS will have the ability to tolerate a minimum of 13 tanking cycles due to launch scrubs and other launch delays before launch. The assembled rocket is to be able to remain at the launch pad for a minimum of 180 days and can remain in stacked configuration for at least 200 days without destacking.[75]

In January 2015, NASA began test firing RS-25 engines in preparation for use on SLS.[30]

Program costs

The Bimodal Nuclear Thermal Rocket engines on the Mars Transfer Vehicle (MTV). Cold launched, it would be assembled in-orbit by a number of Block 2 SLS payload lifts. The Orion crew capsule is docked on the right.

In August 2014, as the SLS program passed its Key Decision Point C review and entered full development, costs from February 2014 until its planned launch in September 2018 were estimated at $7.021 billion.[28] Ground systems modifications and construction would require an additional $1.8 billion over the same time period. As of February 2015 the Orion spacecraft was expected to enter its Key Decision Point C review in the first half of 2015.[76]

During the joint Senate-NASA presentation in September 2011, it was stated that the SLS program had a projected development cost of $18 billion through 2017, with $10 billion for the SLS rocket, $6 billion for the Orion Multi-Purpose Crew Vehicle and $2 billion for upgrades to the launch pad and other facilities at Kennedy Space Center.[14] These costs and schedule were considered optimistic in an independent 2011 cost assessment report by Booz Allen Hamilton for NASA.[77] An unofficial 2011 NASA document estimated the cost of the program through 2025 to total at least $41bn for four 70 t launches (1 unmanned, 3 manned),[2][3] with the 130 t version ready no earlier than 2030.[78]

The Human Exploration Framework Team (HEFT) estimated unit costs for Block 0 at $1.6bn and Block 1 at $1.86bn in 2010.[79] However, since these estimates were made the Block 0 SLS vehicle was dropped in late 2011, and the design was not completed;[80] NASA announced in 2013 that the European Space Agency will build the Orion Service Module.[81]

NASA SLS deputy project manager Jody Singer at Marshall Space Flight Center, Huntsville, Alabama stated in September 2012 that $500 million per launch is a reasonable target cost for SLS, with a relatively minor dependence of costs on launch capability.[4] By comparison, the cost for a Saturn V launch was US$185 to US$189 million in 1969-1971 dollars,[82][83] which is roughly US$1.2 billion in 2014 dollars.[84]

On July 24, 2014, Government Accountability Office audit predicted that SLS will not launch by the end of 2017 as originally planned since NASA is not receiving sufficient funding.[85]

Opposition

The Space Access Society, Space Frontier Foundation and The Planetary Society called for cancellation of the project, arguing that SLS will consume the funds for other projects from the NASA budget and will not reduce launch costs.[86][87][88] U.S. Representative Dana Rohrabacher and others added that instead, a propellant depot should be developed and the Commercial Crew Development program accelerated.[86][89][90][91][92] Two studies, one not publicly released from NASA[93][94] and another from the Georgia Institute of Technology, show this option to be a possibly cheaper alternative.[95][96]

Others suggest it will cost less to use an existing lower payload capacity rocket (Atlas V, Delta IV, Falcon 9, or the derivative Falcon Heavy), with on-orbit assembly and propellant depots as needed, rather than develop a new launch vehicle for space exploration without competition for the whole design.[97][98][99][100][101] The Augustine commission proposed an option for a commercial 75 metric ton launcher with lower operating costs, and noted that a 40 to 60 t launcher can support lunar exploration.[102]

Mars Society founder Robert Zubrin, who co-authored the Mars Direct concept, suggested that a heavy lift vehicle should be developed for $5 billion on fixed-price requests for proposal. Zubrin also disagrees with those that say the U.S. does not need a heavy-lift vehicle.[103] Based upon extrapolations of increased payload lift capabilities from past experience with SpaceX's Falcon launch vehicles, SpaceX CEO Elon Musk stated in 2010 that he would "personally guarantee" that his company could build the conceptual Falcon XX, a vehicle in the 140-150 t payload range, for $2.5 billion, or $300 million per launch, but cautioned that this price tag did not include a potential upper-stage upgrade.[104][105] SpaceX's privately-funded MCT launch vehicle, powered by multiple Raptor engines, has also been proposed for lifting very large payloads from Earth in the 2020s.[106]

Rep. Tom McClintock and other groups argue that the Congressional mandates forcing NASA to use Space Shuttle components for SLS amounts to a de facto non-competitive, single source requirement assuring contracts to existing shuttle suppliers, and calling the Government Accountability Office (GAO) to investigate possible violations of the Competition in Contracting Act (CICA).[87][107][108] Opponents of the heavy launch vehicle have critically used the name "Senate launch system".[54] The Competitive Space Task Force, in September 2011, said that the new government launcher directly violates NASA’s charter, the Space Act, and the 1998 Commercial Space Act requirements for NASA to pursue the "fullest possible engagement of commercial providers" and to "seek and encourage, to the maximum extent possible, the fullest commercial use of space".[86]

Phil Plait has voiced his criticism of SLS in light of ongoing budget tradeoffs between Commercial Crew Development and SLS budget, also referring to earlier critique by Lori Garver.[109] Garver, former NASA Deputy Administrator, has called for cancelling the program.[110] Chris Kraft, the legendary NASA mission control leader from Apollo era, has expressed his criticism of the system as well.[111]

SLS program mission schedule

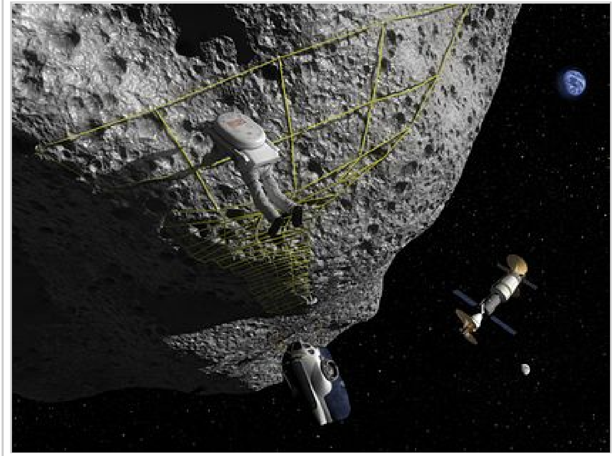
List only includes relatively near missions; more missions are planned than are listed below.

Confirmed SLS missions (Launch history)

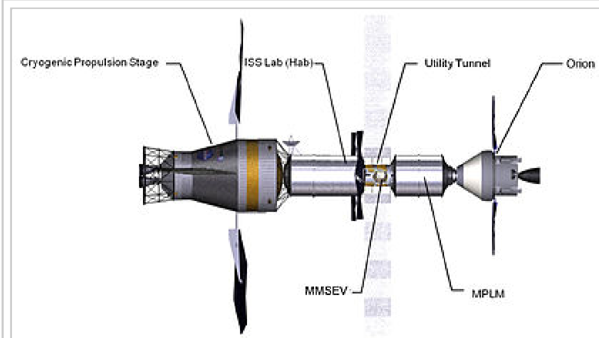
Mission	Acronym	Rocket	Manned	Launch Date	Result	Duration	Remarks	Reference
Space Launch System 1 / Exploration Mission 1	SLS-1 / EM-1	SLS Block I	No	By November 2018	Planned		Send unmanned Orion capsule on trip around the Moon, deploy Near-Earth Asteroid Scout, Lunar Flashlight, BioSentinel, SkyFire, Lunar IceCube, and 6 other small CubeSats.[112][113]	[7][114]
Space Launch System 2 / Exploration Mission 2	SLS-2 / EM-2	SLS Block IB	Yes	2021–2023	Planned		Send an Orion capsule with four crew members in retrograde lunar orbit.	[56][115][116][117]
Space Launch System 3 / Exploration Mission 3	SLS-3 / EM-3	SLS Block IB	Yes	2026	Planned		Send an Orion capsule in 2026 with four crew members to an asteroid that had been robotically captured and placed in lunar orbit in late 2025 (Asteroid Redirect Mission).	[118][119]

Proposed missions

Some of the currently proposed NASA Design Reference Missions (DRM) and others include:[25][68][120][121][122]



An astronaut, possibly part of Exploration Mission 2, performing a tethering asteroid capture maneuver at a near-earth object (NEO). The Space Exploration Vehicle is close by, with the Orion Multi-Purpose Crew Vehicle (MPCV) docked to the Deep Space Habitat in the background.



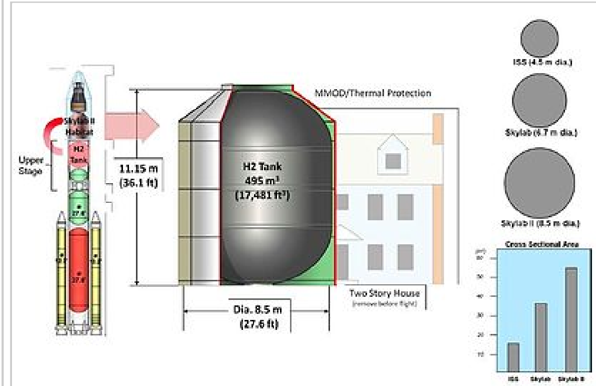
Artist's rendering of the Deep Space Habitat

- **ISS Back-Up Crew Delivery** – a single launch mission of up to four astronauts via a Block 1 SLS/Orion-MPCV without an Interim Cryogenic Propulsion Stage (ICPS) to the International Space Station (ISS) if the Commercial Crew Development program does not come to fruition. This potential mission mandated by the NASA Authorization Act of 2010 is deemed undesirable since the 70 t SLS and BEO Orion would be overpriced and overpowered for the mission requirements. Its current description is "delivers crew members and cargo to ISS if other vehicles are unable to perform that function. Mission length 216 mission days. 6 crewed days. Up to 210 days at the ISS."
- **Europa Multiple-Flyby Mission** orbiter to Jupiter, proposed to be launched on the Atlas V or SLS between 2022 and 2025.[123]
- **Uranus orbiter and probe**, SLS has been proposed by Boeing as a launch vehicle for a Uranian probe. The rocket would "Deliver a small payload into orbit around Uranus and a shallow probe into the planet's atmosphere." The mission would study the Uranian atmosphere, magnetic and thermal characteristics, gravitational harmonics as well as do flybys of Uranian moons.[124][125]

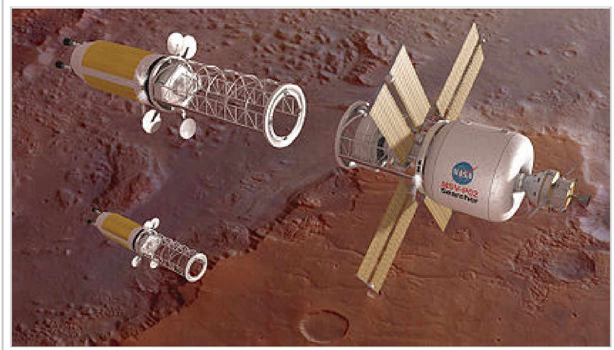
- **Strategic timeframe DRMs**
  - **GEO mission** – a dual-launch mission separated by 180 days to geostationary orbit. The first launch would comprise an SLS with a CPS and cargo hauler, the second an SLS with a CPS and Orion MPCV. Both launches would have a mass of about 110 t.
  - **A set of lunar missions** enabled in the early 2020s ranging from Earth-Moon Lagrangian point-1 (EML-1) and low lunar orbit (LLO) to a lunar surface mission. These missions would lead to a lunar base combining commercial and international aspects.
    - The lunar surface mission set for the late 2020s would be a dual launch separated by 120 days. This would be a 19-day mission with seven days on the Moon's surface. The first launch would comprise an SLS with a CPS and lunar lander, the second an SLS with a CPS and Orion MPCV. Both would enter LLO for lunar-orbit rendezvous prior to landing at equatorial or polar sites on the Moon. Launches would have masses of about 130 t and 108 t, respectively. Its current description is "Lunar Surface Sortie (LSS): Lands four crew members on the surface of the Moon in the

equatorial or polar regions and returns them to Earth," "Expected drivers include: MPCV operations in LLO environment, MPCV uncrewed ops phase, MPCV delta V requirements, RPOD (rendezvous, proximity operations and docking), MPCV number of habitable days."

- **Five Near Earth Asteroid (NEA) missions** ranging from "minimum" to "full" capability are being studied. Among these are two NASA Near Earth Object (NEO) missions in 2026. A 155-day mission to NEO 1999 AO10, a 304-day mission to NEO 2001 GP2, a 490-day mission to a potentially hazardous asteroid such as 2000 SG344, utilizing two Block 1B SLS vehicles,[126] and a Boeing-proposed NEO mission to NEA 2008 EV5 in 2024. The latter would start from the proposed Earth-Moon L2 based Exploration Gateway Platform. Utilising an SLS third stage the trip would take about 100 days to arrive at the asteroid, 30 days for exploration, and a 235-day return trip to Earth.[127]
- **Forward Work Martian Moon Phobos/Deimos**, a crewed flexible path mission to one of the Martian moons. It would include 40 days in the vicinity of Mars and a return Venus flyby.
- **Forward Work Mars Landing**, a crewed mission, with four to six astronauts,[128] to a semi-permanent habitat for at least 540 days on the surface of the red planet in 2033 or 2045. The mission would include in-orbit assembly, with the launch of seven SLS Block 2 heavy-lift vehicles (HLVs). The seven HLV payloads, three of which would contain nuclear propulsion modules, would be assembled in LEO into three separate vehicles for the journey to Mars; one cargo In-Situ Resource Utilization Mars Lander Vehicle (MLV) created from two HLV payloads, one Habitat MLV created from two HLV payloads and a crewed Mars Transfer Vehicle (MTV), known as "Copernicus", assembled from three HLV payloads launched a number of months later. Nuclear Thermal Rocket engines such as the Pewee of Project Rover were selected in the Mars Design Reference Architecture (DRA) study as they met mission requirements being the preferred propulsion option because it uses proven technology, has higher performance, lower launch mass, creates a versatile vehicle design, offers simple assembly, and has growth potential.[68][129]



One section of the Skylab II Habitat would be made from the SLS Block 2 upper-stage hydrogen tank, similar to but larger than Skylab. A unique use for the SLS as no other vehicle is presently being designed with an 8-meter-diameter upper stage tank.



Artist's rendering of the proposed Mars Transfer Vehicle (MTV) "Searcher" that would incorporate NTR propulsion and inflatable habitat technology. A crewed Orion MPCV is docked on the right.

- **Other proposed missions**
  - **2024+ Single Shot MSR on SLS**, a crewed flight with a telerobotic Mars Sample Return (MSR) mission proposed by NASA's Mars Program Planning Group. The time frame suggests SLS-5, a 105 t rocket to deliver an Orion capsule, SEP robotic vehicle, and Mars Ascent Vehicle (MAV). "Sample canister could be captured, inspected, encased and retrieved tele-robotically. Robot brings sample back and rendezvous

with a crew vehicle." The mission may also include a "Possible Mars SEP (Solar Electric Power/Propulsion) Orbiter".[130]

- **Potential sample return missions** to Europa and Enceladus have also been noted.[131]
- **Deep Space Habitat** (DSH), NASA's planned usage of spare ISS hardware, experience, and modules for future missions to asteroids, Earth-Moon Lagrangian point and Mars.[132]
- **Skylab II**, proposal by Brand Griffin, an engineer with Gray Research Inc working with NASA Marshall, to use the upper stage hydrogen tank from SLS to build a 21st-century version of Skylab for future NASA missions to asteroids, Earth-Moon Lagrangian point-2 (EML2) and Mars.[133][134][135]
- **HAVOC**, a manned Venus mission using two SLS Block 1B launches to send a crew of 2 to explore the atmosphere of Venus for 1 month, with retrieval in Earth orbit by a commercial crew vehicle or an Orion.[136][137][138][139]
- **SLS DoD Missions**, the HLV will be made available for U.S. Department of Defense and other US government agencies to launch military or classified missions.
- **Commercial payloads**, such as the BA-330 have also been referenced.[125]
- Additionally "secondary payloads" mounted on SLS via an Encapsulated Secondary Payload Adapter (ESPA) ring may also be launched in conjunction with a "primary passenger" to maximize payloads.
- **Advanced Technology Large-Aperture Space Telescope**, SLS has been proposed by Boeing as a launch vehicle for the Advanced Technology Large-Aperture Space Telescope (ATLAST). This could be an 8 m monolithic telescope or a 16 m deployable telescope at Earth-Sun L2.[124]

One proposed ATLAST concept, a design based on an 8-meter monolithic mirror. The Hubble Space Telescope by comparison is equipped with a 2.5 m main mirror. A telescope with an 8-meter monolithic mirror is possible only with a payload fairing bigger than 8 meters in diameter.

- **Asteroid Deflection Mission**, SLS could be used as a launch vehicle for emergency asteroid defense.[125]

Payload mass to various orbits

Vehicle	Orbit or location	Payload mass (metric tons)	Example mission	Reference
Block 1	Low-Earth Orbit	93.1 t	Send payloads to Low-Earth orbit	[140]
Block 1	Earth-Moon L-2	28 t	Send Orion capsule beyond the Moon	[140]
Block 1	C3=2	12 t	Asteroid Redirect Mission	[140]
Block 1	Distant retrograde Lunar orbit	12 t	Visit captured asteroid	[140]
Block 1	C3=85.4	4 t	Europa Clipper	[140]
Block 1B	Trans-lunar injection	39.2 t	Human assisted Lunar sample return	[140]
Block 1B	Earth-Moon L-2	45 t	Crewed lunar surface mission	[140]
Block 1B	Earth-Sun L-2	40 t	Advanced Technology Large-Aperture Space Telescope	[140]
Block 1B	C3=100	5 t	Uranus Orbiter	[140]
Block 2	Low-Earth orbit	130 t	Preparation for human mission to Mars	[140]

Funding

In Fiscal Year 2015, NASA received an appropriation of US$1.7 billion from Congress for SLS, an amount that was approximately US$320 million greater than the amount requested by the Obama administration.[141]

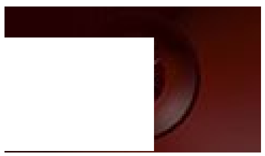
See also

- Ares V - cargo vehicle design for the Constellation Program of the 2000s.
- Comparison of orbital launchers families
- Comparison of orbital launch systems
- DIRECT - Ares V competitor, but with smaller payload capacity, based on Jupiter (rocket family).
- Energia - comparable vehicle to SLS Block 1 for Low Earth Orbit excursions.
- Exploration of Mars
- Human mission to Mars
- Morpheus Lander - rocket powered lander designed to use propellants manufactured on Mars.
- Nautilus-X - proposed deep space habitat module.

- Saturn MLV - modified super heavy lift Saturn V of 1960s, designed for Mars missions by 1980s.
- Saturn V ELV - enlarged Saturn V design concept of 1960s, with strapon Titan IV solid rocket boosters.
- Saturn V-3 - upgraded Saturn V design concept of 1960s, using F-1A 1st stage engines & HG-3 2nd stage engines.
- Shuttle-Derived Heavy Lift Launch Vehicle - concept vehicle with a lower lift capability than Saturn V.
- Magnum (rocket) - a 1990s concept with a similar lift capability to Block 1 and Block 1B but lower than the Saturn V.
- Space exploration technologies
- Space Exploration Vehicle
- Space policy of the Barack Obama administration
- Space Shuttle successors

Videos

Space Launch System Booster Passes Major Ground Test



Igniting the Booster Space Launch System

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- Space Launch System & Multi-Purpose Crew Vehicle page on NASA.gov (http://www.nasa.gov/exploration/new_space_enterprise/sls_mpcv/index.html)
- "Preliminary Report on Multi-Purpose Crew Vehicle and Space Launch System" (PDF), NASA (http://www.nasa.gov/pdf/510449main_SLS_MPCV_90-day_Report.pdf).
- SLS Future Frontiers video (http://www.nasa.gov/multimedia/videogallery/index.html?collection_id=73621&media_id=131955371)
- Video animations of mission to asteroid, moon and mars (http://www.beyondearth.com/)

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