

NASA's Space Launch System: A New National Capability

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Abstract

The National Aeronautics and Space Administration's (NASA's) Space Launch System (SLS) will contribute a new national capability for human space flight and scientific missions to low-Earth orbit (LEO) and beyond. Exploration beyond Earth orbit will be an enduring legacy to future generations, confirming America's desire to explore, learn, and progress. The SLS Program, managed at NASA's Marshall Space Flight Center, will develop the heavy lift vehicle that will launch the Orion Multi-Purpose Crew Vehicle (MPCV), equipment, supplies, and science experiments for missions beyond Earth's orbit. This paper gives an overview of the SLS design and management approach against a backdrop of the missions it will empower. It will detail the plan to move from the computerized drawing board to the launch pad in the near term, as well as summarize the innovative approaches the SLS team is applying to deliver a safe, affordable, and sustainable long-range national capability.

I. Introduction

The SLS will be a one-of-a-kind infrastructure asset for missions of national importance, continuing the tradition of America's first 50 years in space (Figure 1). As the first exploration-class launch vehicle since the Saturn V in the 1960s and 1970s, the SLS offers new possibilities for expanding the boundaries that have limited explorers for the last 40 years. From launching planetary probes and astronomical observatories, to using the Moon to synchronize the human/robotic interface before the first human trips to Mars, to preparing to set the first boot prints on another planet, the SLS is the platform for America's next chapter in space. The imperative to explore with a combination of astronauts and robots will be the impetus for inventions such as new ways to harness solar power, supply clean water, recycle waste, and yet-to-be discovered inventions. Perhaps most importantly, the SLS will provide the capability to perform international missions that foster the peaceful pursuit of mutual objectives on the space frontier, as outlined in the Global Exploration Roadmap, September 2011, and National Space Policy of the United States of America, June 2010 [1, 2].



Figure 1. SLS advances America's tradition of human space exploration.

The launch vehicle concept and management plan outlined in this paper are based on years of study and careful deliberations within the Agency, the Office of Science and Technology Policy, and the Office of Management and Budget. The resulting vehicle architecture and strategy to get to first flight by 2017 are supported by both detailed engineering and business analyses, which have been independently validated (Figure 2). The Agency has integrated the Space Launch System (Marshall Space Flight Center (MSFC)), Orion MPCV (Johnson Space Center), and 21st Century Ground Operations (Kennedy Space Center) Programs, putting the Nation on a steady course to resuming America's human space flight operations.

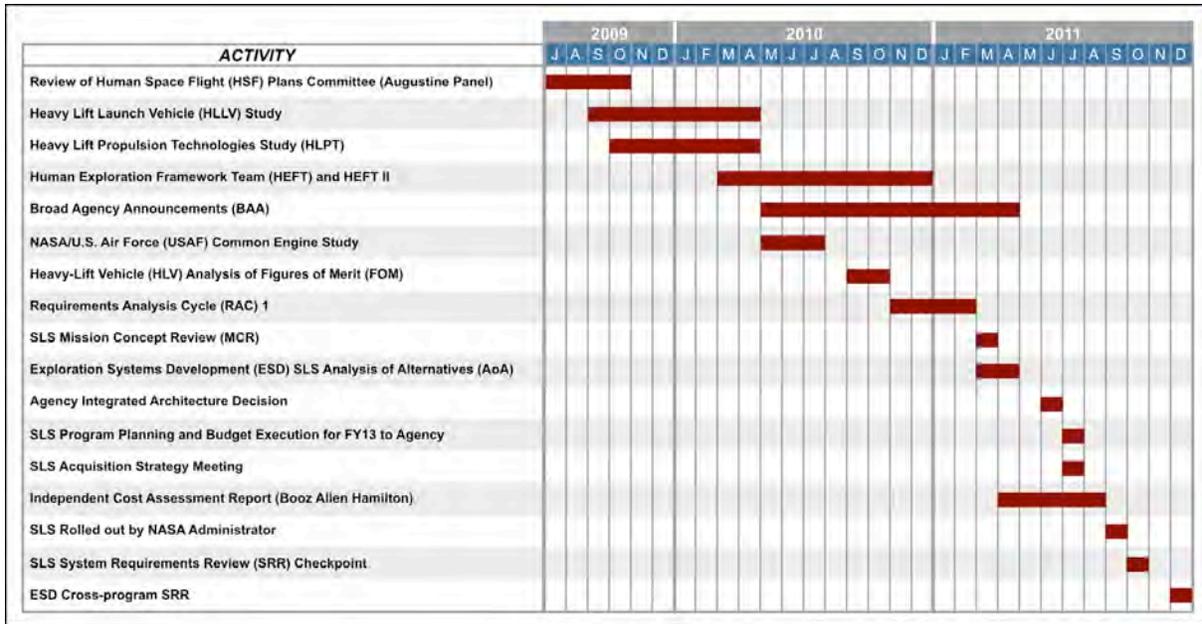


Figure 2. A top-level roadmap leading to the SLS decision.

As is evidenced in Figure 2, the SLS Program has completed a number of studies and milestones, including the Mission Concept Review (MCR) (March 2011). The SLS Program is now making measurable progress toward the System Requirements Review/System Definition Review (SRR/SDR) (Spring 2012). Figure 2, which is not an all-inclusive list, underscores the importance that the Agency placed on this decision — one that has ramifications for decades to come.

Building the world’s most capable rocket is a commitment of limited resources, so the Agency called on some of the top Government and industry experts to gather the information it needed to make this important decision. Throughout the process, the Agency sought input from internal and external stakeholders. As currently planned, the SLS architecture is the most cost-effective choice, while offering unprecedented performance. The decision to leverage existing and hardware in development is a sound path to first flight in 6 years within a resource-constrained environment.

Given below is a summary of the current SLS configuration, along with a sampling of the unique missions it may perform. The SLS management approach incorporates the best practices of lean organizations, knowing that to achieve a first flight in 2017 will require significant heavy lifting — and not just by cranes lifting massive rocket stages and engines. The SLS team understands and embraces the sense of urgency to deliver this national capability on time and within budget. The information that follows provides a balanced picture of the technical and management initiatives now in progress by the nationwide SLS team.

II. Architecture Overview

The Space Launch System will be a super-heavy-lift rocket that will propel human explorers to entirely new destinations and provide the volume needed for astronomical observatories and other decadal-class science missions discussed in the following section. As shown in Figure 3, there are many commercially available rockets in the medium-to-heavy class, whereas super-heavy-lift vehicles are within the Government purview. NASA has taken priority stakeholder requirements and selected a design that provides a platform for national leadership in space, while supporting options that have never before been possible — opening potential new markets and trade routes for the expanding global economy.

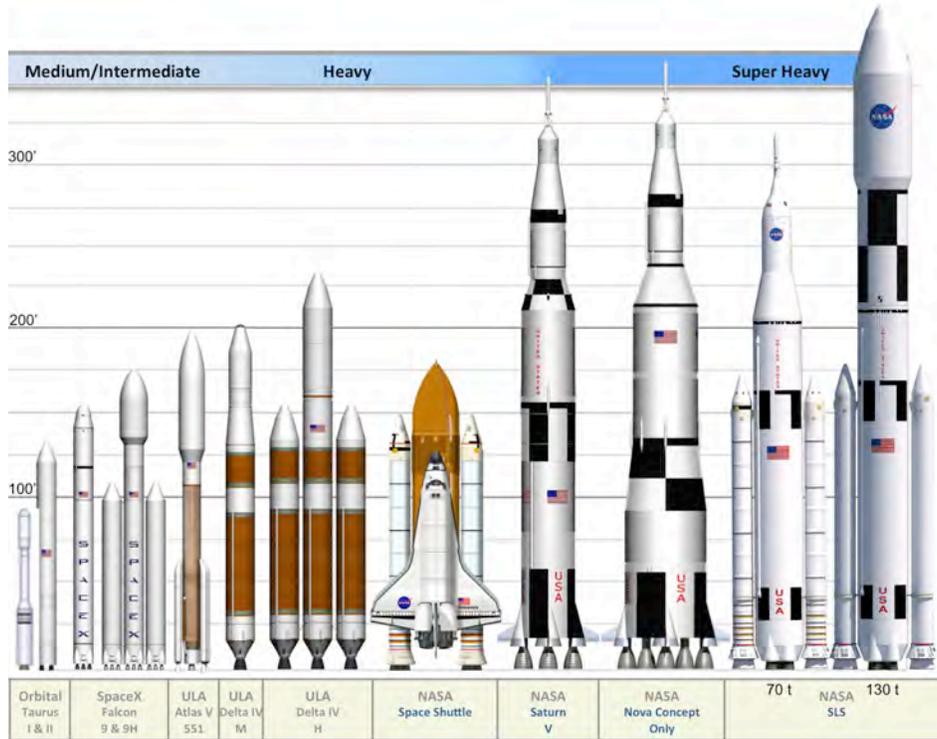


Figure 3. SLS scale relative to other United States (U.S.) fielded and proposed systems.

The NASA Authorization Act of 2010 directs NASA to develop the SLS as the follow-on to the Space Shuttle, with the capability of accessing cis-lunar space and the regions of space beyond low-Earth orbit (LEO) to enable the United States to participate in global efforts to develop this increasingly strategic region [3]. The Act also provides a series of minimum capabilities that the SLS vehicle must achieve: initially lift 70 tonnes (t) to LEO and be evolvable to 130 t or more (Figure 4); lift the Orion Multi-Purpose Crew Vehicle; and serve as a backup system for supplying and supporting cargo and crew delivery requirements for the International Space Station in the event such requirements are not met by available commercial or partner-supplied vehicles. These requirements drive detailed technical trade studies and resource planning as the SLS concept is refined through the development process, in response to the Agency's specific design reference missions (DRMs) and figures of merit (FOMs) (safety, affordability, reliability, etc.).

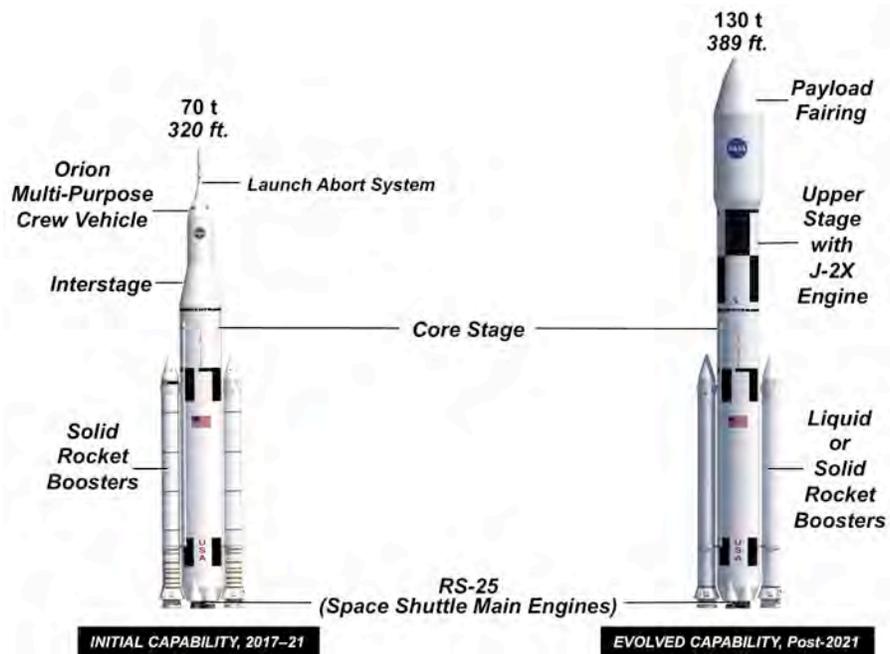


Figure 4. The flexible, modular SLS will be evolved through planned block upgrades.

As shown in Figure 4, the basic SLS design comprises a common 27.5-ft (8.4-m) external tank that delivers liquid oxygen/liquid hydrogen (LOX/LH₂) to RS-25 engines (Space Shuttle Main Engines) to take advantage of 30 years of U.S. experience with this propellant, including manufacturing and launching facilities, and to use the 15 engines currently in stock (Figure 5) [4]. The upper stage shares common attributes with the core stage, such as its outer diameter, material composition, subsystem components, and tooling to capitalize on synergies in those areas. Simply stated, the core stage and upper stage will be designed once and used many times.



Figure 5. Fourteen of the existing RS-25 assets in inventory.

As the SLS is evolved through a series of planned block upgrades, the LOX/LH2 J-2X upper stage engine, now in the testing phase (Figure 6), will provide mission flexibility to suit the performance requirements. The J-2X — an advanced version of the upper stage engine developed for the Saturn IVB and Saturn V launch vehicles — will generate approximately 294,000 pounds of thrust to LEO, or 242,000 pounds of thrust from LEO into deep space [5].



Figure 6. The J-2X testing is in progress at the Stennis Space Center (October 2011).

The SLS initial capability uses the world's most powerful solid rocket boosters (SRBs), now in development (Figure 7). The solid rocket motor is designed to generate up to 3.6 million pounds of thrust at launch. Although similar to the Space Shuttle SRBs, the 5-segment SRB includes upgrades such as a larger nozzle throat and upgraded insulation and liner [6]. The evolved capability will require more-advanced boosters that exceed the current limits of today's technology, providing a competitive opportunity for industry to deliver cost-effective, innovative hardware for deep-space missions post-2021. The engineering demonstration and risk-reduction phase for advanced boosters will begin in late 2011/early 2012, followed by full-and-open competition for design, development, test, and evaluation (DDT&E) [7].



Figure 7. The 5-segment solid rocket booster is in development (September 2011).

The design selected by the Agency comes the closest from among hundreds considered to fitting within a flat \$1.2 billion annual budget, with no planned escalations, and to meeting system-level requirements. This is due to several facts, such as the rocket's relatively simple design (i.e., minimum number of hardware elements to achieve the desired performance) and the plan to start with existing Agency hardware assets and other elements that are well into the development cycle.

This strategy — which is integral to the design analysis cycle as part of the System Requirements Review/System Definition Review process — responds to a nontraditional DDT&E budget curve, which keeps the system affordable and sustainable across the decades that an endeavor such as this will encompass. As such, production and operations (P&O) costs are also considered as independent variables in trade studies, along with nonrecurring development costs.

The SLS architecture is being developed around a low rate of missions, so any additional missions will make it even more affordable. As described, the SLS offers a modular and flexible design that may be configured for the Orion and its associated equipment or may be outfitted with a fairing that encases flagship science instruments and experiments.

III. Potential Missions and Payloads

The SLS will support Orion's missions, including an autonomous demonstration flight around the Moon and back in 2017, and a crewed mission in 2021. This will be the first time astronauts have gone beyond Earth's orbit in over 40 years. The Orion spacecraft will provide emergency abort capability, sustain the crew during space travel, and provide safe reentry from deep space return velocities.

With the SLS rocket, scientists can address some of the most compelling questions imaginable. Design reference missions being addressed through the SLS design process include: LEO, beyond Earth orbit, geostationary orbit, geotransfer orbit, lunar vicinity (Lagrange Point 1), and deep space such as to a near-Earth asteroid and Mars. With its superior lift capability, the SLS can expand the interplanetary highway to many possible destinations, providing transportation to revolutionary discoveries.

Cis-lunar space locations include high-Earth orbit, geostationary orbit, Lagrange points, and other areas between Earth's atmosphere and its Moon. The SLS rocket will enable NASA to verify the potential of these valuable locations for positioning advanced space telescopes and observatories, microgravity processing facilities, and orbiting fuel depots to support construction, fueling, and repair of space systems.

How did the solar system form? Where did Earth's water and organics originate? The SLS rocket can help scientists find these answers — as well as resources to support ever-increasing needs for energy and minerals — on the asteroids that cross Earth's orbit. Potentially hazardous asteroids must be better understood to deploy timely, effective methods for planetary defense, perhaps preventing mass extinctions due to asteroid impacts for the first time in history.

The SLS rocket can take astronauts to Mars and its moons Phobos and Deimos, which are among the most fascinating targets in our solar system. Do they support life as we know it? Can people live there? NASA has learned many exciting things about the Red Planet's environment from the Mars rovers *Spirit* and *Opportunity*, soon to be joined by *Curiosity*. The *Mars Reconnaissance Orbiter* recently helped scientists confirm the seasonal presence of saltwater and raised more questions [8]. In the not too distant future, U.S. astronauts may join forces with robots and science probes, which can neither think independently nor directly detect life on their own, to experience firsthand a land that has many similarities with the home planet.

The SLS rocket may take explorers back to the Moon to discover the cosmic events that shaped it, Earth, and the inner planets of the solar system. Believed to have been the result of an asteroid strike on the Earth, the Moon has a surface area roughly the size of North and South America. NASA recently has confirmed the presence of water stores on Earth's Moon, opening entirely new possibilities for establishing a way station to further destinations, geological operations, and observatories on the dark side of the Moon [9].

The possibility of conducting missions never before attempted makes this flexible capability attractive to multiple partners. A short list of potential partners and payloads includes:

- U.S. Government agencies such as the Department of Defense; Department of Energy; Defense Advanced Research Projects Agency; and National Oceanic and Atmospheric Administration.
- International partners, as reflected in the Global Exploration Roadmap developed by the United States, Canada, Europe, France, Germany, India, Italy, Japan, the Republic of South Korea, Russia, Ukraine, and the United Kingdom.
- Scientific, engineering, and academic organizations such as NASA's Lunar Science Institute and Optimizing Science and Exploration Working Group, the Lunar Exploration Analysis Group, and the International Lunar Exploration Working Group.
- Emerging commercial partners through NASA's Commercial Crew Development and Commercial Orbital Transportation Services contracts, preparing the transportation systems that will provide vital supply lines for future explorers.
- Decadal-class science missions described in the National Research Council's *Vision and Voyages for Planetary Sciences in the Decade 2013-2022* [10].

IV. Management Approach, Plans, and Progress

The SLS management approach engages the existing industrial base and harnesses the critical skills and knowledge the workforce offers. By leveraging investments in heritage systems, while using advancements in launch vehicle design, the SLS concept is moving quickly from the drawing board to the launch complex (Figure 8). The technical challenges of rocketry are daunting. As former Space Shuttle Program Manager Wayne Hale recently opined: “This enterprise is not for the faint of heart” [11]. In this context, he was talking about a series of failures that plagued launch vehicle developments and operations in 2011. Even with a united space-advocacy effort, it is an understatement to say that the SLS Program has a huge task to perform.



Figure 8. The SLS concept on the launch pad at the Kennedy Space Center.

On the list of SLS priorities, affordability is in the top two, with safety being first. The team has contributed many lessons learned over the last few decades and is committed to using best practices from industry and Government so that the SLS Program is executed well within its means. While implementing straightforward lean principles, the SLS team also is injecting a healthy dose of forward-leaning affordability initiatives. The SLS approach includes immediate and future competitive opportunities, intended to spur innovation and drive efficiencies into the system.

Innovation also is a byproduct of being “hungry,” and those who have signed on for the SLS Program are eager and ready to fly. Bringing together wide-ranging backgrounds, the SLS team is product-centric — focused on building and flying hardware. The product is the rocket — processes and documentation must add value toward delivering the product. The expectation has been set for system optimization, with engineering and business solutions that give the best return on investment in terms of both up-front nonrecurring costs and long-term sustainability.

Reducing recurring and fixed operations costs is one of the greatest challenges for the Agency, which must fit human exploration into a budget box that is less than that of the Space Shuttle, yet offers more capability than the Saturn V. Every SLS development activity is an opportunity to calibrate the team and affect cultural change such that affordability is treated as a key performance factor against which success is measured.

As stated above, production and operations costs are carefully considered in tandem with DDT&E activities. With NASA employing modern manufacturing and vehicle processing techniques, implementing risk-based insight/oversight practices, and streamlining contractor deliverables, the many variables leading to affordability are aligning. Figure 9 gives a top-level “fault tree” decomposition that touches on a number of interrelated activities geared toward this goal. The SLS Affordability Plan provides detailed implementation steps for the SLS team.

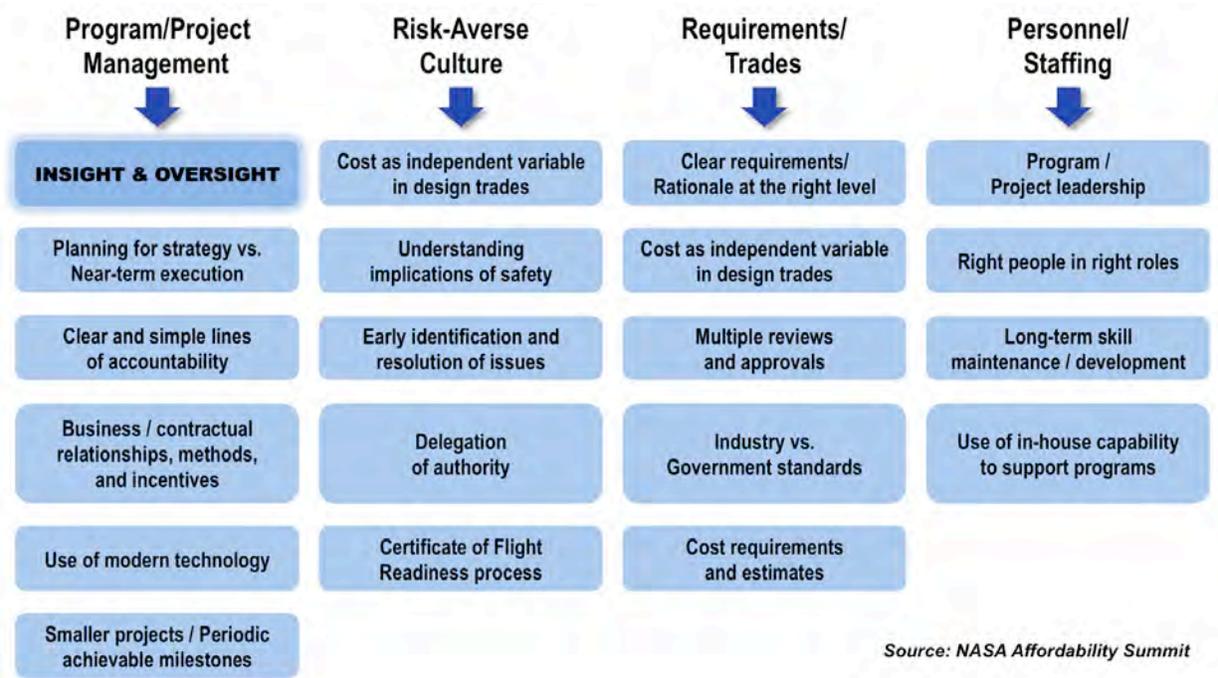


Figure 9. The SLS team is pursuing many opportunities for affordability.

To set the context for the SLS management approach, it is useful to review the undergirding philosophy and assumptions that went into the technical and business trade studies that ultimately led the Agency to select the current configuration, which is now approaching the System Requirements Review/System Definition Review. Cost was the primary figure of merit for both the Government requirements analysis cycle (RAC) teams and the 13 prime-contractor companies that provided input through the Heavy Lift Propulsion Technologies Broad Agency Announcement (BAA). SLS held a technical interchange meeting with industry to further refine insight/oversight suggestions from the RAC and BAA process, and SLS team members are benchmarking profitable companies that employ design-to-cost practices. These and other initiatives will be the subject for future forums and papers.

Within this paradigm, where affordability is an overarching driver, using existing manufacturing and launch-site infrastructure, as well as heritage hardware for early flight capability, quickly emerged as areas ripe for significant DDT&E and P&O cost savings. Along those lines, heavy emphasis was given to design commonality and manufacturing, as well as processing and launch operations simplicity, to keep the budget flat through the DDT&E process, as well as through the out-years. To achieve these design-to-cost goals, the team adopted a “battleship” mentality for robustness, which provides adequate margin to be able to trade performance for cost. This, along with budget reserves held at the lowest levels, streamlines the decision-making process, which is one of the biggest expenses in a developmental program.

The RAC and BAA studies provided cross-validation in many regards. The affordability FOM analyses led to general and specific recommendations that are being addressed early on in the SLS Program’s lifecycle, to infuse this mandate into the fiber of the organization and the Concept of Operations. As a new culture emerges, there is a general revectoring of processes to support product development, not the other way around, and the well-understood expectation that cost is a variable over which the team must exercise judicious control.

To support the reality of the budget climate, SLS managers reduce risk in a number of ways, holding both performance margin and budget reserves to address the unknown-unknowns that inevitably come with engineering feats of this magnitude. By managing cost in a way similar to the way mass is managed, SLS will deliver a 70 t near-term capability that provides lift for Orion in an affordable way.

There are databases and volumes of launch vehicle studies and plans. The SLS process has added to that impressive library. Now, it is time to execute. There are many opportunities for affordability (refer to Figure 9), and the SLS Program is putting a platform in place that serves as a substratum for building in efficiencies on the front end, in ways that support a positive balance sheet in the operations phase.

These principles and practices are being lived daily by a lean team dedicated to doing the right thing in terms of driving affordability into the SLS vehicle’s design, knowing that as much as 80 percent of fixed costs are set during the design phase. There are some things over which rocket developers have no control, but designing to cost is one of the variables over which the SLS team has total control. Empowering some of the world’s top rocket scientists to find new solutions to age-old problems is one of the challenges, and rewards, of program management.

The SLS team has logged many recent accomplishments, including moving from the concept phase into the formulation phase by meeting various Agency decision-gates. The SLS architecture was rolled out by the Agency on September 14, 2011. The SLS Program followed this event with an industry day on September 29, to share the acquisition strategy firsthand with 600 potential business partners and with others watching via the NASA television channel. The SLS Program has provided information to its various stakeholders — from elected representatives, to potential payload provider and partners, to the American public — through a series of interviews, news conferences, and a publically available website at www.nasa.gov/sls.

Given in Table 1 below are some of the upcoming milestones that the SLS team is working toward. Combined with the continued testing of the J-2X upper stage engine at the Stennis Space Center and development of the 5-segment solid rocket booster, plans are being made with partner programs Orion and 21st Century Ground Operations, through NASA's Human Exploration and Operations Mission Directorate, to deliver the next-generation human space flight system.

Table 1. SLS milestones.

Activity	Date
Cross-Program System Requirements Review	December 2011
SLS System Requirements Review/System Definition Review (SRR/SDR) Kickoff	February 2012
SLS SRR/SDR	March 2012
Preliminary Design Review	FY13
Critical Design Review	FY15
Design Certification Review	FY16
First Flight: Orion Autonomous Beyond-Earth Orbit Demonstration	December 2017

It is the blending of the technical and programmatic that creates the healthy tension between the laws of the land and the laws of physics. The SLS Program will be continually challenged to strike a balance between having performance margin to spare and keeping budget reserves to address the unknown unknowns that surely will come with an endeavor of this magnitude and complexity. Building and flying the SLS will be one of the most demanding jobs on the planet, performed by those with the passion to deliver a new national capability for a new day in space.

V. Conclusion

Creating a sound technical climate and business case for sustainable exploration has far-reaching ramifications. Supported by NASA's 2011 Strategic Plan and validated by numerous internal and external and stakeholder organizations, the SLS gives missions defined by the International Space Exploration Coordination Group, the National Research Council, and others a mode of transportation out of Earth's orbit for astronauts to explore new worlds and science instruments to rewrite textbooks with new knowledge. The SLS provides the capacity required for entirely new flagship missions and is an impressive asset with which to advance the U.S. aerospace enterprise and exploration agenda, taking human explorers farther than ever before (Figure 10).



Figure 10. The 70-t SLS will be ready to launch in 2017.

As the SLS design is matured through its forthcoming lifecycle reviews — where peers and independent examiners grade the team's work and give advice — SLS personnel are focused on the rocket as the ultimate product. The SLS planning strategy includes using existing hardware and finishing developments in progress, as well as appropriately incorporating advanced technologies if the return on investment supports the Agency's affordability goals. The overall vehicle design is flexible, evolvable, and provides incremental stakeholder value by fielding an initial capability that is successively refined in line with the budget realities and ever-evolving landscape and space-scape.

NASA's vision is "To reach for new heights and reveal the unknown, so that what we do and learn will benefit all humankind" [12]. The first plank in NASA's strategic goals is to "Extend and sustain human activities across the solar system." The SLS forms the backbone for taking the next step into the great unknown. The SLS team is dedicated to meeting its commitments and doing things differently for the right reasons — to create an entirely new national capability that directly supports America's future in space. The ultimate benefit of this approach will be to decrease the price of flying the Agency's launch vehicle fleet so that more resources can be dedicated to opening the frontiers of science and technology, while solidifying America's leadership in space through human space flight missions that are worthy of a great Nation.

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