

**Hearing of the House Committee on Science, Space, and Technology
Subcommittee on Space and Aeronautics**

**“Developing Core Capabilities for Deep Space Exploration: an Update on SLS,
Orion, and Exploration Ground Systems”**

Wednesday, September 18, 2019

**Testimony of Douglas R. Cooke
Cooke Concepts and Solutions**

Thank you Chairwoman Horn and members of the committee for this opportunity to address the current state of Deep Space Exploration. It is a passion I have devoted much of my life and career to for many years. I feel a certain ownership and responsibility for the Space Launch System, the Orion Crew Vehicle and Exploration Ground Systems as well as many other aspects of our U. S. Space Program.

I began work at NASA just after Apollo, during the last flight to Skylab. I worked in critical positions on Space Shuttle, Space Station and Exploration Programs anticipating the day Americans would travel again and explore places like the Moon and Mars. I believe that NASA human space flight should focus on exploration beyond Low Earth Orbit and transfer the routine travel to Earth orbit to American companies, as they become proven ready, safe, and certified.

I applaud your continued bipartisan support. I also applaud the people at NASA and in industry who work diligently every day to make these and other important space programs successful.

This year, we are celebrating the 50th Anniversary of the Apollo Missions, with the anniversary of Apollo 11 just this past July. Numerous lessons from the Apollo, Space Shuttle, Space Station and Exploration Programs come to mind that should be heeded as we prepare to return explorers to deep space, first to the Moon and then to Mars.

Part of the discussion today will be about the current status of these exploration programs. I know that they are striving to succeed, and believe they must succeed. I will leave the exact status to NASA, representing the programs.

In my written testimony I will provide:

Part-1 a brief history of how SLS and Orion came to be designed based on goals, objectives, requirements and constraints. I will describe what they were designed to do.

Part-2 my views on the current NASA architecture and the roles of SLS and Orion.

Part-3 given the Exploration Program status, some views on potential improvements in the management approach of these programs.

All of these views are my own.

Part 1

How the Space Launch System and Orion are to Be Designed Based on Goals, Objectives, Requirements and Constraints

With the discussions that revolve around the Space Launch System, it is helpful to understand how and why it came to be. This is intended to be a discussion on how this launch vehicle was programmatically and technically shaped by space policy, mission objectives, the technical requirements, schedule and budget, and the realities of the assets and technical capabilities of NASA and the U.S. space industry. My direct experience in Moon and Mars human exploration planning and trade studies has spanned 30 years of participating in, leading, or being responsible for many, if not most of these efforts for human exploration beyond Earth orbit. I will focus on the work accomplished in this era leading up to the SLS and Orion.

It is best to start the discussion by defining what missions are to be addressed and how those drive requirements and what capabilities are needed.

Driving Factors in Development of Requirements

Space Policy

Space Policy sets the framework for what is planned. It has been based largely on a desire for U.S. leadership and a desire for knowledge. These goals can be augmented by desires to reach particular destinations and implementation approaches. The actual implementation is generally shaped by physics and what is practical.

In 1989 on the 20th anniversary of Apollo 11 President George H. W. Bush gave a speech on the steps of the Smithsonian Air and Space Museum. He set the human space policy for returning to the Moon- “Back to stay,” and a “Manned Mission to Mars.” This began what came to be known as the “Space Exploration Initiative.” There have been updates to space policy since that time, including President George W. Bush’s “Vision for Space Exploration” in 2004, the NASA Authorization Act of 2005, the cancellation of the Constellation Program under President Obama, and the Authorization Act of 2010. All of these had an effect on the ultimate design of today’s Space Launch System. Now we have directives from President Trump and his Administration.

In response to high level guidance there have been numerous NASA agency-wide and independent studies to define the missions and the architecture of space vehicles and infrastructure needed to achieve the goals of human space exploration. These efforts have contributed to the rationale and requirements for the Space Launch System. Requirements included not only those for lift performance, but also other factors such as payload size, safety and reliability. The policy of course continues to evolve in terms of how and when the SLS and human exploration end goals will be accomplished.

Factors Influencing Design- Driving to Requirements

Establishing Objectives for Human Exploration

It is important to develop and weigh what the exploration missions should achieve, before discussing what capabilities to develop. Those objectives define the exploration architecture and scale of operation that will be required. Significant effort over the years has helped to define what those objectives should be. A focused NASA effort in 2006 set out to gather lunar objectives from the broad science/exploration community and all stakeholders. This began with a workshop of these experts and led to a continuing effort with the international space community to refine them. This effort continues through the work of the International Space Exploration Coordination Group (ISECG). The objectives were organized into the themes of Human Civilization, Scientific Knowledge, Exploration Preparation (Mars), Economic Expansion, Global Partnerships, and Education.

As a basis for establishing these objectives, an understanding what is currently known about the Moon is essential. Much had been learned from the Apollo missions and the samples that were returned. Evolving instrumentation technology has led to new discoveries from these incredible samples. In 1994, long after Apollo, the Clementine mission flew to lunar orbit with its instruments, and from the data scientists discovered the potential for water-ice in the permanently dark craters in the Polar Regions. All of the information gathered at this point from the Apollo and Clementine missions led to many new objectives to shape exploration of the Moon. These included many scientific objectives to learn more about the Moon, its history and potential resources. This lunar history is of particular interest, because it is shared with Earth's due to the Moon's close proximity. The Moon has no wind or water to erode the historic evidence as they do on Earth. This provides the opportunity to investigate billions of years of exposure to the Sun's solar wind, meteor impact history and other phenomena. For example, the meteor/meteorite impacts that caused many lunar craters indicate a similar experience witnessed by nearby Earth. But here on Earth the history is largely eroded away. The potential for being able to use water-ice and other resources has added to significant interest in the Moon. Much more detailed data and mapping of other lunar resources has been provided by the Lunar Reconnaissance Orbiter (LRO) and the Lunar Crater Observation and Sensing Satellite LCROSS, which were launched together in 2009. LRO has also provided significantly enhanced surface imaging and mapping that have contributed to better understanding of the Moon's features and provides important data to enable the effectiveness of human and robotic missions. LCROSS impacted one of the Moon's polar craters and measured resources in the plume that was produced by the impact. LRO and LCROSS were specifically planned and funded to prepare for renewed human exploration of the Moon. The Gravity Recovery and Interior Laboratory (GRAIL) mission(s), launched in 2011, have provided the valuable information on the internal makeup of the Moon and its effects on the irregularity of the gravity field. This

information is of scientific interest, but also helps to plan more stable orbits around the Moon.

Another important lunar objective is to gain experience in operating on another planetary body in preparing for human exploration of Mars. Yet another objective is the importance of working with international agencies and industry in furthering relationships and US leadership in space. Details of the possibilities for exploring the Moon can be found in the works of the late Paul Spudis and literature of many others who continue studying the Moon and learning from available evidence.

Mars has long been of exceptionally high interest as the planet most like our own. NASA has sent numerous successful spacecraft to land on and orbit Mars. Scientists have learned that it once had running water and had more of an atmosphere than it does today. The data from Mars missions has led scientists to believe there is still water under the surface that could possibly support life. As a result, the development of Mars objectives has been actively pursued for years. There have been incredible discoveries and research based on the robotic Mars missions. There has also been significant work in studying the available resources on Mars and how the water and Carbon Dioxide atmosphere can be utilized to enable/enhance Mars human missions in the future. There is a large body of publicly available work that can be found to gain a more detailed understanding of the potential for further exploration of Mars.

This provides a minute peek at what has driven objectives for human exploration of the Moon and Mars. The intent has always been to reasonably achieve more than “Flags and Footprints” missions.

Defining Requirements for Capabilities to Achieve Objectives

The exploration and science objectives have driven many, many trade studies across the space community over the last 30 years for what is needed in the way of exploration capabilities. They have helped define the scale of operations, mission design and the necessary infrastructure. Objectives have led to the priority of landing sites, which in turn define the lighting, thermal, dust, and radiation environments. These environments form part of the requirements for the surface systems. Examples of needed capabilities include launch vehicles, in-space vehicles, landers, ascent vehicles, habitats for astronauts, rovers, power and thermal systems, science experiments, and potentially mining and resource extraction systems. These integrated studies included developing relatively detailed conceptual designs for each of the elements to understand their mass and sizing. A major part of these studies was also to identify enabling technologies to minimize mission masses and complexity, which seriously affect how much has to be launched from Earth. This relates directly to the overall cost for exploration missions.

Defining an effective exploration architecture, complete with hardware concepts based on the most practical, but enabling technologies leads to sizing of these architecture components in terms of mass and size. This information drives the requirements for the launch vehicle(s) that have to launch them from Earth. They lead to a definition of the

needed capacity in terms of payload diameter and volume in addition to lift performance. Reliability, probability of mission success, and crew safety are also major factors in the definition of the primary launch vehicle(s), numbers of launches per mission, and launch frequency.

Result- Basic Heavy Lift Vehicle Requirements

The **sizes and masses** of each of the space infrastructure elements that must be launched from Earth drive the performance requirements of the primary launch vehicle. Studies that ultimately led to the Space Launch System included both the Moon and Mars as destinations for human missions.


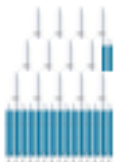


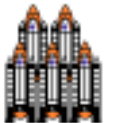




Either and/or both destinations led to the same conclusion. Example- In terms of lifting the mass needed for a single crewed mission to Mars, it would take a non-conservative estimation of six to seven 100+ metric ton launch vehicles. That is assuming advanced technologies for in-space propulsion, structures, aero-braking at Mars, life support systems and others. The major elements to be launched are a surface habitat, a lander/ascent vehicle, a transit habitat and systems for the crew, an in-space propulsion system and other necessary surface systems to enable the mission. In addition significant amounts of fuel are needed for the orbit transfers between the Earth and Mars, landing and ascent at Mars.

Over the years, it has been suggested many times by people inside and outside NASA that existing Evolved, Expendable Launch Vehicles (EELVs) could provide the launch capability rather than build a big new rocket. This would be a fortunate solution if it were realistic. Unfortunately thorough studies showed that it is not, because it would take tens of launches, approximately 27 or more EELV (assuming 23 MT to orbit) launches to lift the same amount of mass as the 6 to 7+ heavy lift (100+ MT) vehicles. Complications in planning to these performance numbers occur because of inefficiencies in packaging the flight elements/payloads. It is not always possible to effectively use the entire lift capacity, because of packaging inefficiency. Breaking designs down to fit into smaller launch vehicles, creates the need for complex and heavy interfaces to join the components during assembly. These interfaces include complex latches, electrical and fluid connections. The average packaging efficiency is about 70 to 75% which compounds the problem of numerous launches. For a mission to Mars, a large part of the cargo is fuel to get there and back. Cryogenic fuel boil-off while loitering in space and assembling the mission components also leads to more fuel launches. This points to one of the important technologies that will be needed- cryogenic fuel management and transfer. The following chart is only illustrative of the issue as mission numbers and launch probabilities have evolved.

Exploration Launch Comparison for a Mars Mission

Chart from 2002

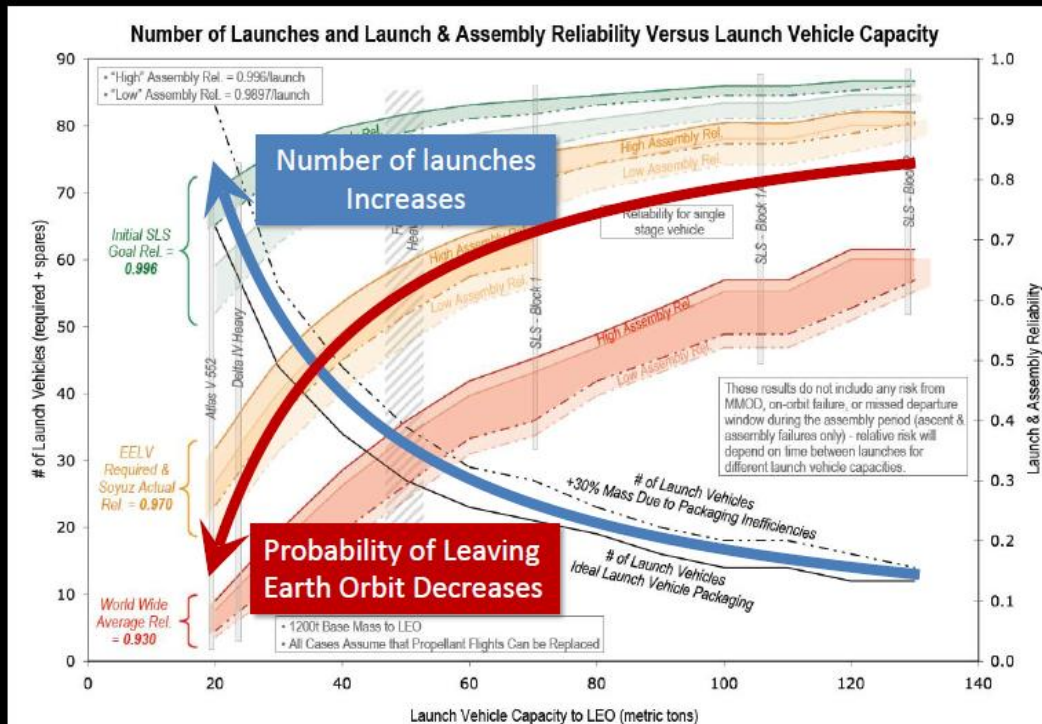
* Note: A launch mass packaging efficiency of 75% is assumed for on-orbit assembly

	Telescope Assembly IMLEO = 150 mt *	Lunar Expedition IMLEO = 240 mt *	Mars Mission IMLEO = 450 mt *
<u>EELV-H</u> Payload to LEO = 23 mt Probability of Launch Failure = 1/40	 <p>9 Launches 80% Prob. Of Launch Success</p>	 <p>13 Launches 72% Prob. Of Launch Success</p>	 <p>27 Launches 50% Prob. Of Launch Success</p>
<u>Shuttle-Class</u> Payload to LEO (small shroud) = 71 mt Payload to LEO (large shroud) = 60 mt [Assumes 4-segment SRMs] Probability of Launch Failure = 1/400	 <p>3 Launches 99% Prob. Of Launch Success</p>	 <p>5 Launches 99% Prob. Of Launch Success</p>	 <p>10 Launches 97% Prob. Of Launch Success</p>
<u>In-Line HLLV</u> Payload to LEO = 100 mt Probability of Launch Failure = 1/400	 <p>2 Launches 99% Prob. Of Launch Success</p>	 <p>3 Launches 99% Prob. Of Launch Success</p>	 <p>6 Launches 98% Prob. Of Launch Success</p>
	<i>Telescope Assembly mission includes launches for infrastructure buildup</i>	<i>Lunar Expedition includes launches for infrastructure buildup</i>	

With increasing numbers of launches, the risk of mission success decreases statistically due to the probability of a launch failure. The reduction in the probability of mission success decreases dramatically as the number of launches (and critical operations) per mission increases.



Example Relationship Between Launches and Reliability



The number of launches for EELV class vehicles was not thought to be practical for a single mission to Mars. Assembly of the International Space Station shared this risk, since it took 40 Shuttle flights to complete. Fortunately, building the Space Station without a mishap on an ISS Shuttle assembly mission was achieved, but there was no room for margin- no backup flight elements. If the Columbia failure had occurred on an assembly flight with a unique flight element, the impact to ISS would have been severe. Using 6 to 7 EELVs for launching lunar missions was also thought to be excessive.

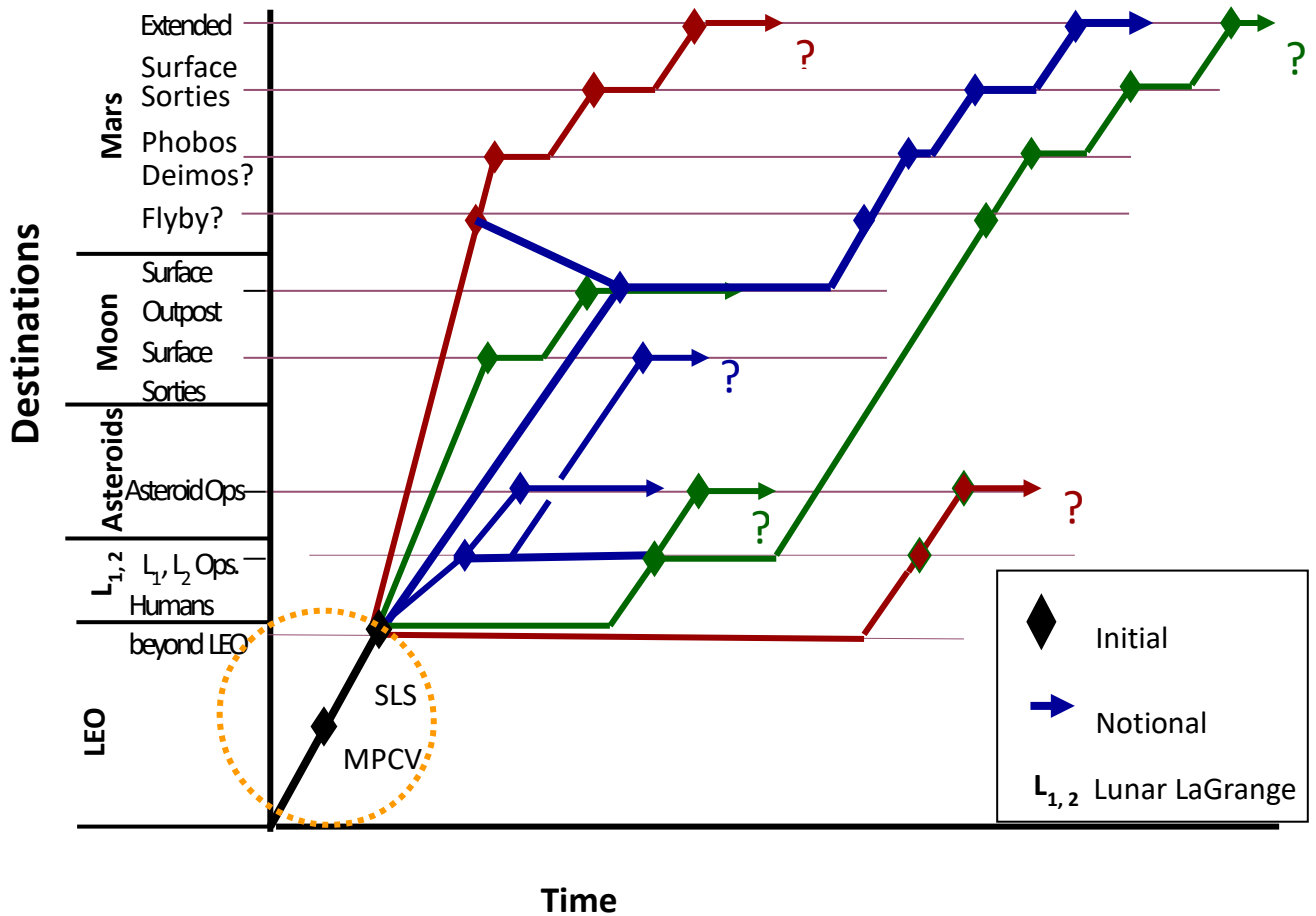
The launch mass is only one part of the problem to be addressed when sizing a launch vehicle. From the earlier discussion exploration mission components are sized by what the missions are to achieve. Lander sizing must accommodate the various payloads it must transport to the lunar or Mars surface. These include ascent vehicles, surface habitats, rovers, and other surface systems. Payloads, such as landers, human habitat modules, future large space telescopes, and other large in-space vehicle designs are enabled by the diameter and volume of a large payload shroud only possible on a heavy lift vehicle that has a large diameter core stage. For instance, landers for the Moon or Mars benefit from the larger diameter to make them wider than they are tall, lowering the center of gravity. This reduces the possibility of turning over if the landing is on a

slope. The diameter and volume aspect of the launch requirement is not often addressed in debates on launch vehicles.

The consideration of mass, volume and diameter along with mission risk probabilities have consistently resulted in the requirement for an SLS class launch vehicle for missions to the Moon and Mars.

Basic Crew Vehicle Requirements

Human Exploration capabilities begin with the heavy lift vehicle as described and a vehicle for transporting the crew into space and returning them safely. There are obviously many specific important requirements for the crew vehicle, such as for life support systems, etc. This vehicle was designed to the requirements for an exploration class vehicle and crew of 4 to 6. Studies have shown that for exploration, the crew vehicle is primarily designed for launch and entry at Earth. In the case of Moon missions the vehicle design can be extended to crew transportation to and from the lunar vicinity because of the relatively short duration, approximately three days one way. For longer mission durations such as to Mars or to asteroids, the crew need more habitable volume, more complex life support and consumables. One of the primary drivers is protecting the crew during entry heating. Entry velocities when returning from the Moon (11M/sec) or Mars (~14 to 17M/sec) are much higher than returning from Earth orbit (7.8 M/sec). Earth entry heating increases drastically with velocity. So the heat shield has to be designed for this heating. Heating for lunar and Mars returns drive the vehicle to a blunt capsule shape and materials that can protect the temperature of the vehicle structure. A winged vehicle for instance is not practical. The Space Shuttle could not have survived at these velocities for example. The stay time in deep space was set at 21 days for this vehicle. Beyond that requires more extensive accommodations and consumables. This is well beyond the support capabilities needed for transfers between Earth and Low Earth Orbit (LEO)/ ISS. The propulsive needs of a deep space crew vehicle are also more than what is required for LEO. It must provide the propulsion for orbit transfers and more extensive maneuvers.



Conclusion- Potential Strategies for Mission Architecture Pathways from Earth Begin with Critical Capabilities- A Heavy Lift Vehicle and a Crew Vehicle for Launch and Entry

The Congress and Administration through the 2010 Authorization Act; and the Chinese and Russians, as reflected in announcements of their intentions, have recognized the need for heavy lift. For the reasons discussed, sustainable human exploration beyond Earth orbit is not practical without heavy lift of 100 to 130 metric tons lift capability to orbit and large payload volumes. It has been a requirement for those have seriously looked at all aspects of design practicality and mission risk. This level of launch capability and operations is not beyond reason. The Space Shuttle launch system launched the Orbiter and its payload into orbit, the total being on the order of 100 MT. Launches occurred several times a year. This launch capacity is something that we have accepted as a norm and has been necessary for human space flight.

Continuing the Path Leading to the SLS Design

The Vision for Space Exploration (VSE) - Update to the Analysis

President George W. Bush announced the Vision for Space Exploration, on January 14, 2004. This vision set a direction for “a sustained and affordable human and robotic program to explore the solar system and beyond.” It set the path for human exploration to the Moon and Mars “and beyond.” It also directed NASA to advance technologies to support this vision and promote international and commercial participation. For the first time, since the Apollo Program, NASA was given a significant budget to pursue development of the flight elements for human space exploration to the Moon and Mars. This direction ultimately led to an in depth and broadly based study known as ESAS- Exploration Systems Architecture Study. There were hundreds of NASA employees from across NASA with a core team at NASA HQ studying and comparing hundreds of combinations of vehicles to satisfy basic requirements. The team recommended the designs that would enter development.

Two launch vehicles were chosen, one for crew launch and one for cargo launch. The crew launch vehicle was to be developed first to transport crew to and from the ISS, since the retirement of the Space Shuttle was projected at the time for 2010. This new launcher was later named Ares I. It consisted of a solid rocket booster with 4 segments, derived from the Space Shuttle boosters, and a Liquid Hydrogen/Oxygen upper stage with a RS-25 engine derived from the Space Shuttle Main Engine (SSME). The design was chosen to take advantage of heritage designs for quick development, and because the probability for loss of crew was much lower than any competing design. The second vehicle was chosen to satisfy the heavy lift requirement for both lunar and Mars missions. It shared components with Ares I to save development and recurring cost. It was to have 2 five segment boosters, derived from the Shuttle boosters and a liquid Hydrogen/Oxygen core stage with 5 RS-25 engines. It would have an upper stage using two J 2S engines derived from the Saturn V upper stage engines. It was named Ares V. Other configurations were analyzed and compared but did not compare favorably when combined factors of cost, risk and extensibility to Mars missions were considered.

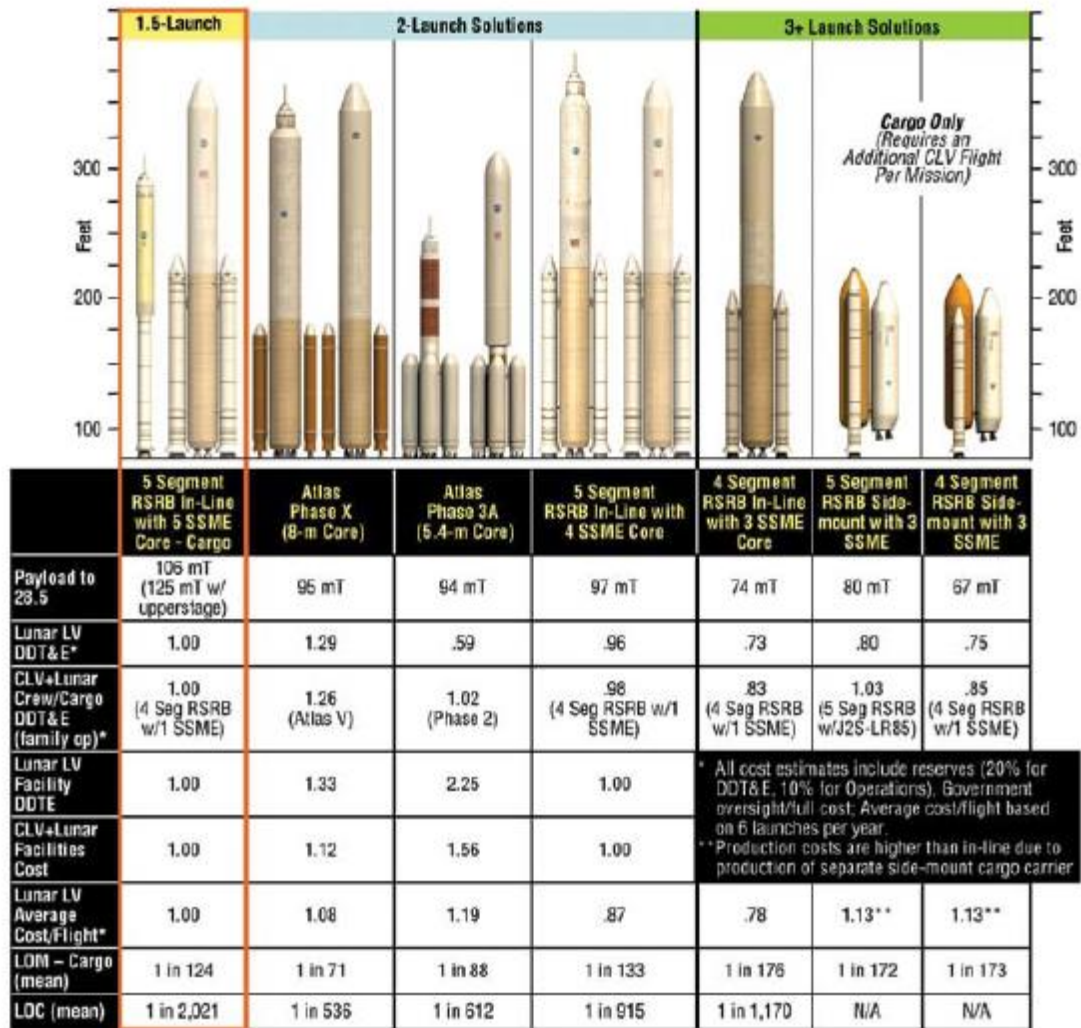


Table from the ESAS report.

After ESAS was completed and the Constellation Program was set up, design studies continued to increase the fidelity of performance, cost, risk, mass of vehicles, etc. Reference designs evolved as a part of this work and as additional factors came into play. The Orion crew vehicle diameter was changed from 5.5 meters to 5 meters. The Ares I first stage was changed to a five segment booster for increased performance. The Ares-1 liquid Hydrogen/ Liquid Oxygen core engine was changed from an RS-25 to a J 2S and be common with the Ares V upper stage engines. Although the RS-25 has been demonstrated to be a reliable in engine in the Shuttle Program, it had never been qualified to be started at altitude as an upper stage engine. The J 2S had been designed as an upper stage engine. The Ares-I upper stage engine would then be common with the Ares V, saving further development cost. This engine was renamed the J 2X engine.

Over time studies led to the adoption of an Ares V core stage using the Liquid Oxygen/ Liquid Hydrogen RS-68 engine from the Delta 4. The RS 68 was in production and had

much more modern manufacturing technology than the RS 25. Using it would make it common with the Delta, potentially saving unit costs. The down side was that the RS 68 had features that would have to be redesigned to human rate it. It also was lower efficiency than the RS 25 and would require a 33 meter diameter vs. 27.5 meter for the RS 25 core stage to hold the additional fuel that would be required. The stage could not be stretched, because the height of the hydrogen tank was constrained by the structure for the forward attach point of the 5 segment solid boosters. The additional diameter would also negate use of Space Shuttle heritage ground equipment. Still, the RS 68 solution was attractive because of the engine manufacturing efficiencies.

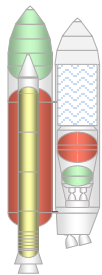
As the newest initiative in human spaceflight at NASA and being early in its development (not operational), the Exploration Directorate had to pay for a few large unanticipated human space flight bills, such as extra Space Shuttle flights. There was also a full year continuing resolution in 2007 that cost the directorate about \$577M.

Change in Administrations from President Bush to President Obama- Update to the Exploration Approach

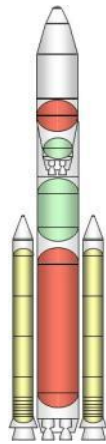
In the budget that was released in February 2009, the Exploration budget was further reduced in the out years, almost exactly the amount of the wedge for lunar developments for Ares V and a lunar lander. Ares I and Orion still had funding and for 2009 and 2010 that was actually higher than proposed the prior year. This budget was not challenged by Congress as they waited to see what policy the Obama Administration would come out with. In the summer of 2009 the Administration was announcing the initiation of an independent review of “ongoing U.S. human space flight development activities as well as alternatives to ensure that the Nation is pursuing the best solution for future human space flight.” It was known as the Augustine Committee review. The committee looked at 5 mission options within the projected budget. Not surprisingly, since the recently released budget runout had been reduced from prior projections, finding an exploration path was not possible. From their report “Seeking a Human Space Flight Program Worthy of a Great Nation,” they stated “Human exploration beyond Earth Orbit is not viable under the FY 2010 budget guideline.” “Meaningful exploration is possible under a less-constrained budget, increasing annual expenditures by approximately \$3B in real purchasing power beyond the FY 2010 budget guidance.”

The Augustine review and surrounding discussions began to indicate that there was pressure to move towards commercial crew transportation and away from Ares I. There was growing interest in the heavy lift vehicle needed for exploration missions. There were different camps with competing ideas of what it should be even though there was a baseline for Ares IV/V. The Exploration Systems Mission Directorate (ESMD) and Space Operations Mission Directorate (SOMD) decided to initiate a broad study comparing all of the viable approaches with experts from across the human space flight field centers. A special effort was made to pick the leadership of the team and set the ground rules to make sure that the concepts were compared on an apples to apples

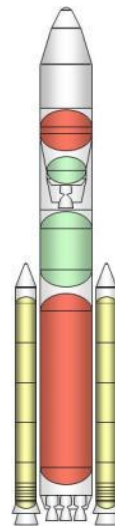
basis. These were thorough studies that compared launch capabilities for all foreseeable human mission destinations, including the Moon, asteroids, Lagrange points and Mars. The concepts were evaluated comparing launch performance, safety and risk, reliability, operability, extensibility to all possible human space flight destinations, cost and schedule. Results narrowed the possible solutions to competitive approaches. The shuttle side-mount approach was eliminated as not fully addressing program performance needs for all destinations. The in-line rocket approaches based on RS-25 engines/solid boosters, RS-68 engines/solid boosters and Liquid Oxygen/Kerosene (RP) engines could each accomplish the missions. Each had their pros and cons when comparing the various metrics. The concepts are shown in the following table. NASA studies continued to refine the designs and comparisons between the in-line concepts.



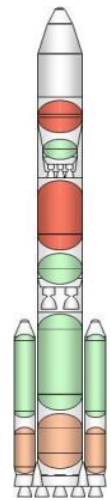
Shuttle Sidemount



RS 25 based In-line



RS 68 based In-line



RP based In-line

Primary concepts studied in ESMD/SOMD joint study

Cancellation of Constellation Program- February 2010

With the rollout of the President’s Budget Request (PBR) in February, 2010, the Administration announced the cancellation of the Constellation Program, including Ares I, Ares V, and associated Ground Systems. The proposed budget replaced the program with increased spending for research and technology, technology flight demonstrations, a hydrocarbon rocket engine technology program, spending on a commercial crew program, and closeout of the Constellation Program.

Within days a letter was written to the NASA administrator signed by 29 members of the House of Representatives warning against terminating Constellation contracts. The letter stated “the Consolidated Appropriations Act for Fiscal Year (FY10) contained bill language prohibiting NASA from terminating current programs which are part of Constellation and also from initiating new programs.” This put NASA into a period of maintaining contracts but not starting new tasks. Contracts were maintained with very constrained funding levels to prepare for the most constraining budget outcome between the policy proposed in the President’s Budget Request and the intent of Congress. Studies continued on heavy lift vehicle options.

NASA Authorization act of 2010

In October, 2010, the 2010 NASA Authorization Act was passed. This Act established the policy of building the Space Launch System and a Multi-Purpose Crew Vehicle (MPCV) for Exploration missions beyond Low Earth Orbit. The Act specified the initial SLS performance was to be between 70 and 100 MT to low Earth orbit with the ultimate capability to be at least 130 MT. The 2010 Act also directed NASA to utilize and modify existing contracts to the “extent practicable” to reduce termination costs.

Decisions for SLS

NASA immediately began work on a program formulation plan to define final configurations for SLS and the Multi-Purpose Crew Vehicle (Orion) and develop acquisition plans. SLS planning was based on the ESMD/SOMD joint study results at that point. The decision would be between in-line concepts- a LOX/RP first stage, an RS-25/solid rocket based first stage, or an RS-68/solid rocket based first stage. A Requirements Analysis Cycle was begun to look for ways to improve affordability of the design. A Broad Area Announcement (BAA) was released to industry- requesting ideas and innovation from the aerospace community, and look for onramps of new capabilities. Thirteen companies were funded through the BAA to provide NASA recommendations. Acquisition planning was begun to determine the best path forward for contracts.

Important parameters for SLS were essentially the same as those from past studies. The basic exploration requirements had to be addressed, including lift capability, payload volume and diameter, which was consistent with the direction in the NASA 2010 Authorization Act. As before safety and risk, reliability, operability, extensibility to potential human space flight deep space destinations, cost and schedule were all important considerations.

Schedule differences between designs were very important. The programs were obviously vulnerable given the recent history, so the most expeditious development schedule was a major factor. Acquisition strategies, including the potential use of current contracts and/or assets was a major factor in schedule.

The budget was still very constrained. Budget became the gate for the ultimate decision.

There were additional factors that had to be considered along with the rationale and requirements for the launch vehicle. What was the state of propulsion technology? What was the effect of vectoring the government/industry work force? What was the effect on the space industrial base? These were not trivial factors. It was important to consider the state of investments in large launch vehicle capabilities and components, the state of technology, reliability, and cost compared with what could be accomplished with new designs and potentially newer technologies. It was important to understand the current state of NASA and aerospace industry expertise and manufacturing capabilities for the potential alternatives. These aerospace industry capabilities have been driven by long-past programmatic decisions such as cancellation of the Saturn program with its huge kerosene first-stage engines, the capabilities from the development of Evolved Expendable Launch Vehicles (EELVs) and the development and long-term reliance on the Space Shuttle Liquid Hydrogen engines and solid rocket boosters.

In evaluating the LOX/RP (kerosene) option, history showed that the U.S. had invested very little in large RP engine technology and had no production since the Space Shuttle design decision was made 40 years earlier. NASA had invested in development of the large liquid Hydrogen/liquid Oxygen Shuttle Main Engine years prior to the Shuttle decision. At that time NASA wanted to use a booster employing the large Saturn V RP F-1 engine for the Shuttle. OMB showed that using large solid rocket boosters would be more cost effective than the F-1 booster, since the Titan IV was also using large solid boosters at the time. There would be cost savings in the shared technology and infrastructure. The decision was to employ solid boosters for the Space Shuttle. The development time and cost to design and build a new large RP engine for SLS would not fit the budget and schedule.

In comparing the RS-68 and RS 25 based versions, the RS 68 was attractive, because of its advanced manufacturing techniques. However as stated earlier, there were design fixes that were needed to human rate it and the tank design would be a larger diameter and more expensive than the RS-25 based design. The tank diameter was driven by the difference in engine efficiency, the RS 25 being more efficient. The tank diameter for the RS 25 was the same as the Shuttle external tank, and there were savings in ground handling equipment. The Shuttle main engine (RS 25) was obviously human rated, and it was still state of the art in LOX/Hydrogen engine performance- near theoretical limits. The engine design had been evolved throughout the Shuttle program to fix problems and improve reliability. The manufacturing technology would have to be improved in the future. The other major benefit was that there was an existing inventory of Shuttle engines that would be available when the Shuttle was retired. Any near term cost would be minimal.

The solid booster technology and much of the hardware for many flights came directly from the Shuttle Program. A five segment booster had already been ground tested as

part of the Constellation Program. Improvements had been made over its life and during Constellation. It was a low risk asset.

As stated earlier the budget was a gate to pass. There was little money for new development in the SLS Program. Development money had to be spent on the Core Stage, consisting of the main Hydrogen and Oxygen tanks, the main propulsion system (highly complex controls plumbing, valves, instrumentation, etc.) and integration of the main engines. There were enough existing RS 25 engines from the Shuttle Program for a number of flights. Solid booster final design and testing would be completed. The RS 25 based design was the lowest in near term cost. The return on investment for the RS 68 was better long term, but the payoff was many years out. The decision was to develop the RS 25 based core stage with the five segment solid rocket boosters.

At the time of the decision the upper stage for the SLS would be based on the Ares I upper stage using the J2X, which was under contract. The stage size would be increased to reach the 100 to 130 MT SLS lift capability. A decision was made to use the Delta IV upper stage (renamed Interim Cryogenic Propulsion Stage-ICPS) for the first SLS test flight.

The Orion Design Decision

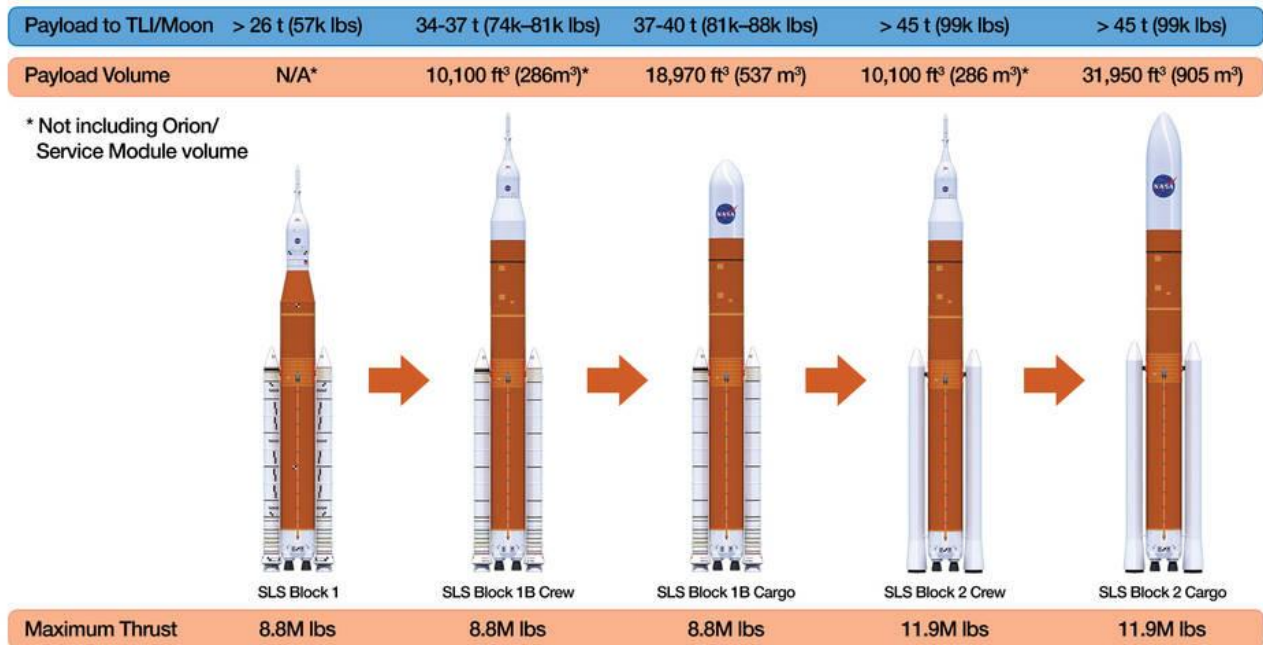
Orion went through a decision process equivalent to the SLS process, and decisions were made at the NASA Administrator level. The decision was to continue with the Orion design, which was ongoing and addressed all of the deep space requirements. Commercial Crew vehicles, which were just getting underway, did not have the requirement to protect for deep space Earth entry velocities or mission duration that Orion did. The deep space mission also required more fuel in the service module for deep space propulsion and maneuvers. This drove the combination of abort systems and service modules to different design concepts.

Summary

All of the factors; space policy, mission objectives, performance and safety requirements, and space industrial base expertise and capabilities were traded and weighed against available budget, which was the biggest constraint, and the objective of having near term accomplishments- schedule.

Resulting SLS Design Implementation

The first stage utilizing the RS 25 and five segment solids is nearing completion and test flight hardware is being completed. The upper stage concept has changed to use the RL 10 engine. This stage is called the Exploration Upper stage. The RL 10 is a proven engine with many years of service. This combination can deliver 100 MT to Low Earth Orbit and is responsive to the requirements for human exploration of the Moon and Mars. It is also responsive to direction in the 2010 NASA Authorization Act for the lower end of the performance range (100- 130 MT). It is shown in the figure below as SLS Block IB for crew and cargo versions.



Part 2-

Views on Use of the SLS in the Current NASA Architecture

The role of the Orion capsule is used in a standard way based on deep space requirements. Therefore this discussion is based on SLS utilization in the architecture, once again, starting with top level requirements. The Trump Administration has taken a keen interest in the U.S. role in outer space. These have been reflected in specific directives. The President Trump Space Directives 1, 2 and Pence Policy Statement are most relevant-

Space Directive 1:

"The directive I am signing today will refocus America's space program on human exploration and discovery," said President Trump. "It marks a first step in returning American astronauts to the Moon for the first time since 1972, for long-term exploration and use. This time, we will not only plant our flag and leave our footprints -- we will establish a foundation for an eventual mission to Mars, and perhaps someday, to many worlds beyond."

Space Directive 2:

"The president is committed to ensuring that the federal government gets out of the way and unleashes private enterprise to support the economic success of the United States," White House officials wrote in an [SPD-2 fact sheet](#) that was released yesterday.

<https://www.whitehouse.gov/presidential-actions/space-policy-directive-2-streamlining-regulations-commercial-use-space/>

Space Directive 3: Space Traffic Management

<https://www.whitehouse.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/>

Space Directive 4: Establishing Space Force

<https://spacepolicyonline.com/news/text-of-space-policy-directive-4-spd-4-establishing-a-u-s-space-force/>

Pence announcement of lunar Landing by 2024

<https://www.space.com/us-astronauts-moon-return-by-2024.html>

Although there is a specific interest in commercialization of space, those desires do not change physics and for the time being run counter to the overriding hard requirement of landing a crew on the Moon by 2024. The NASA concept of operations is shown in the figure below. It is a very complex combination of vehicles flight hardware and operations to put a crew on the Moon by 2024. Only Orion and SLS are in hardware development. All of the other flight elements have only very recently been awarded or are just now being solicited by NASA. Remember, the hard requirement is to land a crew on the Moon by 2024.

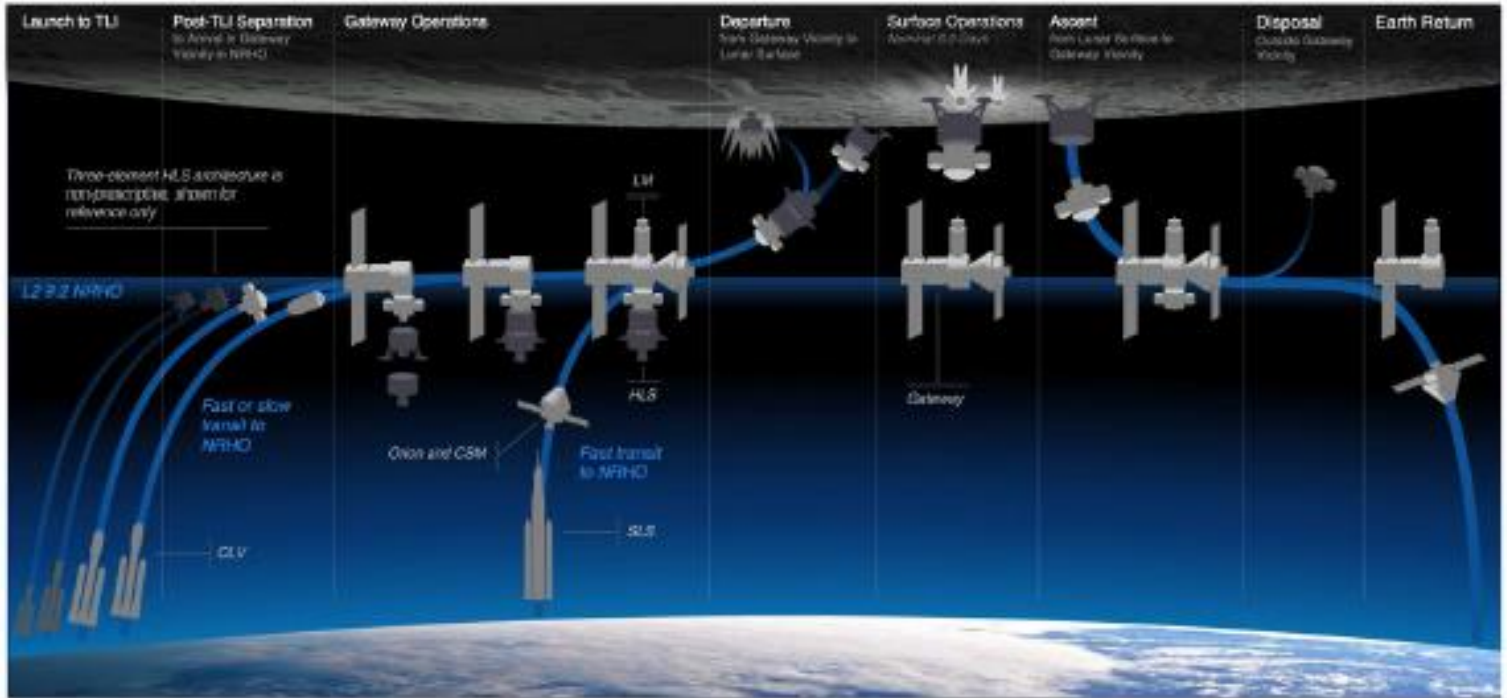


Figure 1 - Generic Concept of Operations for the initial mission capability. The three-element architecture is for reference only and represents one possible approach, hence two of the three elements are shown in grey.

Questions:

1. Fifty years ago NASA flew Apollo 11 on a single rocket with a capsule and a lander. Why does it take numerous flights of small rockets to send two astronauts to the Moon?
2. Isn't NASA in fact building a large rocket- the Space Launch System with a large upper stage (EUS) that could fly the crew to the Moon and back potentially in as little as 2 flights with many fewer complex operations and fewer new spacecraft needing design and development from scratch?

Discussion

NASA is on a contractual path to complete the SLS 1A and the hardware is being built. It is also on the path to design and build the Exploration upper Stage that will provide the SLS 1B lift and volume capability. NASA must also design a cargo shroud for the 1B version

Using an SLS Block 1B Cargo Vehicle, carrying a lunar lander/ascent vehicle, and an SLS Block 1A Crew Vehicle, carrying the Orion Crew vehicle and possibly a transfer stage if needed, the United States could send a crew to the Moon and return them safely.

The following is a simplistic comparison of the numbers of developments, launches, and complex in-space operations leading to the combined probability of a successful mission to the Moon for Apollo, the NASA architecture including the Gateway, and a simpler approach taking advantage of SLS capabilities. It uses a probability of .98 for each launch and operation for simplicity.

	Apollo Program	NASA Baseline	Alternative
Developments	(1) Saturn V (2) Apollo (CM + DM) (3) LEM (AE + DE)	SLS (near completion) Orion (near completion) (1) DE (2) AE (3) AETV (4) TE (5) RE (6) PPE (7) MHM (8) GLS	SLS (near completion) Orion (near completion) (1) DE (2) AE
Launches	(1) Saturn V (Co-Manifest)	(1) SLS Block 1 (Orion) (2) CLV (DE) (3) CLV (AE + AETV) (4) CLV (TE) (5) CLV (RE) (6) CLV (PPE) (7) CLV (MHM) (8) CLV (GLS)	(1) SLS Block 1 (Orion) (2) SLS Block 1B (DE+AE)
Mission Operations	(1) Apollo/LEM Mating after launch (2) Apollo/LEM De-mating (3) LEM Landing (4) Ascent Boost (5) Apollo/Ascent Mating (6) LEM Separation/Disposal (7) Apollo Return to Earth	(1) MHM docking with PPE (2) TE docking with MHM (3) DE docking with MHM (4) RE docking with DE (5) Refueling of DE (6) AE docking with MHM (7) AE mating with DE (8) AE/DE mating with TE (9) GLS mating with MHM (10) Orion mating with MHM (11) AE/DE/TE separate from MHM (12) TE staging (13) AE/DE landing (14) AE boost from lunar surface (15) AE docks with MHM (16) Orion separates MHM (17) Orion returns to Earth	(1) Orion mating with DE/AE (2) AE/DE separates from Orion (3) AE/DE landing (4) AE boost from lunar surface (5) AE docks with Orion (6) AE separates from Orion (7) Orion returns to Earth
Probability Analysis	Assumed probability per event 98%		
Developments	3	8	2
Launches	1	8	2
Mission Operations	7	17	7
Total Events	11	33	11
Probability of Mission Success	80%	51%	80%

In viewing recent documentaries of Apollo 11 during the 50th anniversary it reminded me about how much anxious anticipation you have as each critical operation occurs, knowing it can be a mission ending or life threatening event. This can also be seen in robotic missions, recalling the JPL Curiosity Mission and the “Seven Minutes of terror” as the team awaited the signal of the successful Mars landing. Minimizing the number of events can significantly improve the probability of mission success.

In contrast to the SLS approach to the first lunar landing, the NASA architecture uses the SLS only to launch the Orion. It plans to use commercial vehicles to launch the components of the lander and ascent vehicle separately. The lander must then be refueled in space, because of commercial launch vehicle lift limitations. Refueling in space is not a well-developed technology at this point in time for that matter. The lander size will also be constrained to commercial launch vehicle shroud diameters. Without the benefit of defining concepts for the surface hardware based on mission objectives, as described earlier, will this lander have the capacity for all the hardware it will take to the surface over time? Will it be forced to use hypergolic storable fuels because of the launch vehicle constraints? If so, this does not fit the scenario of using commercially provided fuels manufactured on the Moon. The concept seems to consider only the crew transfers for 2024. All of the assembly complexity occurs, because NASA does not use the SLS for what it was designed to do. This adds cost, complexity and mission risk. Taking advantage of the SLS lift and volume capability would allow the Gateway to be deferred to later, when it could help to provide longer mission durations by supporting Orion stay times in orbit. Therefore Gateway would not be on the critical path for 2024.

From a procurement standpoint, it would seem that following through on the SLS and EUS contracts with the addition of a cargo shroud, and focusing on the procurement of a lander/ascent vehicle would have a better chance of making an early lunar landing date rather than betting on the large number of brand new procurements in the current architecture. What is the probability of all of these procurements going well simultaneously? Any one procurement could hold up the entire architecture.

In my view, the SLS solution for early lunar flights is a lower risk solution compared to forcing the current NASA architecture. It has the best chance of meeting the number 1 requirement set by the Administration. There will be time for the rest of the architecture, which will provide opportunities for commercial flights. The launch vehicles can be better suited for flying the intended payloads.

Part 3- Space Exploration Program Performance

The Role of Systems Engineering and Integration in Large Government/NASA Programs

SE&I is a major function in any program, necessary to ensure safety and successful operation of a design and ensure that it satisfies the intended performance. This is particularly true in large space programs where there is little margin for error. SE&I is comprised of a number of functions including engineering analysis across the

components of a design- major systems such as power, thermal, structures, mechanical systems, data systems/avionics, life support systems, etc. It is the work that assures all components are compatible and work together according to the overall design in the various environments they have to operate. SE&I efforts establish requirements for performance, safety, reliability, environments, etc., Power/electrical, fluids, data, environmental and mechanical interfaces between flight elements and components are established and documented. Components are designed to those interfaces so the spacecraft functions successfully as a unit when the components are assembled. Through SE&I analysis and testing are defined that will verify that the technical and interface requirements have been met, once designed and built. SE&I assures that the data systems and software will successfully control the vehicle functions over the entire range of intended operational envelopes. Throughout the design process SE&I activities maintain documentation on the risks in the design and in the program as a whole. Analysis and even design changes are authorized to work down these risks. Managing SE&I involves complex decisions to ensure all disputes and negotiations between the systems designers in these areas are resolved and that all are operating to the same baseline. SE&I is also where the detailed integrated schedule is managed and funding allocations are proposed to assure the components of the design come together for assembly and test at the appropriate time. SE&I is a function that should operate across the program, and also at project and component levels to assure that all of these requirements and functions flow down for a successful integrated design. This is but a brief discussion of a very complex programmatic function- SE&I.

Discussion of Program Performance on SLS, Orion, Ground Systems

The recent GAO report in June, 2019 (19-227) "NASA Human Space Exploration – Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs" raises concerning issues. The GAO report focusses on poor reporting of metrics by programs, inadequate program plans/cost baselines and accounting, and award fees not aligned with observed performance. The report talks about the program reporting cost performance against baselines that have reduced content, due to rephrasing of work. It talks about identified schedule risks for known work that is not currently scheduled. It also recognizes the contribution of technical problems that arise in these complex programs. And of course the report expresses the concern about program delays due to these and related issues. A closely linked GAO report in October 2017 (18-28) titled "NASA Human Space Exploration – Integration Approach Presents Challenges to Oversight," raises concerns about the NASA Integration approach, including dual roles for oversight organizations. It gives the program credit for cost avoidance for not having a significant Systems Engineering and Integration (SE&I) workforce at the Top Program level (HEOMD/ESD) Successful large programs do. The cost avoidance is quoted as being on the order of \$150M when compared with the Constellation Program. But the report goes on to talk about many of the reporting problems listed in the most recent GAO report. It raises concerns about this program level being able to cover all of the reviews and the ability to cover added work as the

programs reach test and verification needs coming up with this small SE&I effort. Issues of poor reporting metrics and lack of adequate integrated program/cost plans can be attributed to the lack of an adequate Systems Engineering and Integration level at the top of the program. I have heard what they have described as SE&I “Light”. My experience in The Space Shuttle, ISS, and Exploration Programs has been that strong SE&I function is crucial to having a healthy and successful program. Many of the program reporting criticisms and lack of integrated cost and schedule could be alleviated with this function in place. Adequate cost and schedule planning would minimize the risks associated with parallel design and manufacturing and testing. What is worse than poor reporting and metrics is that without a rigorous Systems Engineering and Integration effort, there can be major incompatibilities with the major hardware components, such as hardware interferences and interfaces that don’t work. In the current Artemis architecture, there are many interfaces between major components to be built by different companies, i.e., Orion, SLS, Ground Systems, PPE, minihab, Descent Element, Ascent Element, Transfer Element, Logistics Element, Commercial Launch Vehicles, lunar surface systems, robotic arm, etc. Interfaces that must work include structural/mechanical, air, power, thermal, data, fluids; all at compatible conditions.

The lack of a thorough SE&I function is a high risk for the programs, and may well have led to many of the current schedule and cost issues. It may also mean there are more coming without it. Without the oversight/insight at this high level across the program it is difficult to assure consistent working practices and due diligence in resolving inevitable problems, and difficult to ensure that NASA and contractor organizations bring their A-teams to these programs. This function with strong leadership helps to instill the urgency needed in getting the job done on cost and schedule.

In my view this current concern is repeating what occurred during the Space Station Freedom Program, when projects called “Work Packages” had their own prime contractors. There was a Program Office and integration effort at NASA in Reston, Virginia. There was a support contractor for Reston, which had an SE&I support function but was not legally accountable for the integration of the vehicle. The Program Office in Reston had no budget control, because the Work Packages worked for JSC, MSFC and GRC Center Directors, respectively and were paid through the centers by other NASA HQ directorates. The various offices fought. The integration and interface control was dysfunctional, not for lack of trying by a lot of excellent people at Reston. When the redesign of the Space Station occurred during 1993, and the new ISS Program Office was assembled in Houston, there were lingering serious design and interface issues. The management was coalesced, a strong SE&I organization was formed between NASA and a new overall Prime Contractor for ISS. I believe this was all a large factor in the success of ISS. All of the reporting, metrics, and schedules against cost were mandated. Technical problems were worked. Even the Russians were brought on as partners during this time and integrated into the design. Processes were put in place to assure diligence to getting the job done, through strong leadership and

creating a strong culture. I recommend that this be done for these programs as soon as possible to fix the problems described in these reports. It will cost money, since they don't have it allocated now, but it will bring order and a successful program. **NASA needs a strong program office, prime contractor, and a skilled SE&I Organization.** It will be said we can't do it now with the 2024 mandate. Over the years it has often been said you never have time to do things right. That is until you find it's the only way to get it done.

It is possible to use award fees as described in the GAO report, but the NASA team has to do their part and be a part of a strong team described above. For example, if NASA owes direction to contractors and doesn't provide it on time, work does not get done. It's not fair to ding contractors for it. Much of the integration work in these programs has been taken on by NASA organizations and their support contractors. If NASA does not produce its deliverables according to the program schedule, the contractors have a valid claim that they cannot proceed. If NASA does not show excellence on their side and show leadership, it's hard to blame the contractors. These issues are another reason for having a prime contractor that can be held accountable. Award fee periods are much clearer under these circumstances.

My Management Lessons

The following are key program management lessons I take away from the Apollo, Space Shuttle, Space Station, and Exploration Programs. It's not an exhaustive list.

1. Prioritize the highest requirements above desires. NASA has been given a hard goal to achieve a lunar landing by 2024. Other top priorities have to include safety and risk, cost and schedule. Basic safety requirements should provide the check and balance for the others.
2. Define key mission objectives to drive sustainability, mission design, scale of operation, mission architecture and sizing of vehicles and capabilities. Develop a long term plan. It should be flexible for what is learned and as new technologies and capabilities emerge.
3. Don't design in dead ends. Developments should all contribute to downstream goals for the Moon, Mars and beyond.
4. Strive for simplicity in design and operations to reduce mission risk. It will still be more complicated than would be desired.
5. Organize to execute the program efficiently and effectively. Implement a strong Systems Engineering and Integration function. Streamline program processes and decision making.
6. Strive to develop an A-team at NASA and industry partners. Operate the program with urgency- not business as usual and not at the expense of safety.
7. Streamline requirements for all programs, but maintain basic safety requirements

Summary

I have provided a brief history of the Current SLS and Orion designs and why they are important to human spaceflight based on their requirements and capabilities. These capabilities were designed for both the Moon and Mars Missions. The programs have certainly had issues of various kinds during their development thus far. There are management approaches and remedies that can improve the path forward. It includes a lot of hard work and dedication. These programs have great potential for inspiring missions. NASA should take advantage of the progress made in these programs and across the board in space flight. NASA still needs to develop a long term plan that will guide the mission architecture and missions. I have testified on this subject before with the following recommendations:

- Missions should address science, exploration, commerce, geopolitical and other objectives to maximize the potential for great achievements and discoveries. It is not enough to describe vehicles and how we are technically going to perform missions. Well-vetted objectives provide the important rationale for the exploration plan and help guide specific missions.
- International collaboration is essential in planning, development of hardware, and participation in missions and operations. We have learned through the International Space Station (ISS) Program, and science missions the value of international collaboration on many levels. Collaboration provides the opportunity for pooling resources to accomplish more than any one country can on its own. Collaboration is a rewarding experience among nations and is a positive influence in international relationships. The International Space Exploration Coordination Group (ISECG) continues to work on exploration objectives, roadmaps and planning for future human space exploration. NASA has provided the leadership in these relationships and I believe must continue to do so. The critical geopolitical considerations of our time strongly mandate that the United States step up to the responsibilities of that leadership role and guide the proper use of space. What's more, these nations look to the U.S. and NASA for this leadership.
- The needed capabilities and technologies should be developed incrementally, paced with available budgets. A long-term plan will help define the specific capabilities that are needed and will provide the priorities and phasing of these developments. Without a plan, capabilities developed can miss the mark and fall short of what will be needed. Other NASA programs, international agencies and companies, industry, academia, DOD, and other agencies and their programs can be leveraged to maximize progress.
- Every mission and capability developed should contribute to long-term exploration needs and objectives. To the degree possible, each flight element, including in-space habitat modules, landers, rovers, space suits, power systems, and others should be developed for multiple use. This begins with the foundation of International Space Station (ISS) testing and research, routine transportation

to Low Earth Orbit, and the development of the Space Launch System (SLS) heavy lift rocket and Orion Multi-Purpose Crew Vehicle (MPCV).

- Exploration capabilities should be made available for commercial and other interests to further the utilization of space. As NASA develops capabilities to explore farther and farther from Earth, other interested parties may find advantage in using these capabilities at destinations in space, where NASA has paved the way.
- The long-term plan should be adaptable based on discoveries and budget realities. With it we can envision a logical sequence of missions based on known objectives. However, by the nature of exploration, missions will lead to discoveries that may change priorities. The plan should be adaptable based on these discoveries. A perfect example of this idea in practice is the NASA Mars Science Program. Roadmaps with specific sets of objectives and missions have been developed for the last two decades. Discoveries have been prevalent in this program, and the plan has been adjusted to make the most of every upcoming mission.
- Constant progress should be made towards the long term goal of landing people on Mars to explore this planet. Mars is globally accepted as an ultimate human space flight goal based on the fact that it is the planet most like our own and may hold evidence of past or present life. It is habitable with known systems, and can be reached within foreseeable technological capabilities.

Once again, thank you for inviting me to give my personal views. I also want to thank this committee and your staff for your continued bipartisan support for human space flight.

I welcome your questions.

Doug Cooke

Short Biography - Douglas R. Cooke

Doug Cooke is an aerospace consultant with over 46 years' experience in human space flight programs, advising clients on program strategies, program management, contract proposal development, strategic planning and technical matters. In 2011 Doug Cooke retired as Associate Administrator for NASA's Exploration Systems Mission Directorate (ESMD), having been assigned to this position in 2008. As Associate Administrator, he was responsible for the Constellation, Space Launch System (SLS), the Orion crew vehicle, Ground Systems Development and Operations, Lunar Reconnaissance Orbiter, Lunar Crater Observation and Sensing Satellite, Commercial Cargo and Crew, Human Research and Exploration Technology Programs. The development programs were responsible for design and manufacture of flight vehicles and hardware systems for human exploration into deep space, including the Moon, Near Earth Asteroids, Mars and its moons and other destinations. The research programs developed critical technologies, new capabilities, and human research to support future human spacecraft and exploration missions. Responsibilities also included partnering with industry to develop commercial vehicles for cargo and crew transportation to and from low Earth orbit and the International Space Station. In his last year at NASA, Doug Cooke led the directorate and program teams in the analysis, designs and establishment of the Orion Multipurpose Crew Vehicle and the Space Launch System. He personally presented the proposals at agency level meetings, where the administrator approved these programs.

Doug Cooke has 38 years of unique experience at NASA, with 32 years at Johnson Space Center and 6 at NASA Headquarters. He held significant responsibilities during critical periods of the Space Shuttle, Space Station and Exploration Programs, including top management positions in all three programs.

Doug Cooke's first major challenge began in 1975 when he was tasked with defining and implementing the entry aerodynamic flight test program for the Space Shuttle. He led this effort through the Approach and Landing Tests in 1977, and initial orbital flights of the Space Shuttle beginning in 1981 through 1984, opening flight constraints to meet entry design specifications.

Doug Cooke led the Analysis Office when the Space Station Program Office was first organized in 1984 at the Johnson Space Center. He led the work that defined the Space Station configuration, many of its design details, technical attributes and requirements.

Following the Space Shuttle Challenger accident, Doug Cooke was assigned to the Space Shuttle Program Office. He helped lead a Civil Service and contractor team to provide the system engineering and integration function that resulted in the return of the Space Shuttle to flight on September 29, 1988. He reached the position of Deputy Manager of the Space Shuttle Engineering Integration Office.

Doug Cooke has played a pivotal role in planning for human space exploration into deep space beginning in 1989. He helped to lead a NASA team that produced the "90 Day Study" on lunar and Mars exploration. He was subsequently assigned to the Synthesis Group led by Lt. General Tom Stafford, Gemini and Apollo Astronaut. The

team produced a report for the White House entitled “America at the Threshold: America’s Space Exploration Initiative.” Doug Cooke was selected to be the Manager of the Exploration Programs Office at JSC, where he initiated and led NASA agency-wide studies for the human return to the Moon, and exploration of Mars.

In March of 1993, the agency undertook the redesign of Space Station Freedom. Doug Cooke was assigned the responsibility of leading the engineering and technical aspects of the redesign. He was subsequently chosen to serve in the Space Station Program Office as Vehicle Manager, leading and managing the design, hardware development and systems engineering and integration for the International Space Station. From April to December of 1996, He served as Deputy Manager of the Space Station Program Office.

In 1996, strategic emphasis was again placed on NASA planning for human exploration beyond Low Earth Orbit. Doug Cooke served as manager for the Advanced Development Office at the Johnson Space Center. He provided NASA leadership for the planning of human missions beyond Earth orbit; including the Moon, Mars, libration points, and asteroids. This team developed integrated human and robotic mission objectives, defined investment strategies for exploration technologies, and managed NASA exploration mission architecture analyses. He was detailed to NASA headquarters during portions of this period to contribute to headquarters level strategies for human exploration.

In 2003, Doug Cooke served as NASA technical advisor to the Space Shuttle Columbia Accident Investigation Board from the time of the accident to the publishing of the report. He made significant contributions to forensic analysis of the Columbia debris and to the education of the Investigation Board in various aspects of the Shuttle design, program, operations and interpretation of investigation data.

Doug Cooke served as Deputy Associate Administrator for the Exploration Systems Mission Directorate, NASA Headquarters, from 2004 until 2008. In 2008 he became Associate Administrator. He made significant contributions to the structuring of its human exploration programs, defining the program content, budget planning and providing technical and programmatic leadership. Doug Cooke also led the efforts to define long term NASA field center assignments for hardware development and operational responsibilities. He was the Source Selection Authority for the major exploration contract competitions. In this role he successfully selected the companies who have been on contract for SLS, Orion and Commercial Cargo. He initiated and led the team of international space agencies in development of the Global Exploration Strategy activity, which resulted in the establishment of the International Space Exploration Coordination Group and the release of the Global Exploration Roadmap.

Doug Cooke’s many awards include the SES Presidential Distinguished Rank Award, the SES Presidential Meritorious Rank Award, NASA Distinguished Service Medal, two NASA Exceptional Achievement Medals, the NASA Outstanding Leadership Medal, the NASA Exceptional Service Medal, two JSC Certificates of Commendation, the first

Texas A&M Outstanding Aerospace Engineer Alumni Award, the Space Transportation Association Lifetime Achievement Award, the 2017 Werner Von Braun Astronautics Engineer Award. Most recently, in 2018, he was awarded the Texas A&M Distinguished Aerospace Engineering Alumni Award. Doug Cooke is a graduate of Texas A&M University with a Bachelor of Science degree in Aerospace Engineering.

Short Biography - Douglas R. Cooke

Doug Cooke is an aerospace consultant with over 46 years' experience in human space flight programs, advising clients on program strategies, program management, contract proposal development, strategic planning and technical matters. In 2011 Doug Cooke retired as Associate Administrator for NASA's Exploration Systems Mission Directorate (ESMD), having been assigned to this position in 2008. As Associate Administrator, he was responsible for the Constellation, Space Launch System (SLS), the Orion crew vehicle, Ground Systems Development and Operations, Lunar Reconnaissance Orbiter, Lunar Crater Observation and Sensing Satellite, Commercial Cargo and Crew, Human Research and Exploration Technology Programs. The development programs were responsible for design and manufacture of flight vehicles and hardware systems for human exploration into deep space, including the Moon, Near Earth Asteroids, Mars and its moons and other destinations. The research programs developed critical technologies, new capabilities, and human research to support future human spacecraft and exploration missions. Responsibilities also included partnering with industry to develop commercial vehicles for cargo and crew transportation to and from low Earth orbit and the International Space Station. In his last year at NASA, Doug Cooke led the directorate and program teams in the analysis, designs and establishment of the Orion Multipurpose Crew Vehicle and the Space Launch System. He personally presented the proposals at agency level meetings, where the administrator approved these programs.

Doug Cooke has 38 years of unique experience at NASA, with 32 years at Johnson Space Center and 6 at NASA Headquarters. He held significant responsibilities during critical periods of the Space Shuttle, Space Station and Exploration Programs, including top management positions in all three programs.

Doug Cooke's first major challenge began in 1975 when he was tasked with defining and implementing the entry aerodynamic flight test program for the Space Shuttle. He led this effort through the Approach and Landing Tests in 1977, and initial orbital flights of the Space Shuttle beginning in 1981 through 1984, opening flight constraints to meet entry design specifications.

Doug Cooke led the Analysis Office when the Space Station Program Office was first organized in 1984 at the Johnson Space Center. He led the work that defined the Space Station configuration, many of its design details, technical attributes and requirements.

Following the Space Shuttle Challenger accident, Doug Cooke was assigned to the Space Shuttle Program Office. He helped lead a Civil Service and contractor team to provide the system engineering and integration function that resulted in the return of the Space Shuttle to flight on September 29, 1988. He reached the position of Deputy Manager of the Space Shuttle Engineering Integration Office.

Doug Cooke has played a pivotal role in planning for human space exploration into deep space beginning in 1989. He helped to lead a NASA team that produced the "90 Day Study" on lunar and Mars exploration. He was subsequently assigned to the Synthesis Group led by Lt. General Tom Stafford, Gemini and Apollo Astronaut. The

team produced a report for the White House entitled “America at the Threshold: America’s Space Exploration Initiative.” Doug Cooke was selected to be the Manager of the Exploration Programs Office at JSC, where he initiated and led NASA agency-wide studies for the human return to the Moon, and exploration of Mars.

In March of 1993, the agency undertook the redesign of Space Station Freedom. Doug Cooke was assigned the responsibility of leading the engineering and technical aspects of the redesign. He was subsequently chosen to serve in the Space Station Program Office as Vehicle Manager, leading and managing the design, hardware development and systems engineering and integration for the International Space Station. From April to December of 1996, He served as Deputy Manager of the Space Station Program Office.

In 1996, strategic emphasis was again placed on NASA planning for human exploration beyond Low Earth Orbit. Doug Cooke served as manager for the Advanced Development Office at the Johnson Space Center. He provided NASA leadership for the planning of human missions beyond Earth orbit; including the Moon, Mars, libration points, and asteroids. This team developed integrated human and robotic mission objectives, defined investment strategies for exploration technologies, and managed NASA exploration mission architecture analyses. He was detailed to NASA headquarters during portions of this period to contribute to headquarters level strategies for human exploration.

In 2003, Doug Cooke served as NASA technical advisor to the Space Shuttle Columbia Accident Investigation Board from the time of the accident to the publishing of the report. He made significant contributions to forensic analysis of the Columbia debris and to the education of the Investigation Board in various aspects of the Shuttle design, program, operations and interpretation of investigation data.

Doug Cooke served as Deputy Associate Administrator for the Exploration Systems Mission Directorate, NASA Headquarters, from 2004 until 2008. In 2008 he became Associate Administrator. He made significant contributions to the structuring of its human exploration programs, defining the program content, budget planning and providing technical and programmatic leadership. Doug Cooke also led the efforts to define long term NASA field center assignments for hardware development and operational responsibilities. He was the Source Selection Authority for the major exploration contract competitions. In this role he successfully selected the companies who have been on contract for SLS, Orion and Commercial Cargo. He initiated and led the team of international space agencies in development of the Global Exploration Strategy activity, which resulted in the establishment of the International Space Exploration Coordination Group and the release of the Global Exploration Roadmap.

Doug Cooke’s many awards include the SES Presidential Distinguished Rank Award, the SES Presidential Meritorious Rank Award, NASA Distinguished Service Medal, two NASA Exceptional Achievement Medals, the NASA Outstanding Leadership Medal, the NASA Exceptional Service Medal, two JSC Certificates of Commendation, the first

Texas A&M Outstanding Aerospace Engineer Alumni Award, the Space Transportation Association Lifetime Achievement Award, the 2017 Werner Von Braun Astronautics Engineer Award. Most recently, in 2018, he was awarded the Texas A&M Distinguished Aerospace Engineering Alumni Award. Doug Cooke is a graduate of Texas A&M University with a Bachelor of Science degree in Aerospace Engineering.