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United States Human Access to Space, Exploration of the Moon and Preparation for Mars Exploration

A White Paper on the Status of the NASA Constellation Program

September 2008

Prepared by the Staff of the Constellation Program

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1. Executive Summary

Introduction

In the past, men like Leonardo da Vinci and Jules Verne thought of the future and foresaw fantastic inventions such as winged flying machines, submarines, parachutes, and air conditioning; and posited human adventures like routine transoceanic flight and even exploratory trips to the Moon. Today, many of their ideas are reality and form the basis for our modern world.

Visionaries like da Vinci and Verne are remembered as much for their unique preoccupation with the future as they are for the accuracy of their predictions, but today entire nations are involved in the process of envisioning and defining the future development of mankind, both on and beyond the Earth itself. In recent years, teams formed by the Russians, Europeans and Chinese have all announced plans for developing their own next generation human space vehicles. The Chinese, who have announced their intention to conduct human lunar exploration, have flown three crewed space missions since 2003, including a flight with three crewmembers to test their extravehicular (space walking) capability in September 2008. Very soon, the prestige, economic development, scientific discovery and strategic security advantage historically associated with leadership in space exploration and exploitation may no longer be the undisputed province of the United States.

Much like the sponsors of the sea-faring explorers of da Vinci's age, we are motivated by the opportunity to obtain new knowledge and new resources for the growth and development of our own civilization. NASA's new Constellation Program, established in 2005, is tasked with maintaining the U.S. leadership in space, exploring the Moon, creating a sustained off-world human presence, and eventually extending operations to Mars and beyond.

Through 2008, the Constellation Program developed a full set of detailed program requirements and is now completing the preliminary design phase for the new Orion Crew Exploration Vehicle and the Ares I Crew Launch Vehicle, along with associated infrastructure necessary for humans to explore the moon. Component testing is well underway, and integrated flight testing will commence in 2009. This white paper summarizes three years of Constellation Program progress and accomplishments; and describes the foundation set for human lunar return in 2020.

A Brief History of U.S. Human Space Exploration

Beginning in the late 1950s, the U.S. embarked upon the ongoing campaign of human space exploration. The first human spaceflight initiative was Project Mercury, established in October 1958 with single-pilot spacecraft first launched from Cape Canaveral Air Force Station (CCAFS) in the early 1960s. Project Mercury was followed by Project Gemini and the Apollo Program. Project Gemini was announced in January

1962 and served to perfect spacecraft maneuvers and multi-crew operations in Earth orbit. The Apollo Program was initiated in 1961, successfully allowing humans to travel beyond Earth orbit for the first time and to explore the surface of the Moon with six teams of astronaut/scientists between 1969 and 1972.

In the mid-1970s, NASA began development of the Space Transportation System (commonly called the Space Shuttle) as the next crewed vehicle. Over the past 27 years, the Space Shuttle fleet has supported more than 100 research and technology missions and 26 missions (so far) in the construction and operation of the International Space Station (ISS).

Planning for the ISS program began in the late 1980s. Building on our experience with the Skylab program of the 1970s, and eventually incorporating the Russian experience with Salyut and Mir space stations, the first components of the ISS were placed into orbit in 1998. During the past ten years, the United States, Japan, Canada, Russia, and 11 countries represented by the European Space Agency have worked together to simultaneously construct the ISS and use the growing laboratory as a base for increasingly complex science research and technology development. As the assembly of the ISS nears its scheduled completion in 2010, ambitious plans are being developed for larger rotational crews and full use of its capabilities as an international research facility in orbit for many years to come. The international partnership of space agencies involved in ISS research met in July, 2008, to assess the progress and potential of the space station and agreed that there were no technical challenges to extending ISS operation beyond 2015.[1]

Our New Exploration Initiative

After the Space Shuttle *Columbia* accident on February 1, 2003, NASA established the Columbia Accident Investigation Board (CAIB) to perform an in-depth review of the Space Shuttle Program. As a result of this review, the CAIB concluded that it was in the best interest of the U.S. to develop a replacement for the Space Shuttle.

Comment [j1]: Add CAIB Report citation (from my 2007 IAC paper)

In January 2004, President George W. Bush announced a new exploration initiative (the *Vision for Space Exploration*) to return humans to the Moon by 2020 in preparation for human exploration of Mars and beyond. As part of this initiative, NASA was directed to continue to use the Space Shuttle fleet to fulfill its obligation to complete assembly of the International Space Station and then retire the fleet by 2010. As the first step toward developing the vehicles to explore the Moon, Mars, and beyond, the President directed NASA to build and fly a new Crew Exploration Vehicle (CEV, since named Orion) by 2014. The Orion spacecraft will be a new multi-functional human-rated space vehicle capable of supporting a maximum of six crew members and will be used to transport humans to low Earth orbit for missions to support the International Space Station and will also be used to transport crews and equipment to and from lunar orbit.

Comment [j2]: Add citation here (also in 2007 IAC paper)

As originally envisioned, during the period between Space Shuttle retirement in 2010 and the new CEV operational launch capability in 2014, the U.S. would rely on the Russian Soyuz rocket and space capsule launched from the Baikonur spaceport in central Kazakhstan to ferry American crew members and delicate research samples to and from the ISS. Russian transportation for U.S. crew and cargo is paid for through a direct contract with the Russian Federal Space Agency. NASA announced in April, 2007, a $719 million modification to a current contract with the Russian Federal Space Agency "for crew and cargo services through 2011."[2] Due to NASA budget constraints, the Full Operational Capability (FOC) date for the CEV has slipped from 2014 to late 2015, and the launch support for the remaining transportation gap between 2012 through 2015 is currently undefined. Since the Russian space agency requires a three-year lead time to manufacture the Soyuz hardware, a decision to purchase additional services beyond 2011 is needed by the end of 2008. Congress is currently considering an additional waiver to the law passed in 2000 that prohibits the United States from purchasing technology from countries, including Russia, that export nuclear or missile technology to Iran in order to extend the contract for Soyuz support. A counter argument for increasing funding to the Orion and Ares projects in order to accelerate development and FOC, rather than extend the Soyuz contract, is also being considered.[3]

Comment [j3]: Revise per bill passed this weekend

Congress has expressly endorsed the President's exploration initiative with authorization legislation and provided additional direction for the initiative in the NASA Authorization Act of 2005, authorizing NASA to "…establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations".

The Exploration Systems Architecture Study[4]

In May 2005, in response to the President's exploration initiative, NASA Administrator Michael Griffin commissioned the Exploration Systems Architecture Study (ESAS) to perform four specific tasks:

1. Complete assessment of the top-level Orion CEV requirements and plans to enable the vehicle to provide crew transport to the International Space Station and to accelerate the development of the Orion CEV and crew launch system to reduce the gap between Space Shuttle retirement and CEV initial operational capability
2. Provide definition of top-level requirements and configurations for crew and cargo launch systems to support the lunar and Mars exploration programs
3. Develop a reference lunar exploration architecture concept to support sustained human and robotic lunar exploration operations
4. Identify key technologies required to enable and significantly enhance these reference exploration systems and reprioritize near- and far-term technology investments.

The ESAS Team was composed of representatives from all NASA centers, private industry consultants, and retired NASA personnel. The team also included an independent review team composed of members from the Congressional Review Service, George Washington University, the United States Air Force, the University of Arizona, and the Naval Research Laboratory.

The ESAS Team took on the task of developing Orion CEV requirements and a baseline configuration to meet those requirements. Many design studies were performed to address potential CEV shapes, including blunt-body, slender-body, and lifting shapes.

Aspects of an Orion CEV mission to the International Space Station were examined in detail, including docking approaches and the use of the CEV as a cargo transport and return vehicle.

The ESAS Team examined multiple combinations of launch elements to perform missions to the International Space Station, the Moon, and Mars. Different types and sizes of launch vehicles and numbers of launches required to meet specific mission configurations called Design Reference Missions were evaluated. The ESAS Team performed a detailed examination of the costs, schedule, reliability, safety, and risk of using launch vehicles derived from the Space Shuttle and from current and proposed U.S. heavy-lift launch vehicles (*e.g.*, Delta IV and Atlas V launch vehicles) for crew and cargo missions. Other studies included propellant types for launch vehicle stages, numbers of engines per stage, use of common components and systems on vehicle stages, and number of stages.

In order to determine the crew and cargo transportation requirements, the ESAS Team examined a variety of lunar surface mission types, surface systems, and approaches to constructing a lunar outpost. These assessments of the exploration goals and mission requirements were formulated into the ESAS as a set of recommendations for a future exploration architecture. The study concluded that the launch vehicles should be derived from existing technologies, leveraging the lessons learned from past programs, such as the Apollo Program and the Space Shuttle Program. Specifically, the ESAS recommended an architecture which included a Crew Launch Vehicle (CLV [since named Ares I]) to ferry crew and cargo to the International Space Station and to carry crew to Earth orbit and a heavy-lift Cargo Launch Vehicle (CaLV [since named Ares V]) to support missions to the Moon and Mars.

The Constellation Program

NASA established the Constellation Program to plan, develop, test, integrate, and operate all of the elements necessary to comply with Presidential and Congressional directives regarding this new exploration initiative. The Constellation Program used the ESAS Team's recommendations and the underlying Presidential and Congressional directives as a starting point and has continued to refine the mission requirements, evaluate capabilities for the technologies studied by the ESAS, and perform more detailed examination of the developmental requirements (*e.g.*, test and verification requirements). As the long-term objectives of U.S. space exploration continue to evolve, the near-term goals are well-established and underway: to develop the flight systems and ground infrastructure required to enable continued access to space and to enable future crewed missions to the International Space Station, the Moon, and Mars.

The exploration vehicles being developed to meet this goal include the Orion CEV spacecraft and two new launch vehicles, the Ares I and the Ares V. The Ares I launch vehicle will carry the Orion CEV to low Earth orbit where it will dock with either the International Space Station or with a payload launched earlier on an Ares V launch vehicle for transit to the Moon. For lunar missions, the Ares V launch vehicle will carry an Earth Departure Stage and Lunar Payload (e.g., a lander) in a single launch. After the Orion CEV docks with the Earth Departure Stage/Lunar Payload in Earth orbit, the Earth

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Departure Stage engine will ignite and propel the Lunar Payload and the Orion CEV to the Moon. For future missions to Mars, Ares V launch vehicles would be used to launch the components needed to send and return a crew to Mars. This could include a Mars transfer vehicle, a lander, a surface habitat, and surface equipment. The Ares I and Orion CEV will also be used for crew transport to and from low Earth orbit for the Mars missions.

The primary components of this campaign architecture and an exploration timeline are shown in **Figure 1-1.**

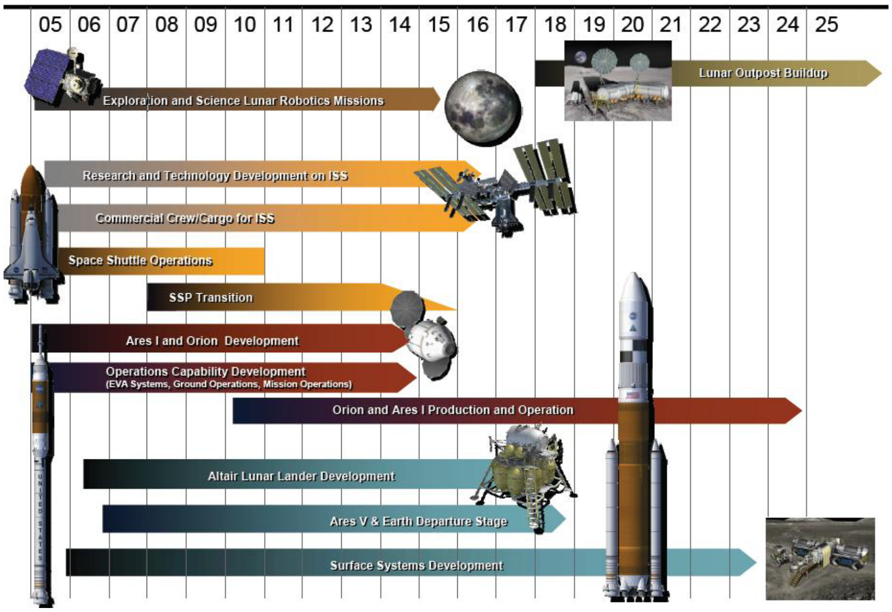

Figure 1-1. The Overall U.S. Human Space Exploration Roadmap

In support of this exploration plan, the Constellation program manages the following seven "hardware development" project offices:

- Crew Exploration Vehicle Project (the Orion spacecraft) at the Johnson Space Center in Houston, Texas
- Exploration Launch Projects (the Ares I and Ares V launch vehicles) at the Marshall Space Flight Center in Huntsville, Alabama
- Ground Operations Project (development of launch and recovery facilities) at the Kennedy Space Center, Florida

- Mission Operations Project (development of flight and mission control facilities) at the Johnson Space Center in Houston, Texas
- Extra Vehicular Activity (EVA) Systems Project (spacesuit & tool development) at the Johnson Space Center in Houston, Texas
- Lunar Lander Project (the Altair lunar decent and ascent module) at the Johnson Space Center in Houston, Texas
- Lunar Surface Systems pre-Project (advanced planning for lunar habitats and surface support systems) at the Johnson Space Center in Houston, Texas.

In addition to these project offices, work assignments for specific Constellation hardware development and testing also involve major NASA facilities in California, New Mexico, Louisiana, Mississippi, Virginia, Maryland and Ohio. A geographic summary of NASA and contractor work distribution is shown in **Figure 1-2**.

The current program schedule (with major milestones established by Presidential and Congressional direction) calls for the transport of humans to and from the ISS by 2015 (Full Operational Capability (FOC) for the program), and the transport of humans to and from the moon by 2020. As directed by the President, retirement of the Space Shuttle fleet is expected to occur by 2010 and is a separate activity within NASA from the Constellation Program.

The initial target date for the first crewed ISS flight had been 2014, however, during 2007, the Constellation program was allocated less funding than planned in the annual Federal appropriation bill. Since a primary rule adopted by this program is a “go as you can afford to pay” philosophy, this funding shortfall resulted in a six-month operational delay that slipped the ISS launch and FOC from 2014 to 2015.

As currently envisioned, an incremental buildup to lunar exploration would begin with up to four-person crews making several short-duration trips of up to 14 days to the Moon until power supplies, rovers, and living quarters become operational. These initial missions would be focused on the establishment of a lunar outpost and would be followed by long-duration lunar missions, increasing up to 180 days. The eventual goal of these lunar exploration efforts is the establishment of a sustained human presence on the Moon as part of an international scientific research effort similar to both the current ISS human presence in Low Earth Orbit and polar research activities that are currently conducted on Earth.

In addition to basic science and research activities, this lunar exploration will allow the United States to develop and test the necessary engineering, technology, social and legal infrastructure that will support the beginning of human exploration of our solar system, most notably of Mars, the Martian moons, the gravitationally-stable Lagrange points in the Earth-Moon-Sun system, and a variety of Earth-approaching asteroids and comets. Another important aspect of sustained lunar activity will be the opportunity to engage the international community in a long-term, high-visibility program of cooperation and mutual benefit following the success of the International Space Station.

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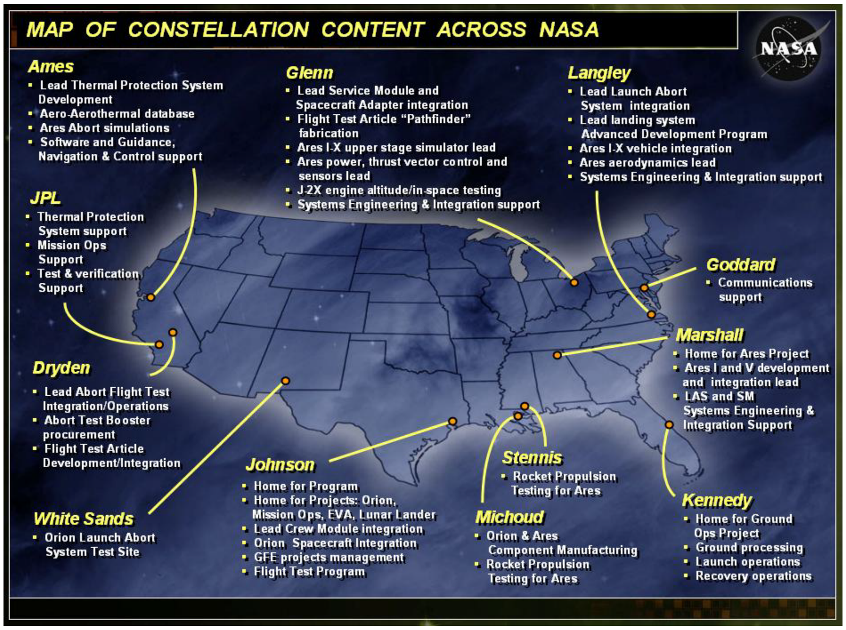

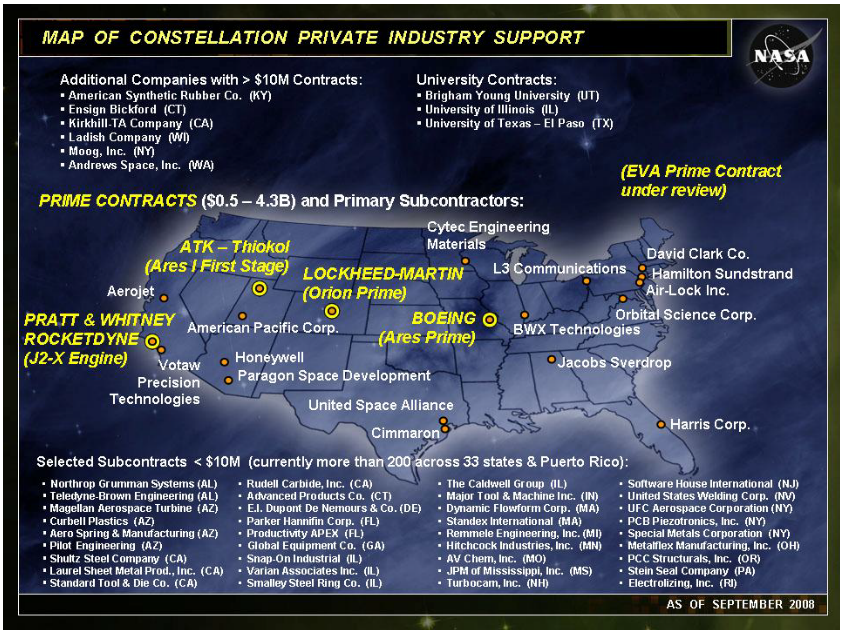

Figure 1-2. Constellation Work by NASA Center (above) and by contractor companies (below)

In May, 2007, NASA developed a Global Exploration Strategy with a number of space agencies from around the world (Italy, United Kingdom, France, China, Canada, Australia, Germany, the European Space Agency, India, Japan, Republic of Korea, Ukraine, and Russia). The Global Exploration Strategy framework document[5] envisions the formation of a voluntary, non-binding coordination group through which individual agencies may exchange information regarding interests, objectives and plans in space exploration with the goal of strengthening both individual exploration programs as well as the collective effort. This coordination group is now called the International Space Exploration Coordination Group (ISECG). The ISECG has agreed upon five broad Global Exploration Strategy themes which can serve as the basis for future global cooperation in space:

- New knowledge in science and technology – a global, science-driven methodology to generate new discoveries and produce new tools which will enhance the quality of life for all people on Earth.

- A sustained human presence in space – extending human frontiers and acknowledging our common human need for exploration and expansion.

- Economic expansion – laying the groundwork for commercial activities in and supporting space exploration and promoting participation by the private (non-government) sector, resulting in the creation of new industries, new jobs, and increased financial returns for both private and government participants (profits and taxes).

- Global partnership – no single nation has the resources to fully explore and exploit the space environment, and all nations will benefit from cooperation through sharing of information and elimination of expensive duplication of effort. Establishing a strong international tradition of cooperation and interdependence in the early phase of global space exploration will help ensure that these activities remain peaceful, financially efficient, and beneficial for all of humanity.

- Inspiration and education – space exploration captures the human attention and imagination in a special way. The concept and allure of space exploration is common to all people, evident in stories from our earliest civilizations and in our latest films and novels, and is a powerful motivating force behind advances in real-life science and technology. Space exploration can provide unique educational inspiration and employment opportunities for young people around the world.

While the majority of current activities within the Constellation program are, by necessity, concerned with developing the initial pieces of hardware and processes to support this space exploration infrastructure, there are significant efforts being undertaken with regard to the international cooperation, commercialization, and education aspects of our space exploration policy. These efforts will be discussed in more detail later in this paper.

Current Constellation Progress and Activities

Established in 2005, the Constellation program developed a full set of detailed program requirements by 2007 and is now completing the formulation (or design) phase associated with development of the new Orion CEV and Ares vehicles, and associated infrastructure necessary for humans to explore the Moon. This formulation phase has included the study of various design options, the definition of system requirements, finalizing conceptual methodologies, and the selection of contractor organizations to help NASA develop and build the new hardware and software.

Comment [j4]: Cite 2007 IAC paper

By the end of 2008, Constellation projects Orion and Ares will have completed their Preliminary Design Reviews (PDRs), released and awarded procurements for their required hardware and software, and begun developmental testing on components of their respective systems. In addition to extensive computer design and simulation work, these projects have already conducted engine test firings, parachute drop tests, airbag landing tests, thermal protection system tests, and vehicle wind tunnel tests.

Orion is planning to conduct the Pad Abort 1 (PA-1) launch from the White Sands Missile Range in New Mexico in early 2009, in order to test the crew capsule launch abort system, a secondary rocket system which will allow crew escape if severe problems develop on the launch pad or during ascent to orbit after launch. PA-1 will be followed by a series of- increasingly complex suborbital flights to test pad and ascent abort systems between 2009 and 2012.

The Ares I-X launch is scheduled for early-2009 from Pad 39-B at the Kennedy Space Center and will be the first integrated flight test of the Ares I core rocket. This test will be a 2-minute suborbital flight and will include mass-simulators for the upper stage and Orion crew vehicle (since both components are still in development at this time). The core Ares I rocket is derived from the Space Shuttle solid rocket booster. This will be followed by another uncrewed Ares I-Y test flight in late 2013. Section 3 ~~of this handbook (whitepaper?)~~ provides a detailed description of the Constellation test flight strategy, as well as descriptions of each of these planned test flights.

These Orion and Ares test flights are leading up to an uncrewed orbital flight test of the complete vehicle in early 2014 (Orion-1), and the first crewed launch in late 2014 (Orion-2). At this point, the Orion vehicle will begin routine operations of two flights per year to Earth orbit to support the International Space Station. Based on our current budget, the program is committed to Full Operational Capability with Orion--4 in 2015. A summary schedule of Constellation flight test activity is shown in **Figure 1-3**.

In addition to preparations for the vehicle tests mentioned above, construction of key test, processing and launch facilities are already well underway in New Mexico, Ohio, Mississippi, Alabama, Virginia, California, Texas and Florida. Some of these facilities are new, and some are being refurbished from existing Space Shuttle and Apollo-era facilities. These facility projects are described in more detail later in this paper.

The human lunar return flight of the Altair lunar lander and Earth Departure Stage is

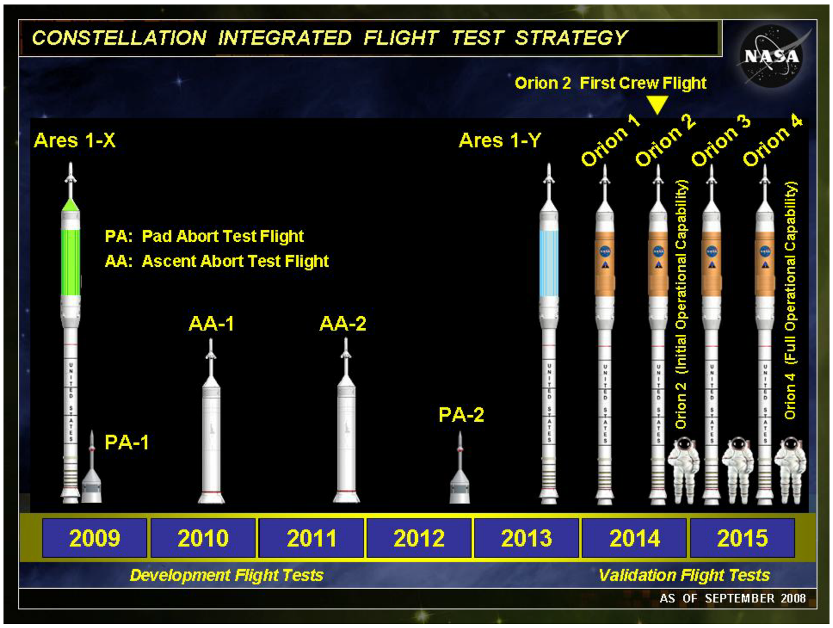

Figure 1-3. Constellation Flight Test Program and the beginning of Full Operational Flights in 2015

scheduled for 2020 aboard the heavy-lift Ares V rocket. It is anticipated that a series of test vehicles will be used for flight tests in Earth orbit prior to this milestone (similar to the flight tests of the Apollo Saturn vehicle and lunar module). Altair will be capable of landing four astronauts on the lunar surface, providing life support and a base for the initial week-long surface exploration missions, and returning the crew to the Orion spacecraft in lunar orbit. A follow-on version of the Altair will be an uncrewed autonomous cargo carrier which will deliver outpost elements, rovers and other scientific equipment to the lunar surface. **Figure 1-4** shows the major lunar exploration vehicle elements and a simplified mission profile.

A seventh Constellation project, the Lunar Surface Systems Project, is now in the early stage of formulation. The ESAS team defined only a limited framework for lunar surface activities, and their lunar surface work has been continued by the Constellation Lunar Architecture Team (CxAT Lunar). A number of CxAT Lunar studies culminated in a nine-month Lunar Capability Concept Review which was completed in June, 2008[6]. This study investigated possible extended-stay lunar mission scenarios, including the use of lunar resources for the on-site (or in-situ) production of power, oxygen and fuel, and compared them with the capabilities of the emerging Orion, Altair and Ares designs in order to provide a basis for the Lunar Surface Systems Project to begin initial hardware and software requirements development. In turn, the Orion, Altair and Ares projects have begun to incorporate key design requirements from the Lunar Capability Concept Review into their designs, and are working with the Lunar Surface Systems Project to ensure a compatible program design which will support eventual long duration stays on the lunar

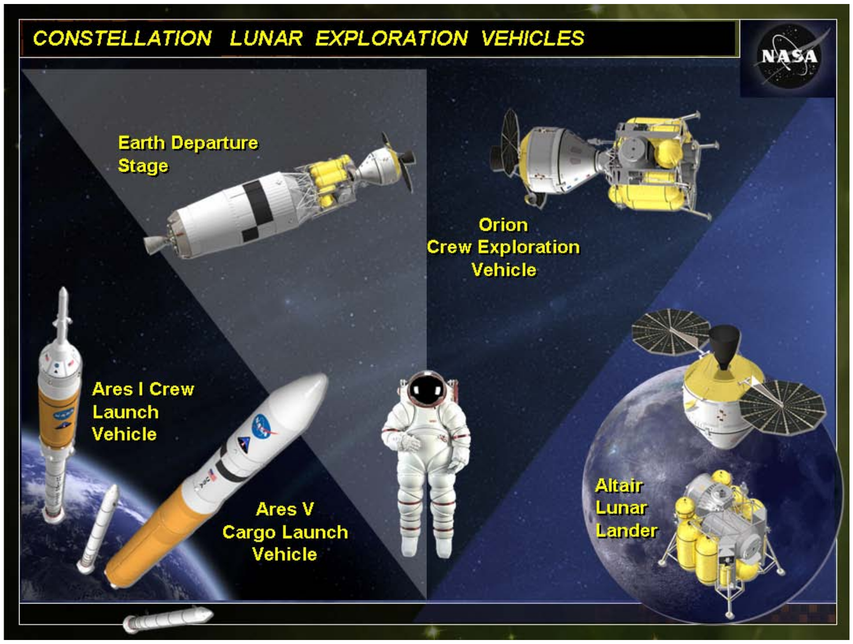

Figure 1-4. Basic Constellation Lunar Exploration Vehicle Architecture

surface. The Lunar Capability Concept Review established a feasible point-of-departure architecture (not a final baseline) that will now be used as a common starting point by the Constellation projects to refine concepts and begin to discuss and define requirements, and eventually hardware, for extended lunar operations A Lunar Surface Concept Review (LSCR) will be conducted in mid-2010 to assess specific proposals and potential international partner contributions for an early lunar outpost.

This type of concurrent short-term and long-term design development between Constellation projects is a key element of efficient systems engineering and will help minimize program cost and risk, while allowing the optimization of performance among all vehicles and key elements in program architecture.

NASA has already begun to construct and test prototype lunar surface hardware in an effort to determine which designs show promise for future development. **Figure 1-5** below shows a variety of habitat modules, mobility equipment and planetary surface navigation techniques currently being tested in harsh environments from the Arctic Circle to Antarctica.

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Figure 1-5: Prototype inflatable lunar habitats are tested in the Antarctic. Surface suits and a new rover concept vehicle, along with mobile lunar habitats and scout robots, are tested at Moses Lake in Washington. An experimental Humvee rover and all-terrain scout vehicles are used to test planetary surface navigation techniques (a 230 kilometer trek using only satellite imagery and topography data) on the Mars-like polar desert terrain of Devon Island inside the Arctic Circle.

Based on this prototype testing and studies presented at the LCCR, a variety of feasible lunar surface outpost architecture elements are shown in **Figure 1-6**.

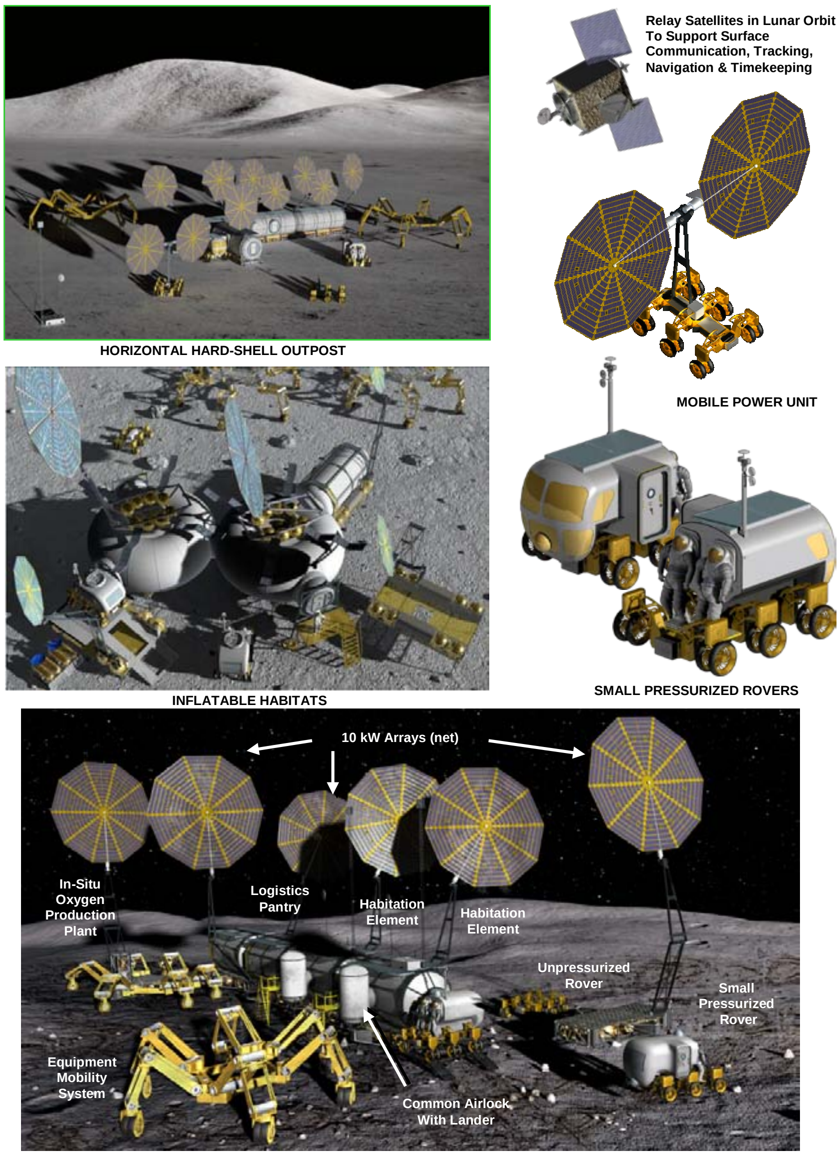

Figure 1-6. A Variety of Feasible Lunar Surface Outpost Concepts

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Why the Moon?

The Moon offers intriguing scientific opportunities and a unique testbed to develop and perfect the technology necessary to begin long-term, extended exploration of the Moon and Mars, and to use the vast natural resources available beyond the Earth. Unlike Mars or other locations, the Moon can be reached with existing or derived launch and environmental support systems. From the brief Apollo explorations, we know that the lunar surface is rich in materials necessary for extended operations and that lunar soil can be a fertile growth medium for terrestrial plants and can be used for building material and insulation from solar radiation. In addition to silica, iron, titanium, and small amounts of hydrogen and helium from the solar wind, most lunar rocks are approximately 40% oxygen. In-situ (i.e., on site) production of exploration staples such as water, oxygen, rocket fuel, solar cells, and other building materials should be possible, and the lunar environment offers some unique environmental advantages (e.g., unfiltered sunlight for power generation and low gravity and pressure to support a vacuum deposition manufacturing process). Some of these same characteristics will pose special problems for equipment and human health maintenance (e.g., extended exposure to a low gravity environment and potential concerns about exposure to fine-powdered silicates) which will need to be quantified and overcome by human experience in an environment which is impossible to accurately simulate on the Earth.

The transport systems and processes which we develop to reach the Moon can also be used to access geosynchronous Earth orbit, various areas of gravitational stability (Lagrange Points) within the Earth-Moon system (these locations are ideal for long-term astronomical telescopes and scientific platforms) and a variety of Earth-approaching asteroids. Experience with complex crew-rated engine system reliabilities will be critical for more long-term exploration missions in the future.

Perhaps most significant, the Moon is a ‘natural space station’ that is only three days away in transit time (and three seconds away for round-trip communication – as opposed to a gap of between eight minutes and forty minutes for round trip communication between Earth and Mars, depending on orbital alignment of the planets). This physical and communication proximity may be as important for psychological considerations in our early exploration as it is for treating medical emergencies, transferring emergency supplies, or mounting a rescue mission.

Mars is a thousand times farther away than the Moon; perhaps greater than a two year minimum round trip. The complexity and expense of a human Mars mission will be orders of magnitude greater than lunar operations. The long-term lunar outpost will allow the perfection of the necessary engineering technology and techniques close to home, and perhaps give us the experience and confidence to build international relationships with which to share the Mars human exploration adventure.

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Summary

In response to Presidential and Congressional direction following the Columbia space shuttle accident in 2003, NASA conducted the Exploration Systems Architecture Study utilizing internal and independent expertise and identified the key elements and milestones necessary to enable human exploration and exploitation of the Moon and to develop a long-term space infrastructure that will permit evolutionary growth and the future human exploration of Mars and other parts of our solar system. The Constellation program began in 2005 with the goal of a first crewed mission in 2015 and a sustainable human return to the Moon by 2020.

In 2006, the new NASA Strategic Plan[7] outlined and adopted six strategic goals in support of this new agency direction:

Strategic Goal 1: Fly the Shuttle as safely as possible until its retirement, not later than 2010.
Strategic Goal 2: Complete the International Space Station in a manner consistent with NASA's International Partner commitments and the needs of human exploration.
Strategic Goal 3: Develop a balanced overall program of science, exploration, and aeronautics consistent with the redirection of the human spaceflight program to focus on exploration.
Strategic Goal 4: Bring a new Crew Exploration Vehicle into service as soon as possible after Shuttle retirement.
Strategic Goal 5: Encourage the pursuit of appropriate partnerships with the emerging commercial space sector.
Strategic Goal 6: Establish a lunar return program having the maximum possible utility for later missions to Mars and other destinations.

The Constellation program is a key participant in all of these goals except the retirement of the Space Shuttle. Work has begun to design, manufacture and test the necessary hardware and software. New, cost-effective and efficient approaches are being adopted (e.g., on-going review by external experts, concurrent short-term and long-term design compatibility development, new applications of risk reduction and manufacturing techniques, and in situ lunar resource utilization planning, to name a few). New emphasis is being placed on international cooperation, both with existing partners and with new, non-traditional participants (e.g., China, India and the Republic of Korea). New opportunities are being studied to encourage commercial space development and to inspire a new generation of scientists and engineers in our educational system.

All of the critical design and development activities described in this paper establish the foundation for a U.S. Lunar Capability that will enable humans to depart low earth orbit for the first time in nearly 40 years.

Figure 1-7 on the next page shows a variety of Constellation activities currently underway across the country.

Photo Key: 1) Orion flight test crew capsule prepared for testing at Glenn Research Center. 2) Ares-I first stage main parachute test. 3) Crew capsule launch abort system jettison motor test. 4) Crew capsule airbag drop tests. 5) Abort flight test launch pad under construction in White Sands, New Mexico. 6) Crew seat and harness testing underway on acceleration sled at Wright Patterson Air Force Base. 7) Launch abort motor full scale test stand in Promontory, Utah. 8) Prototype lunar surface spacesuit and lunar rover vehicle testing at Johnson Space Center. 9) Crew module arrives at Dryden Flight Research Center for Pad Abort 1 test launch. 10) Ares-V RS-68 core stage engine test firing at Stennis Space Center. 11) Crew module preparation area at Dryden for Pad Abort and Ascent Abort launch tests.

Figure 1-7. A small sample of Constellation design and test activities underway prior to beginning test flights in 2009.

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2. Constellation Program: Major Vehicles, Hardware and Facilities

The Constellation Program is developing the flight systems and Earth-based ground infrastructure for an expanded human presence in the Solar System. Building on the achievements of previous lunar exploration efforts and much technological advancement made over the past five decades, this evolving infrastructure will provide the foundation for the United States to continue to access the International Space Station, return humans to the Moon, and enable human exploration of Mars and beyond.

The first step in this ambitious national undertaking is to formulate a safe, cost-effective and sustainable strategy, or architecture, for lunar return and then design and develop the building blocks of vehicles and systems necessary to accomplish this goal. **Figure 2-1** illustrates the basic plan (reference mission) for the first human lunar landings.

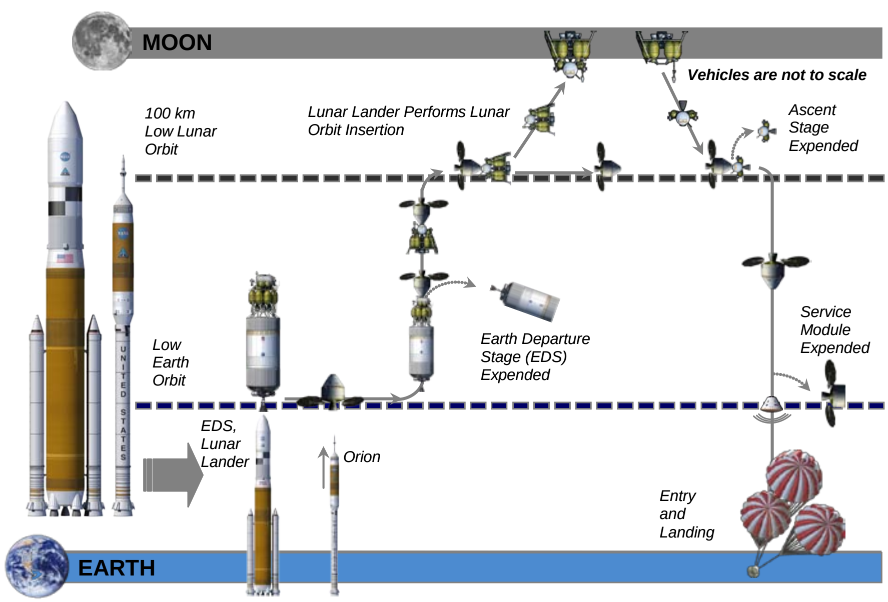

Figure 2-1: Reference Mission Profile for the First Human Lunar Return Flight

For these missions, the Altair lunar lander vehicle is mated with the Earth Departure Stage (EDS) booster and launched on the heavy-lift Ares-V rocket. For safety and cost considerations, this new architecture stresses the separation of crew from cargo launches (it is easier and less expensive to human-rate the smaller and less complicated vehicle required for crew transport). The crew will launch in the Orion Crew Exploration Vehicle (CEV) on the Ares-I rocket. The Orion CEV will rendezvous and dock with the Altair/EDS. The EDS will perform the trans-lunar injection burn necessary for the integrated Orion CEV/Altair vehicle to leave Earth orbit and begin a coast trajectory to the Moon. During this coast phase the EDS is jettisoned after its fuel is spent. Upon arrival at the Moon, the Altair lunar descent engine is used to reduce the vehicle's velocity and enter lunar orbit. The crew then transfers to the Altair lander (unlike the Apollo missions, there are no plans to leave an astronaut in lunar orbit), separates from the Orion spacecraft and descends to the lunar surface. Unlike Apollo, which could only reach equatorial regions of the moon, Altair will carry enough fuel to land in all lunar regions, including the poles. Once the surface mission is complete, the crew will use the Altair ascent stage to lift-off from the lunar surface, leaving the descent stage on the lunar surface. Once the crew has docked and transferred to the orbiting Orion CEV, the Altair ascent stage is jettisoned to the lunar surface.

The primary infrastructure components that are necessary to accomplish this mission are:

- The Orion Crew Exploration Vehicle (CEV), comprised of a Crew Module (CM), Service Module (SM), Launch Abort System (LAS), and spacecraft adapter hardware which attaches the Orion spacecraft to the Ares launch vehicle.
- The Ares I rocket, the launch vehicle for the Orion CEV.
- The Ares V rocket, a heavy-lift vehicle designed to launch the Altair lunar lander (or any heavy payload element) and an Earth Departure Stage rocket.
- The Altair lunar lander, which includes a crew cabin with lunar descent and ascent stages.
- Extravehicular Activity (EVA) support hardware, which includes new tools and spacesuits for crew work in space and on the lunar surface.
- Lunar Surface Systems (LSS) equipment for advanced lunar operations, including rovers, habitat and logistics modules, communication and power systems, and other hardware needed for extended stays on the lunar surface.
- Ground support facilities, including launch pads and launch control center, vehicle integration and test facilities, recovery and refurbishment facilities, the mission control center, and various engineering and training support facilities.

The Orion Crew Exploration Vehicle (CEV)

The basic design of the Orion spacecraft consists of the Crew Module, Service Module, Spacecraft Adapter, and Launch Abort System (see **Figure 2-2**). The Orion spacecraft is approximately 5 meters (m) (16.4 feet [ft]) in diameter and 15.3 m (50.3 ft) in length with a mass of approximately 14,000 kg (31,000 lb). The Orion spacecraft provides crew habitation in space; docking capability with other launched components and the International Space Station; and performs Earth return, atmospheric entry, and landing. The Orion spacecraft can be configured to carry a crew of up to four to and from lunar orbit and up to six to and from the International Space Station.

Due to the physics associated with atmospheric entry, the overall shape of the Crew Module is similar to that of the Apollo Command Module; however, the Orion Crew Module is much larger, providing more than twice the usable interior volume and carrying double the crew size to the Moon. The Crew Module includes a pressurized crew transfer tunnel and docking device capable of mating with the International Space Station and the Altair lunar lander.

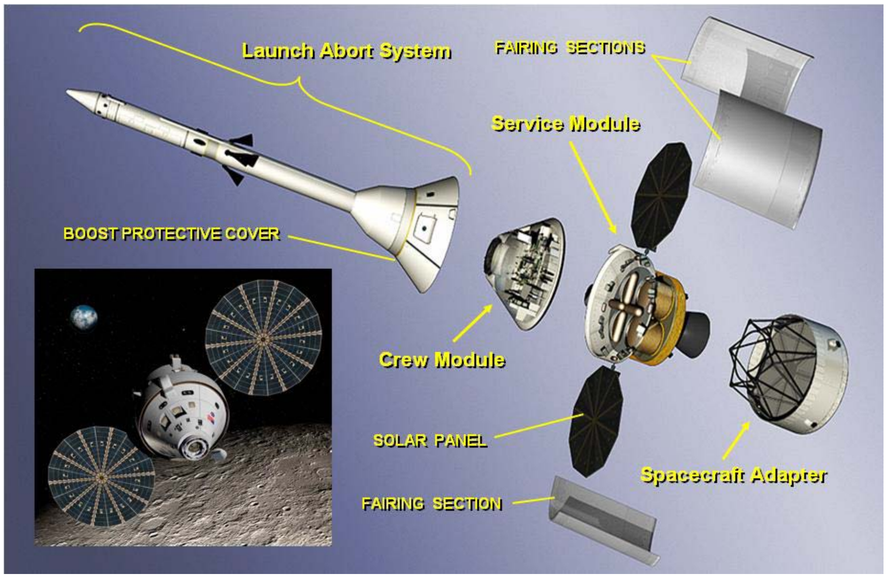

Figure 2-2. Orion Crew Exploration Vehicle (CEV)

New features of the Orion spacecraft include a digital "glass cockpit" control system, derived conceptually from the systems used in today's most advanced aircraft, and the use of high-data-rate, low-weight fiber optic systems. The spacecraft will be able to "autodock" with the ISS using onboard sensors and computers, with provision for the crew to take over in an emergency. Previous American spacecraft (Gemini, Apollo, and Shuttle) have all required manual piloting for docking. The final interior layout of the Crew Module and its controls are still being designed, but a reasonable representation is shown in **Figure 2-3**.

The primary landing mode for the Crew Module will be an ocean landing near the western U.S. coast supported by parachutes and inflatable water flotation airbags, however, contingency landing and recovery of the crew and capsule will be possible anywhere in the world. Current planning is focusing on a nominal water landing within 200 miles of the Navy's San Clemente Island Range Complex, using a local retrieval ship with helicopter support and cost-sharing of a Deep Submergence Rescue Vehicle with the Navy and Military Sealift Command.

After recovery, various components of the Crew Module will be refurbished and reflown. Hardware associated with Launch Abort System, Service Module and Spacecraft Adapter is jettisoned at various points during the flight and either disintegrates during atmospheric reentry or is targeted for impact in a remote ocean location.

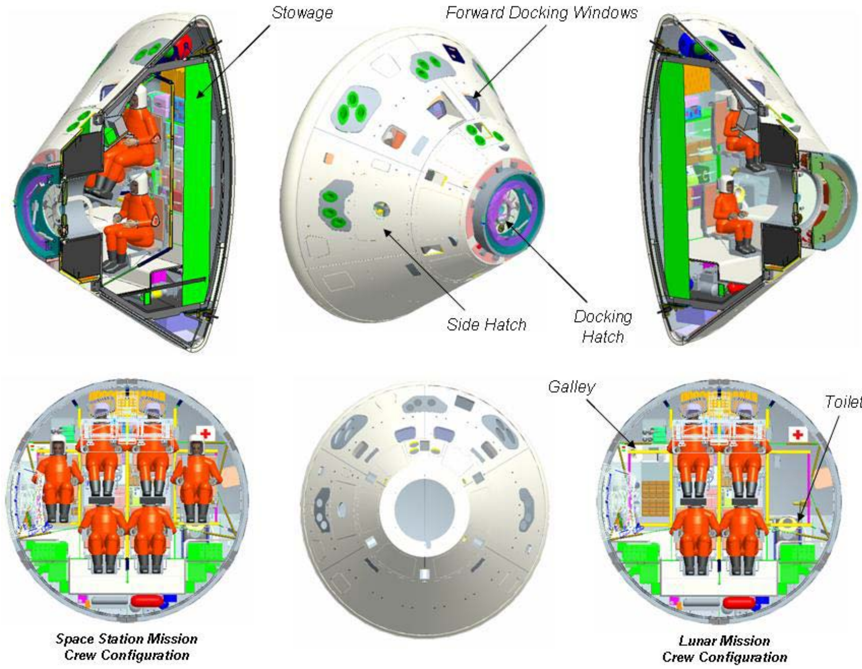

Figure 2-3. Proposed Interior of the Crew Module (which is in the detail design phase)

Prior to splashdown, the Crew module will encounter high aerodynamic heat loads from the Earth's atmosphere, just as the Apollo Command Module did as it returned from the Moon, and as the Space Shuttle does on its gliding descent from Low Earth Orbit. Thermal protection of the crew capsule is a significant design challenge. Orion's Crew Module Thermal Protection System consists of an expendable heat shield on the bottom of the spacecraft and reusable external and internal insulation. A number of candidate materials were evaluated for use in the Thermal Protection System (*e.g.*, silica, carbon fibers, ceramics, and combinations of these materials). Phenolic Impregnated Carbon Ablator (PICA), a low-density composite, is the currently preferred material based on the test results so far. PICA was first used on the NASA Stardust robotic sample return mission. Unlike the thermal protection system used on the Space Shuttle, the Orion heat shield will not be exposed during launch, ascent to orbit, or during operations in space (it is exposed only after separation from the Service module just before reentry), so extensive in-space inspections and repair capability will not be necessary.

The Orion Service Module is a cylindrical structure attached aft of the Crew Module and contains propulsion and power systems (including two large deployable circular solar arrays), a high-gain antenna for communication, and the radiator panels used to reject heat developed within the Crew Module (see **Figure 2-4**).

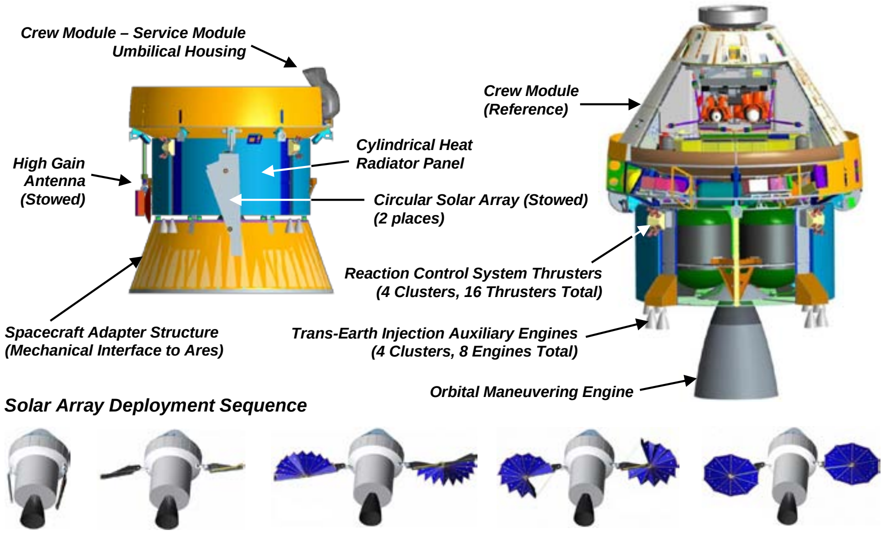

Figure 2-4. Orion Service Module

Should an emergency situation arise during launch or early ascent operations, rapid escape of the crew from the Orion/Ares I launch stack is accomplished by means the Launch Abort System, which is essentially a smaller solid rocket motor and guidance control system mounted on top of the Orion Crew Module (see **Figure 2-5**). This is a significant safety improvement over the design of the Space Shuttle. In an emergency, pyrotechnics will separate the Crew Module from the Service Module and the Launch Abort System rocket will pull the Crew Module away from the remainder of the launch vehicle stack. Once the Crew Module is clear of danger, the Launch Abort System and Boost Protective Cover assembly are jettisoned and the Crew Module returns to Earth using its normal landing parachutes. This system is being designed to operate in all critical phases of launch and ascent: from a zero-velocity start (a launch pad accident prior to liftoff) and at either subsonic or supersonic phases of the ascent profile. The Launch Abort System rocket motor itself is more powerful than the Atlas 109-D booster that launched John Glenn into orbit in 1962.

During a routine launch, the Launch Abort System will be jettisoned approximately 30 seconds after First Stage separation and will splash down in the Atlantic Ocean. After the Launch Abort System is jettisoned, emergency abort capability for the crew is provided by the Service Module propulsion system.

The Orion/Ares I is estimated to be as much as 10 times safer for the crew than the Space Shuttle, primarily due to its in-line design and incorporation of the Launch Abort System for crew escape.

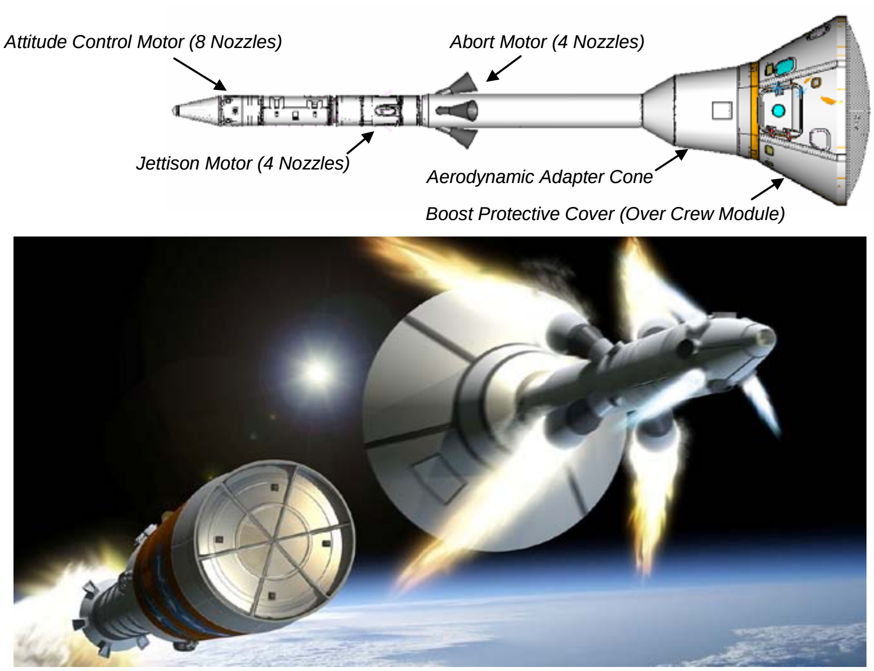

Figure 2-5. The Orion Launch Abort System for crew escape during a launch emergency.

The Service Module is connected to the Ares I launch vehicle by the Spacecraft Adapter, which consists of a W-Truss and a fairing. The Spacecraft Adapter provides a smooth physical transition from the Ares I Upper Stage to the Orion and a conduit for data transfer between the vehicles. This arrangement allows structural load sharing between the Service Module internal structure and the fairing during peak loading events of the ascent phase, but allows the fairing to be jettisoned once the vehicle has left the atmosphere. The Spacecraft Adapter fairing sections also provide protection for the Service Module structure (including the main engine, the solar arrays, and the high gain antenna) during ascent. After main engine cutoff, the Spacecraft Adapter, now without the fairings, remains attached to the Ares I Upper Stage while the Service Module separates and continues into orbit.

The Ares Launch Vehicles

The Ares I launch vehicle carries the Orion spacecraft to low Earth orbit where it can rendezvous and dock to the International Space Station or to the Altair lunar module previously launched by an Ares V heavy-lift rocket. The Ares I and Ares V are being developed concurrently with propulsion and structures hardware commonality, which results in significant design and manufacturing cost savings. Common elements being developed for the Ares I and Ares V launch vehicles include the solid rocket motors and the J-2X Upper Stage engine. Cost and risk reduction are also enhanced by utilizing existing and proven hardware and systems whenever possible. This includes Solid Rocket Booster technology from the Space Shuttle Program used as the basis for the Ares I First Stage and Ares V booster rockets. The Ares I Upper Stage J-2X engine (and the Earth Departure Stage of the Ares V) is a generational upgrade of the J-2 engine used on Saturn V and Saturn IB launch vehicles during the Apollo program. The RS-68 engines of the Ares V core stage were developed in the late 1990s and early 2000s for the U.S. Air Force's Evolved Expendable Launch Vehicle Program (Delta IV).

The Ares I Launch Vehicle

The Ares I is a two-stage launch vehicle (see **Figure 2-6**). The First Stage is a five-segment Solid Rocket Booster fueled with approximately 1.4 million pounds of solid propellant. The Upper Stage is a structurally self-supporting cylindrical system that houses the liquid oxygen and liquid hydrogen tanks that contain propellant for the single J-2X engine, along with the avionics, roll control, and thrust vector control systems.

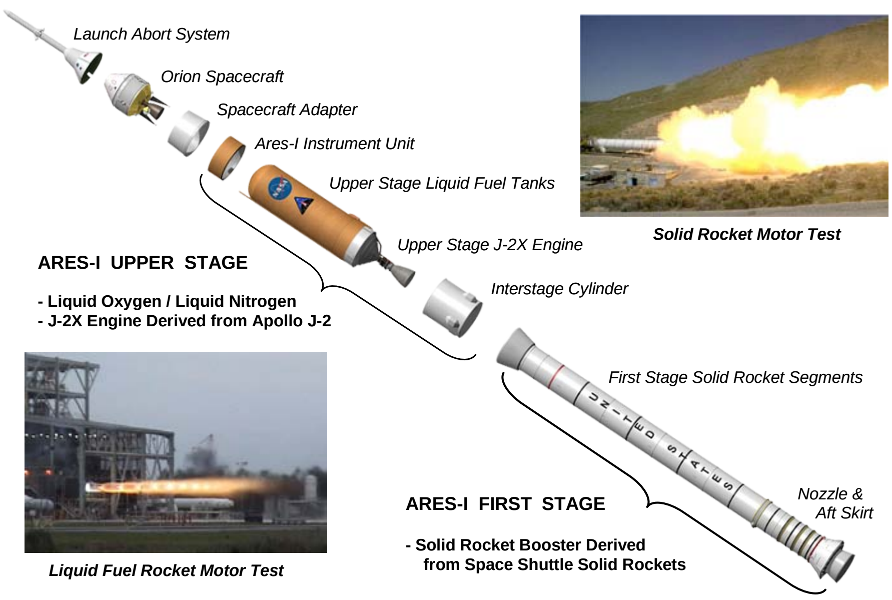

Figure 2-6. The Ares I Launch Vehicle

The Ares I will be able to lift an estimated 56,500 lbm (25.6 mT) to low Earth orbit (by comparison, the Space Shuttle currently has a 25.0 mT payload capacity to low Earth orbit). During a mission, the Ares I First Stage will be jettisoned a little more than two minutes after launch. A parachute system will allow the First Stage to be recovered from the Atlantic Ocean and returned to the Kennedy Space Center for disassembly and cleaning. The solid rocket motor casings will be returned to Utah for refurbishment and refueling. Other components of the First Stage (e.g., separation motors and parachutes) will be refurbished at KSC. The Constellation Program is studying the possibility of not recovering the spent Ares I First Stage for certain missions. This could gain additional performance margin for certain missions by eliminating the launch weight of the booster recovery systems (e.g., parachutes, transponders, flotation devices, etc.).

The Upper Stage will separate from the Orion spacecraft after main engine cutoff. The Upper Stage will enter the Earth's atmosphere and splash down in the Indian Ocean (see **Figure 2-7**).

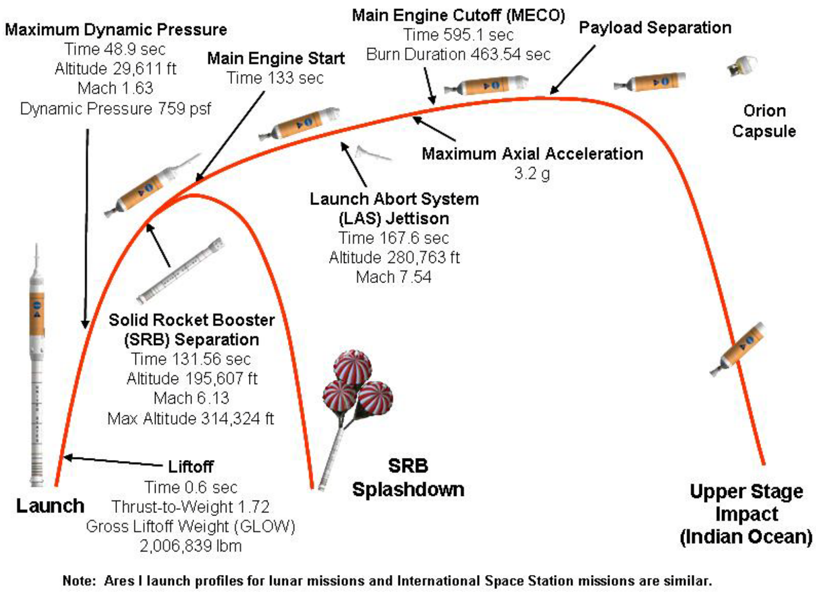

Figure 2-7. Orion/Ares I Mission Profile to Low Earth Orbit

The Ares V Launch Vehicle

The Ares V launch vehicle provides heavy lift capability. The vehicle is roughly 110 m (360 ft) tall and will lift 143.4 mT (316,100 lbm) to low Earth orbit or propel 55.6 mT (122,600 lbm) on a lunar trajectory. The 143 mT to low Earth orbit compares to a maximum payload capacity of approximately 25 mT for the Space Shuttle. In its current design configuration, the Ares V consists of a liquid oxygen/liquid hydrogen propellant Core Stage with two Solid Rocket Boosters and an Earth Departure Stage derived from the Ares I Upper Stage. Atop the Earth Departure Stage is a payload shroud to protect the payload for lunar and future Mars missions. (See **Figure 2-8**)

The Ares V Core Stage leverages manufacturing processes and materials used on the Space Shuttle External Tank. The Core Stage is 10 m (33 ft) in diameter and 65 m (212 ft) in length, making it the largest rocket stage ever built. It is roughly the same diameter as the Saturn V First Stage, but its length would be about the same as the combined length of the Saturn V First and Second Stages. The Core Stage will use a cluster of six RS-68B liquid hydrogen/liquid oxygen engines, each supplying about 3.1 million N (700,000 lbf) of thrust.

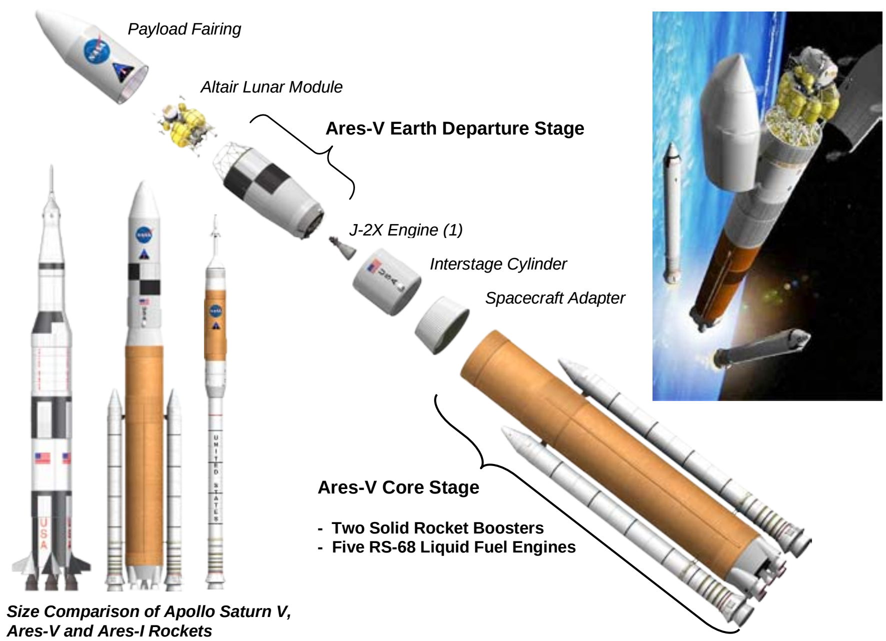

Figure 2-8. The Ares V Launch Vehicle

The two Ares V Solid Rocket Boosters are derived from the SRBs currently used on the Space Shuttle and from the First Stage planned for the Ares I. These solid boosters will separate from the Core Stage during ascent and be recovered in the Atlantic Ocean. The Constellation Program is studying the possibility of not recovering the spent Ares V SRBs for certain missions. This could gain additional performance margin for certain missions by eliminating the launch weight of the booster recovery systems.

The Second Stage of the Ares V is called the Earth Departure Stage. The Earth Departure Stage is powered by one J-2X engine developed for Ares I but modified with an air restart capability. The Earth Departure Stage has two functions: 1) provide a suborbital burn to place the lunar payload into a stable Earth orbit and 2) ignite a second time after the Orion spacecraft, launched separately on an Ares I, docks with the Earth Departure Stage to place the combined vehicle into a trajectory towards the Moon.

The Altair Lunar Lander

The Altair Lunar Lander will provide access to the lunar surface for astronaut crews and/or cargo via a descent stage and will return the crew via an ascent stage to the Orion spacecraft in lunar orbit. A cargo-only version of the Lunar Lander will be able to transport cargo to the lunar surface and may not include an ascent stage. Basic elements of the Lunar Lander will include the propellant tanks and engines associated with the ascent/descent stages, a living module for the crew (*i.e.*, pressure vessel), a landing gear system, internal power supplies (*e.g.*, rechargeable batteries) and provisions for crew access to the lunar surface. Propellants proposed for the Lunar Lander include liquid oxygen/liquid hydrogen for the descent stage and liquid oxygen/methane for the ascent stage; although a final decision on propellants has not been made.

After the Earth Departure Stage is jettisoned, the astronauts will pilot the docked Altair and Orion spacecraft on to the Moon. In lunar orbit, the Orion crew will transfer into the Altair lander (unlike the Apollo missions, an astronaut will not remain behind in lunar orbit), undock from the Orion CEV and fly to the lunar surface. During the surface mission, the Orion spacecraft is monitored from Mission Control and held in a 'station keeping' mode in lunar orbit. When the surface mission is complete, the crew will fire the Altair ascent stage to lift-off from the lunar surface, leaving the descent stage behind. Once the crew docks and moves into the orbiting Orion CEV, the Altair ascent stage is jettisoned and targeted for impact on the lunar surface. **Figure 2-9** shows two conceptual designs for the lunar lander, which is still in the design phase. An important common characteristic of these designs are the large descent stage fuel tanks. This amount of fuel enables the lander to reach any point on the lunar surface, rather than being restricted to regions near the lunar equator, as was the Apollo program. **Figure 2-10** illustrates the ascent stage after liftoff from the lunar surface and docking with the CEV.

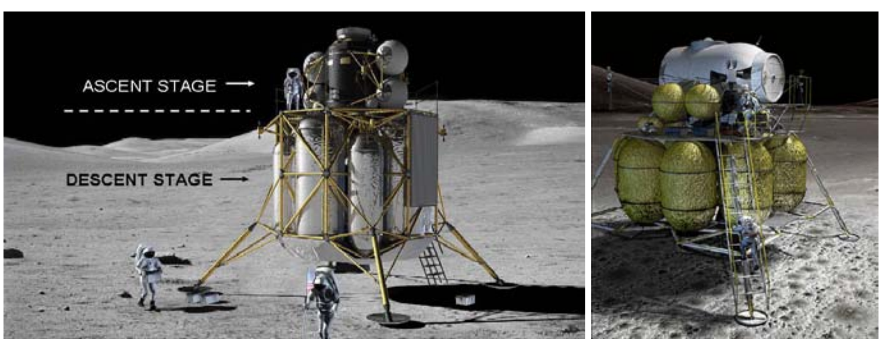

Figure 2-9. Conceptual Designs for the Altair Lunar Lander

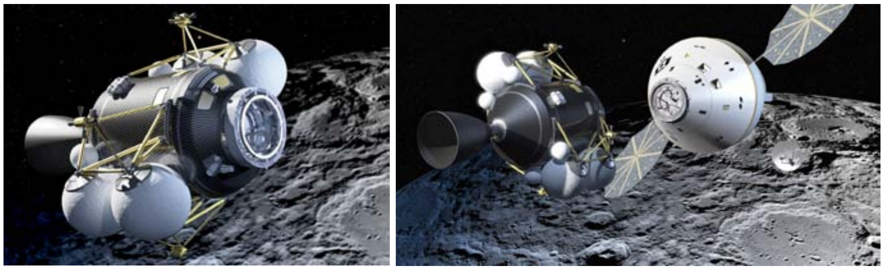

Figure 2-10. Ascent stage returning to Orion after liftoff from the lunar surface.

Extravehicular Activity (EVA) Support Equipment

The EVA Systems Project provides the spacesuits and necessary tools for astronauts to work outside of the protective confines of a space vehicle. EVAs can be conducted in space or on the lunar surface, and are used for planned activities, such as research tasks or site exploration, and for contingency tasks, such as inspection or vehicle repair.

The EVA Systems Project will develop, certify, produce and sustain flight and training hardware systems necessary to support EVA and crew survival during all Constellation mission phases.

The following spacesuit capabilities are being developed:

- Crew protection and survival capability for launch and atmospheric entry, landing, and abort scenarios
- Contingency zero-gravity in-space EVA capability for the Orion spacecraft
- Surface EVA capability for exploration of the Moon.

The spacesuit, called the Extravehicular Mobility Unit, currently being used by the Space Shuttle Program and on the ISS is not compatible with either the lunar or the Martian environments because it was designed for zero-gravity operations in Low Earth Orbit. NASA is developing a new modular spacesuit system that will be used during launch, atmospheric entry, abort, in zero-gravity and in lunar environments. The spacesuit will support long-duration (180 days) missions, perform multiple EVAs, and function under conditions expected at lunar exploration sites. **Figure 2-11** illustrates the two basic types of spacesuits being developed: the Launch-Entry-Abort Suit and the Lunar Surface Suit. These designs share many common elements, but the Lunar Surface Suit provides additional micrometeoroid and dust protection and has an enhanced range of mobility to allow astronauts to work for extended periods of time in the lunar 1/6-gravity environment. **Figure 2-12** shows engineers testing a prototype Lunar Surface Suit in conjunction with a new lunar rover concept vehicle at the Johnson Space Center in early 2008.

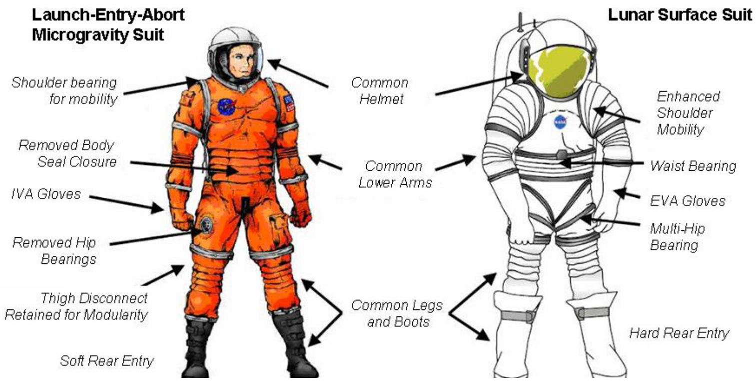

Figure 2-11. Early Designs for the Launch-Entry-Abort (LEA) Suit & Lunar Surface Suit.

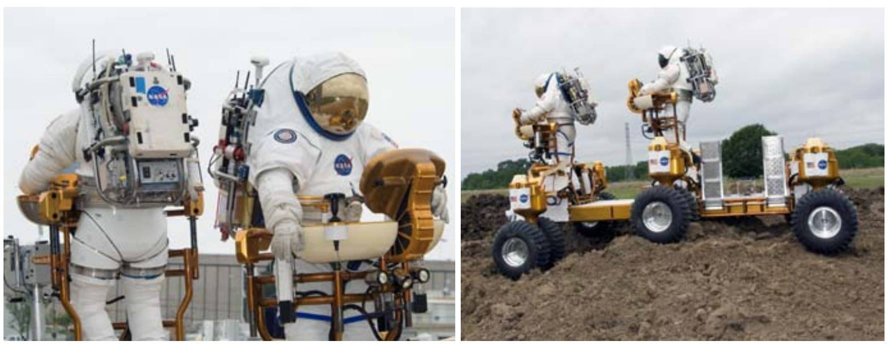

Figure 2-12. Prototype Lunar Surface Suits are tested in early 2008 in conjunction with an omni-directional lunar rover concept vehicle (the "lunar truck") developed at NASA. These designs and tests will help establish performance requirements and a baseline for evaluating future proposals.

Lunar Surface Systems

The primary goal of developing all of the launch capability and vehicle and suit infrastructure discussed above is to enable a sustained human presence on the Moon. In June, 2008, the Constellation program completed the Lunar Capability Concept Review (LCCR). The LCCR was a major milestone and the result of over nine months of various lunar exploration-related studies, including:

- lunar exploration requirements definition

- lunar surface infrastructure compatibility and maximum leverage with the Orion, Altair and Ares vehicles already in development

- lunar mission concept evaluations

- habitat and logistics module concepts (hardside and inflatable)

- lunar rovers and equipment mobility devices

- construction equipment concepts for lunar soil excavation and movement

- equipment and processes for oxygen extraction from lunar soil

- lunar surface communications and navigation services

- outpost evolution and growth (in both lunar equatorial and polar regions), and

- lunar infrastructure extensibility to Mars exploration.

The Lunar Surface Systems Project is tasked with continuing study and definition in all of these areas, and more, in order to refine an overall architecture for lunar surface operations, as well as engaging the international community in preliminary discussions about long-term lunar outpost development. **Figure 2-13** shows prototypes of lunar surface systems being tested at Moses Lake, Washington, in June, 2008.

Figure 2-13. With mobile lunar habitat modules in the background, astronauts on a "lunar truck" deploy a robot scout rover. The lunar truck doubles as a bulldozer. An automated drilling unit makes its way over simulated lunar terrain. An electric crane is tested for removing equipment from a simulated lunar lander.

Ground Support Activities at the Launch Site and Other Test and Development Facilities for Constellation Missions

As the Orion and Ares vehicles are being designed, developed and tested, a major refurbishment and update of launch site facilities to accommodate these new vehicles is underway at the Kennedy Space Center (KSC) in Florida. As the Space Shuttle program proceeds toward a planned retirement in 2010, construction is already underway at KSC to convert existing facilities used during the Apollo and Space Shuttle programs to support the new Constellation vehicles.

A primary goal of ground system planning has been to reuse as much existing infrastructure (processes and facilities) as possible, while minimizing operational costs. Orion spacecraft assembly and checkout will take place in the Operations & Checkout building originally used to assemble and test Apollo vehicles. Ares assembly and mating with the Orion CEV will take place in the familiar Vehicle Assembly Building used for both Apollo and Shuttle missions. The existing (although modified) Mobile Launch Platforms, Crawler-Transporter vehicles, launch pads, and launch control center will also support Constellation launches. **Figure 2-14** shows the Vehicle Assembly Building (VAB) and an artist's concept of the Ares-I vehicle assembled in the VAB highbay and on the launch pad.

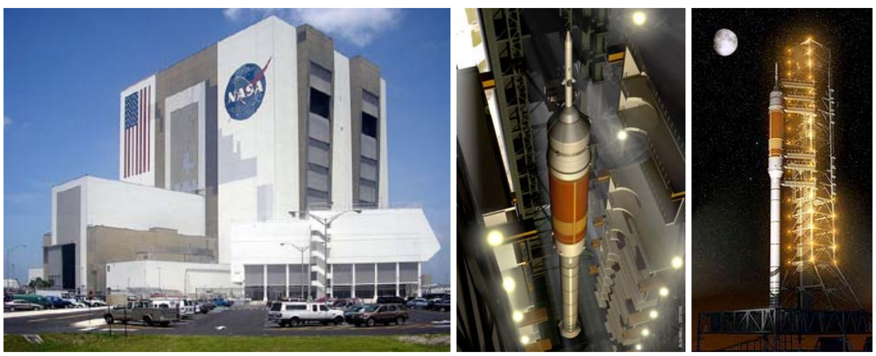

Figure 2-14. The Ares-I vehicle will be assembled in the Vehicle Assembly Building High Bay 3 (the right-side set of vertical shutters in the photo), and the Ares-V will be assembled in the adjacent High Bay 1 area. Artists' concepts show the Ares-I in VAB High Bay 3 and at launch pad 39B.

Launch complex 39 (launch pads 39A and 39B), currently used by the Space Shuttle, will be converted to support the Constellation missions. Modifications will begin on launch pad 39B to accommodate the Ares I-X test flight immediately following its last use as a stand-by launch pad in the event that a rescue Space Shuttle mission is required to support the final Hubble Space Telescope repair mission in late 2008. The Space Shuttle fixed and rotating service structures at the pad will be dismantled and a new fixed service structure for the Ares-I will be permanently installed on the Mobile Launch Platform that will transport the vehicle from the VAB to the launch pad. Work will begin in 2010 following the last Space Shuttle launch to modify pad 39A for the Ares-V vehicle. Constellation has implemented a 'clean pad' design approach, which involves minimizing the interfaces to the launch vehicle on the launch pad. This approach is intended to simplify launch operations along with the timeline and costs associated with preparation of the vehicles for launch.

In addition to modifications to the VAB, launch pads and mobile launch platforms, Firing Room 1 in the Launch Control Center is being redesigned to support Ares and Orion missions with improved computers and far fewer support personnel. While it currently requires more than 200 people in the Launch Control Center to launch a Space Shuttle mission, it is anticipated that the Constellation launch support team will number less than 50 people. This is the result of improved technology and the fact that the Co~~O~~nstellation vehicles are a far less complex than the Space Shuttle.

In addition to work taking place at the launch site, the Constellation program is modifying or constructing a number of support facilities which will help manufacture spacecraft, plan missions, train personnel, support flight operations, and test new vehicles and subsystems for spaceflight. One of our most fundamental program challenges is balancing the benefits of using heritage hardware and facilities versus the projected long-term cost of this use. Constellation is still in the process of examining all processes and procedures for optimization of cost and time resources. Significant facility projects underway include:

- Construction of a new rocket engine test platform at the Stennis Space Center, Mississippi. The A-3 test stand, currently under construction, will allow full-scale testing of the J-2X engine at simulated high altitude. This is critical to assure restart capability of this engine for the lunar missions. The A-3 test stand is the first new full-scale engine test stand constructed at Stennis Space Center since the Apollo Program.

- Modifications to the Structural Dynamics Test Facility at Marshall Space Flight Center in Huntsville, AL. This facility was used to conduct full scale ground vibration tests of the Apollo and Space Shuttle vehicles. It is being modified to conduct similar testing for the Constellation vehicles.

- Installation of the CEV Avionics & Integration Laboratory (CAIL) at JSC in Houston, Texas. CAIL is being constructed in the existing Building 29 at JSC and will contain vehicle mock-ups and computers to simulate mission phases and conduct end-to-end avionics testing in support of planning, pre-flight crew training, and real time problem troubleshooting during actual missions.

- Upgrade of the Integrated Environment Testing (IET) facility at Plumbrook Station near Sandusky, Ohio (managed by the NASA Glenn Research Center in Cleveland). The existing IET facility is being refurbished to provide state-of-the-art test capabilities for full-size spacecraft. Complete Orion CEVs and Altair lunar landers will undergo vibration, acoustic, thermal, vacuum and electromagnetic testing in the large IET chambers.

- Implementation of The Exploration Development Laboratory (EDL), a distributed software development and test facility that has linked facilities in Denver, Colorado; Houston, Texas; and Glendale, Arizona. The EDL performs systems level avionics and software testing for Orion in realistic mission equipment configurations. The EDL became operational in late 2007 and has already begun software development, as well as initial testing of the Orion Guidance, Navigation, and Control (GN&C) subsystem, Automated Rendezvous and Docking (AR&D) subsystem, and crew interfaces.

- Modifications at The Michoud Assembly Facility (MAF) in New Orleans, Louisiana, (managed by the NASA Marshall Space Flight Center in Huntsville, Alabama). MAF will provide manufacturing and assembly facilities for large portions of the Orion, Ares I and V spacecraft. This facility has previous been responsible for manufacture of the Space Shuttle external fuel tanks, and contains one of the largest production buildings in the U.S.

- Construction of the Orion Flight Test Facility at the White Sands Missile Range in Las Cruces, New Mexico, will provide the integration area, control facilities and launch pad necessary for the series of suborbital flight tests of the Launch Escape System.

In addition to these major, dedicated facilities, there are numerous existing government and contractor test facilities which are supporting the Constellation program for engine firings, thermal protection system sample tests, wind tunnel testing, material research, crew interface development, crew capsule drop tests, and many other design and development activities. A detailed description of the planned construction and modification of facilities in support of the Constellation Program can be found in the *Final Constellation Programmatic Environmental Impact Statement.*[8]

3. Constellation Missions: Flight Test, ISS Support, Lunar and Mars Exploration

The Constellation Program is developing the first new human-rated spacecraft in three decades, and a comprehensive series of flight test activities are planned in order to find and fix any design problems, and verify and document vehicle performance capabilities (including safety designs) before crew flights begin.

Historically, flight test operations are unpredictable by nature, and this is especially true when new designs and new hardware are being tested for the first time in extreme operational environments. The Constellation Program fully expects to learn from failures during flight test activities, and to apply what is learned to make the operational Constellation vehicles the safest human spacecraft ever developed.

Beginning in early 2009 and lasting through 2012, flight test of the Orion Launch Abort System using a heavily instrumented, mass/dimension equivalent model of the Orion spacecraft will be conducted at the White Sands Missile Range in New Mexico. As currently planned, there will be two uncrewed pad abort tests (PA-1 and PA-2) to demonstrate Orion Crew Module escape on the launch pad from zero altitude and zero velocity and three uncrewed ascent abort tests (AA-1, 2 & 3) to demonstrate a simulated crew escape during ascent of the vehicle after launch in critical phases of flight. (Refer to Figure 2-8 for details of the Orion flight profile prior to Launch Abort System jettison.)

PA-1 and PA-2 will demonstrate the capability of the Launch Abort System to boost the Crew Module to an altitude sufficient to allow safe parachute deployment and to a sufficiently safe lateral separation from the launch site.

The ascent abort tests (AA-1, 2 & 3) will use a launch vehicle being developed from surplus Air Force Peacekeeper first stage and/or second stage motors. This solid-fuel booster will launch the Crew Module to an altitude high and fast enough to test the Launch Abort System to operate at supersonic vehicle speeds, during periods of ascent profile maximum dynamic pressure, and during unstable (tumbling) flight modes. All flight test activities are designed to take place entirely within the White Sands Missile Range.

The first developmental flight test of the Ares I vehicle (designated Ares 1-X) will be an uncrewed launch from the Kennedy Space Center in mid-2009. Test flight objectives will focus on first-stage flight dynamics, controllability, separation of the first and upper stages, ground operations, and first stage recovery. Ares I-X will test the integration and performance of a simulated Ares/Orion "stack' prior to Critical Design Review (CDR) so that any resulting design changes could be incorporated before production of flight articles begins. Ares I-X utilizes a four segment solid rocket booster excessed from the Space Shuttle Program, with a mass-simulator for the fifth segment. There will also be mass/dimension simulators for the upper stage and the Orion CEV. The solid rocket booster casing will be recovered from the Atlantic Ocean; the upper stage and CEV simulators will not be recovered. **Figure 3-1** shows an artist's concept of the Ares 1-X launch configuration and lift-off at pad 39B.

Figure 3-1. Left: Artist's concept of the Ares 1-X flight test configuration at KSC in mid-2009. Note that many pad elements from the Space Shuttle program are still present at this time (e.g., the Rotating Service Structure on the right) and a lightning protection tower has been added atop the Fixed Service Structure to protect the increased height of the Ares vehicle. Right: Artists's concept of the Ares 1-X launch.

The second uncrewed developmental flight test of the Ares I vehicle (designated Ares I-Y) will also be launched from KSC; this flight test will consist of a five-segment booster with real upper stage and simulated J-2X engine. The Ares I-Y test flight will validate the operation of the Ares I five-segment first stage, and demonstrate performance of a high altitude abort of the Launch Abort System with a boilerplate Orion capsule, after separation of the first stage. As with Ares I-X, only the first stage booster will be recovered from this flight.

The first orbital flight test of the Orion/Ares-I vehicle is designated Orion-1. This will be an uncrewed first test flight of a complete Ares I first stage and operational upper stage, paired with an operational Orion CEV. The Orion CEV will be inserted into an orbit compatible with the International Space Station (although there are no plans to dock with the ISS on this first flight) to test onboard systems such as the solar panels, RCS thrusters and main engine. A water landing and recovery off the coast of Australia is under study for this mission.

The first flight of the Constellation vehicle that will carry astronauts is designated Orion-2 . This will be a 2-crew mission which will rendezvous and dock with the International Space Station. After the Orion-2 mission, the Constellation vehicle will have achieved Initial Operational Capability and begin approximately 2 flights per year to ISS to support crew rotations and to have the Orion spacecraft docked for 180-day intervals as an emergency crew return vehicle. **Figure 3-2** illustrates the Orion CEV approach and docking to the International Space Station.

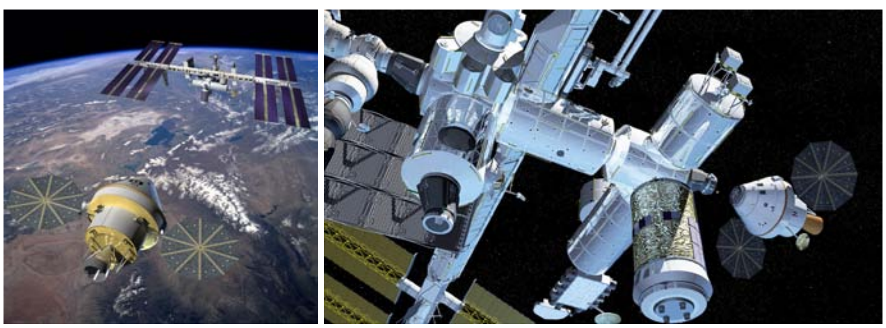

Figure 3-2: Orion CEV Approach and Docking with the International Space Station

In preparation for these first Orion missions, the Constellation program is planning a series of two complete Virtual Missions in 2009 and 2010. The Virtual Missions will use existing software and hardware resources to simulate all critical mission milestones and products required to successfully execute an Orion to International Space Station crew rotation. This will include an end-to-end real-time simulation of all flight and ground phases (e.g., flight prep, launch, on-orbit ops and reentry) that involves flight crew, flight control teams, and mission management teams.

The primary object of the Virtual Missions project is to exercise the data architecture and flight readiness certification process that will support the actual Orion missions. Engineering and management meetings leading up to these simulated missions will be conducted as if they were planning actual flights. These virtual missions (VM1 and VM2) have been added to the flight test manifest, and lessons learned from these simulations will be used to refine procedures, software and the distribution of personnel across the support infrastructure (i.e., this will also serve as a high-fidelity test to determine the optimum number of support personnel needed during all phases of Orion ISS support operations).

After three crewed flights to the ISS between 2013 and 2015, when it is proven that the Constellation systems can operationally support the Orion vehicle with routine operations in Earth orbit to the ISS, the Constellation vehicle and ground support infrastructure will be certified for Full Operational Capability with the Orion 4 flight. Based on the current budget, the Program is committed to FOC with Orion-4 in early 2015. Orion flights will provide Station crew rotation and serve as an emergency crew return vehicle while docked at the ISS for 6-month intervals. This will insure that the international research facility is not dependent on a single vehicle design, or single government, for continued operation.

While the fully-operational Constellation vehicles support research and engineering activities onboard the ISS, NASA will continue with the planning and development of the additional vehicles and systems required for lunar exploration. As a roadmap for future planning and design studies, NASA recently developed a set of Design Reference Missions (DRMs) associated with progressive growth of the lunar exploration capability over time. In order of time horizon and increasingly mature technology, DRMs 1 through 5 are described below.

- DRM 1 : Lunar Sortie Crew
  This mission lands anywhere on the Moon, uses only on-board consumables, and leaves within ~1week. This mission enables exploration of high-interest science sites, scouting of Lunar Outpost locations, technology development objectives, and the capability to perform EVAs. This is the reference mission illustrated in Figure 2-1.

- DRM 2 : Uncrewed Cargo Lander
  Used to support an Outpost, help build one, or preposition assets for a subsequent Sortie Lander, this uncrewed mission lands anywhere on the Moon, and has enough resources to sustain itself until a component of the Lunar Surface Systems takes over.

- DRM 3 : Visiting Lunar Outpost Expedition
  Analogous to an assembly flight to ISS, this mission lands at the site of a complete Outpost or one under construction, and allows crewmembers to extend their stay by using assets of the Outpost rather than only what is carried onboard their Lander.

- DRM 4 : Resident Lunar Outpost Expedition
  Realizing one of the goals of US Space Policy, this mission allows a sustained human presence on the surface of the Moon, since it follows a single crew of four to the surface, transitions them to a habitat at an Outpost, and gets them back to Earth after transitioning over to a replacement crew.

- DRM 5 : Remote Outpost DRM
  This mission is separated in function from the other DRMs by focusing only on those Lunar Surface Systems which need to operate without human intervention, either because humans are not present to operate them, or the task is more easily performed in an autonomous or automatic manner.

The engineering and technical challenges associated with establishing a lunar outpost are formidable. Requirements to sustain human life and support useful activities will mean the development of new technologies and new machines to operate in a harsh and alien environment. NASA is just beginning to quantify the requirements for a lunar outpost and identify the types of equipment that will be necessary for extended lunar exploration.

A top-level set of Outpost requirements include:

- Habitation systems that will support a crew of 4 for 180 days on the lunar surface
- Demonstrated ability to produce in-situ-based oxygen from lunar soil at a minimum rate of 1 ton per year
- Unpressurized rovers that can be operated autonomously or by the crew
- Pressurized roving systems that can travel for hundreds of kilometers from the Outpost
- Power production of at least 35 kW of net power and storage for crewed eclipse periods
- Surface based laboratory systems and instruments to meet science objectives
- Sufficient functional redundancy to ensure safety and mission success .

From these requirements, key new technologies will be needed (and are already being developed). Unlike the Apollo lunar lander which used toxic hypergolic fuels, new propulsion technology and non-toxic fuels will be required for long-term lunar operations. Solar energy will be a primary power source on the lunar surface, and more efficient methods of producing (solar cells and films) and storing this energy (batteries and regenerative fuel cells) will be required. Procedures and devices (advanced filters and air purification systems) will need to be developed to deal with lunar dust contamination of mechanical systems, airlock seals, and human lungs. An assortment of machines will need to be designed, tested, evaluated and redesigned to excavate, transport and process lunar soil (and perhaps ice) for the production of oxygen, water and fuel. New communication systems will be required using lunar orbiting satellites and/or ground relay stations to support voice and data transmission, and allow GPS-style navigation and emergency-location on the lunar surface. Radiation protection and medical countermeasures for humans (both in transit and on the lunar surface) will take on a new research priority. Enhanced plant growth and food production in lunar soil and reduced gravity will be studied (crews can simply not carry all of the pre-processed food necessary for extended exploration). A spectrum of habitat designs, hard-shell versus inflatable, must be evaluated and improved (prototype modules are already being tested in Antarctica), as a precursor to using indigenous construction materials (e.g., lunar soil-based cement and blocks). And all of these systems and techniques require international operability to be negotiated with anticipated international partners.

These are only a few of the exploration building blocks necessary for a sustained human presence on the Moon and to develop the experience and technologies necessary for exploration of Mars and beyond. Clearly the vehicles and propulsion and life-support systems developed for lunar exploration will not take humans to Mars, but they will serve as the necessary stepping stones to new science and technology that will permit humans access to their solar system. Some of the key lunar exploration technologies mentioned above will have direct applications for deep space exploration, and many of the lunar hardware designs and processes will be used as part of the initial exploration of Mars. **Figure 3-3** shows some artists' concepts of Mars exploration hardware with a clear heritage of systems that NASA is designing and building today.

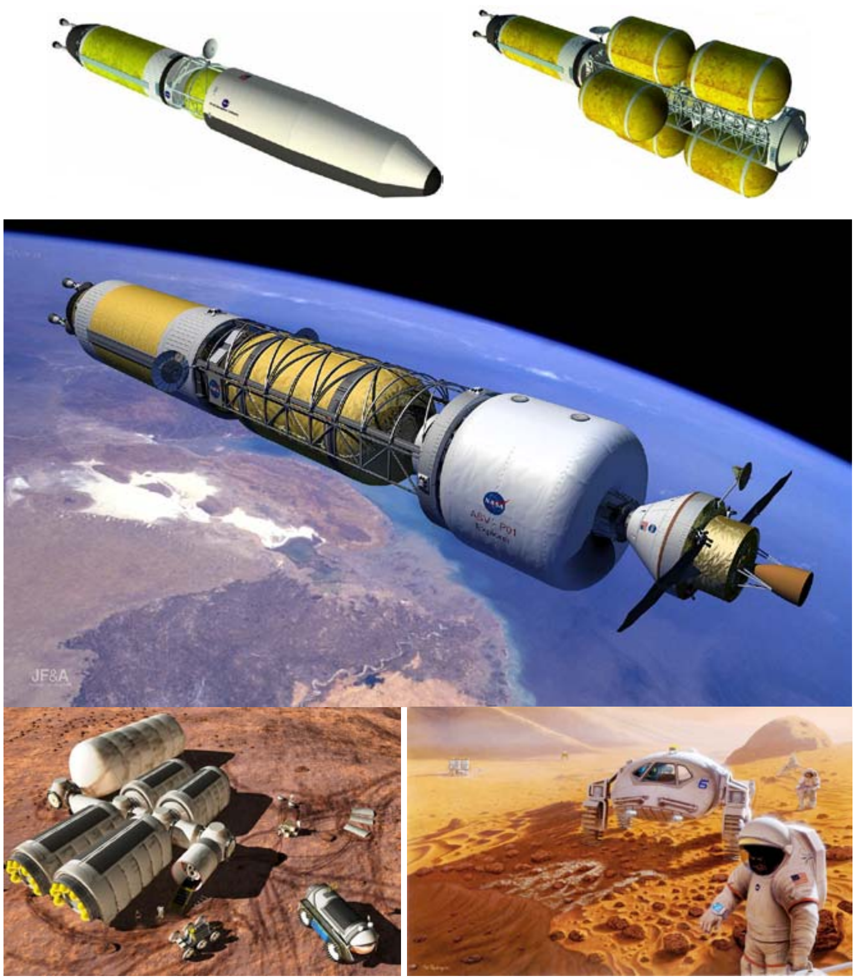

Figure 3-3. Within Our Lifetime – The Exploration of Mars and Beyond

4. Other Aspects of the Constellation Program

Space Commercilization

The International Space Station is scheduled for completion of Shuttle-supported assembly operations in 2010. The number of Shuttle flights required to complete the Station was the prime factor that determined the Shuttle retirement date. The completed ISS will contain large laboratory modules from the United States, Russia, Europe and Japan, as well as a fully operational solar power system and a 6-person permanent crew.

NASA estimates more than 8000kg of internal cargo and 5000kg of external cargo will need to be delivered annually during the fully-assembled phase of ISS, and the agency is working to develop a commercial space market that will help transport equipment and supplies to the ISS during the gap between retirement of the Space Shuttle and the fully operational Constellation vehicles (2010-2015).

The Commercial Crew and Cargo Program Office (C3PO) is leading a first-ever commercial project designed to entice private firms to invest in space exploration technology. The Commercial Orbital Transportation Services (COTS) project provides milestone-based seed money to develop and demonstrate unscrewed, earth-to-orbit launch and rendezvous capabilities. COTS is the first NASA project to allow private companies to completely own and profit from the products developed in partnership with NASA.

> ***"If we are to make the expansion and development of the space frontier an integral part of what it is that human societies do, then these activities must, as quickly as possible, assume an economic dimension as well. Government-directed space activity must become a lesser rather than a greater part of what humans do in space.***
>
> ***"To this end, it is up to us at NASA to use the challenge of the Vision for Space Exploration to foster commercial opportunities which are inherent to this exciting endeavor. Our strategy to implement the Vision must, and we believe does, have the potential to open a genuine and sustainable era of space commercialization."***
>
> - NASA Administrator Mike Griffin (October 2005)

The NASA Authorization Act of 2005 provided NASA approximately $500 million to award to selected companies for meeting financial and technical benchmarks. Space Exploration Technologies (SpaceX) of El Segunda, CA, and Orbital Sciences Corporation of Dulles, VA, the two remaining COTS companies, have each earned approximately $200 million each during performance reviews of their evolving orbital capabilities, and their continued success could potentially open new markets and pave the way for other companies to follow suit.

More information on the NASA Commercial Crew and Cargo Program Office can be found at http://www.nasa.gov/directorates/esmd/ccc/ .

NASA is also working to maximize space exploration capabilities through its Innovative Partners Program (IPP), which leverages technology for its missions through investments and partnerships with industry, academia, government agencies, and national laboratories. Three IPP program strategies, Technology Infusion, Innovation Incubator, and Partnership Development, engage private citizens and companies in aerospace technology development, bring fresh ideas into NASA, help mature emerging technologies, and promote the growth of a competitive private space industry.

The Technology Infusion strategy offers small businesses the opportunity to participate in NASA research and development with an initial cash limit of $100K (for the first six months), and a follow-on limit of $600K (for the next 24 months). An IPP Partnership Seed Fund provides bridge funding for larger, cost-shared, joint-development efforts which continue to show promising results.

The Innovation Incubator strategy hosts the Centennial Challenges, which uses competitions and cash prizes for the most innovative solutions to different design challenges. Competitors range from student groups to individual inventors to private companies. Some of the Centennial Challenges have direct application to Constellation Program design activities. For example, Maine engineer Peter Homer collected the $200,000 Astronaut Glove Centennial Challenge prize in 2007 for an innovative design that is being studied for further application by NASA and private industry. NASA is also interested in the work by Armadillo Aerospace Company of Mesquite, TX, on vertical take-off and landing rockets and new fuel research work done as part of a lunar lander design competition. Additional Centennial Challenges underway include designs for a lunar regolith (soil) excavator, equipment and processes for extraction of oxygen from lunar soil, and demonstration of wireless power beaming as a method for vehicles to travel without the need to carry onboard batteries or other power sources (e.g., during lunar night or crater shadow operations). Figure 4-1 shows some private projects involved with the NASA Centennial Challenges.

Figure 4-1. Left-to-right: Armadillo Aerospace's Pixel lander vehicle hovering in tethered flight, Peter Homer demonstrating his winning astronaut glove design, and a prototype lunar regolith excavator vehicle being demonstrated at 2008 Regolith Excavation Challenge.

Companies that require testing their technology in a microgravity environment can use the commercial jets in NASA's Facilitated Access to the Space Environment for Technology Development and Training (FAST) project.[4] The Zero-G Corporation of Las Vegas, NV, has a contract with NASA to provide parabolic flights for Challenge experiments requiring only short-durations of microgravity. More information on the NASA Centennial Challenges is available at http://centennialchallenges.nasa.gov/ .

NASA's Partnership Development strategy identifies and facilitates opportunities among companies, schools and individuals to co-develop technology alternatives for NASA mission directorates in response to specific technology needs or new mission requirements. The IPP typically facilitates over 200 new partnerships with the private and other external sectors each year. More detailed information on current partnerships and other IPP activities is available at http://ipp.nasa.gov/index.htm .

Education & Outreach

> ***"The greatest contribution that NASA makes in educating the next generation of Americans is providing worthy endeavors for which students will be inspired to study difficult subjects like math, science, and engineering because they too share the dream of exploring the cosmos. These students are our future workforce and our education investment portfolio is directly linked to our overall workforce strategy."***
>
> - NASA Administrator Michael Griffin (Statement to the House Science Committee, February 2006).

NASA has a long commitment to promoting interest and educational opportunities in science and engineering-related fields of study. Few other government agencies have such a dramatic and sustained need for a well-educated and highly skilled workforce. To help ensure NASA's future workforce, as well as to encourage general science and mathematics interest in students at all grade levels, the NASA Strategic Plan articulates three major education goals, which will continue to support U.S. innovation and competitiveness now and in the future:

- Strengthen NASA and the Nation's future workforce — NASA will identify and develop the critical skills and capabilities needed to achieve the U.S. Space Exploration Policy. To help meet this demand, NASA will continue contributing to the development of the Nation's science, technology, engineering and mathematics (STEM) workforce of the future through a diverse portfolio of education initiatives that target America's students at all levels, including those in traditionally underserved and underrepresented communities.
- Attract and retain students in STEM disciplines —To compete effectively for the minds, imaginations and career ambitions of America's young people, NASA will focus on engaging and retaining students in STEM education programs to encourage their pursuit of educational disciplines critical to NASA's future engineering, scientific and technical missions.
- Engage Americans in NASA's mission—NASA will build strategic partnerships and linkages between STEM formal and informal education providers. Through hands-on, interactive, educational activities, NASA will engage students, educators, families, the general public and all Agency stakeholders to increase Americans' science and technology literacy.

These goals are in effect across all of NASA, and the Constellation Program is no exception. To that end, NASA's Exploration Systems Mission Directorate (ESMD), the lead management organization of the Constellation Program, funds and develops a number of education initiatives to engage students in the science and engineering aspects of human space exploration. To aid educators who seek to use NASA resources as part of their classroom curriculum, ESMD provides a number of customized programs and resource materials that are available to public and private educational organizations across the country. A selection of these programs are described below.

College-Level Programs

Space Grant (SG) Internships/Senior Design Projects: ESMD offers SG consortia funding to involve students (graduate and undergraduate) in hands-on training relevant to science and engineering projects. The ESMD Higher Education Internship Grants find and place students in summer or school-year internships in industry or at NASA centers, where they are able to work side-by-side with scientists and engineers and are involved with real-world application of their academic skills.

The second part of this project provides funds to integrate ESMD mission challenges into university senior engineering design courses. These funds are used to support student senior engineering design projects (i.e. to buy materials, build prototypes, etc.) or to bring in subject matter experts to consult with the class. Systems engineering experience is a key aspect of the overall program and to emphasize this, ESMD has offered cash prizes and travel to teams that write winning papers describing the role that systems engineering played in their senior design project.

ESMD Faculty Fellows*:* This project funds five faculty annually, each of whom is paired with two NASA centers to help gather senior design project ideas and internship opportunities relative to space exploration in support of the ESMD Space Grant Program. In addition, the faculty members learn about other ESMD education programs and help the education offices at their sponsor centers develop new programs.

University Student Launch Initiative (USLI): This annual competition challenges university-level students to design, build and fly a reusable rocket with scientific payload to an altitude of one mile. The project engages students in scientific research and real-world engineering processes with NASA engineers. USLI requires a NASA review of the teams' preliminary and critical designs and post-flight performance analysis, basically identical to the real-world process used at NASA. The reviews are conducted by panels of scientists and engineers from NASA and from NASA contactors.

Figure 4-2. University Student Launch Initiative teams during launch and recovery operations.

Spaceward Bound: An educational program to engage students and teachers in the exploration of remote and extreme environments on Earth as analogs for human exploration of the Moon and Mars. Working with undergraduate and graduate students in STEM and in-service STEM K-12 teachers and education faculty, this program uses field expeditions and Mars environment simulations to study the science and engineering required for human exploration beyond the Earth.

Systems Engineering Educational Discovery (SEED): NASA collaborates with the University of Texas to host a national workshop on systems engineering education and curriculum dissemination to engineering faculty engaged in undergraduate education. Additionally, three engineering students who complete this course will intern at JSC in Systems Engineering jobs. SEED also provides undergraduate seniors and their faculty mentors from across the nation the opportunity to fly their projects in microgravity on NASA research aircraft.

ESMD Senior Design Course: An annual workshop for ten faculty members on the subject of developing a Senior Design course at their schools based on one of the four ESMD-related areas: Propulsion, Lunar and Space Sciences, Spacecraft, or Ground Operations.

Elementary and Secondary Education Programs

Engineering Design Challenge: Lunar Plant Growth Chamber. In anticipation of the need for research into lunar plant growth, NASA and the International Technology Education Association (ITEA) sponsor this classroom design activity which allows elementary, middle and high school students to design, build and evaluate lunar plant growth chambers. Teams can request cinnamon basil seeds that have flown in space on the STS-118 space shuttle mission so that students can compare plants grown from both space-flown and Earth-based control seeds, and test the designs of their lunar plant growth chambers.

Figure 4-3. Students working with the Lunar Plant Growth Chamber program.

Human Exploration of Space: The International Technology Education Association (ITEA) is working with ESMD to create grade-appropriate classroom activities related to space exploration topics that require student teams to research a question or problem, break into teams to conduct specialized research, synthesize information, and develop recommendations and conclusions based on what they have learned. The ITEA showcases materials developed in this program through their on-line web-based network, providing a forum for educators to share strategies for implementing additional activities associated with lunar power production, space transportation, and space project management techniques.

NASA's Beginning Engineering Science and Technology Students (BEST): This middle school project provides a three-week summer bridge program for students entering 9th-grade in STEM Magnet Schools. These students study Fundamentals of Lunar Robotics, including the history of lunar exploration, motivations for past and future exploration, introduction to physical properties of the Moon, remote imaging and hands-on projects about lunar exploration.

21st Century Explorer: This project includes websites that deliver multi-media products and NASA exploration information; an after-school program targeting Hispanic communities to engage students, educators as well as the community; and development of educational packages that are ready for the 3rd – 5th grade classroom and which revolve around ESMD space exploration themes. This project also concentrates on the bilingual aspect of the material.

High School Mathematics Modules: This project infuses exploration content into a number of independent learning modules that are aligned with the national mathematics standards and the scope and sequence of the algebra-one curriculum.

Space Faring: The Radiation Challenge: This project instructs students about the dangers of radiation in space. The activities and videos deal with questions regarding "What is Radiation" (Space Radiation), "How does it affect humans" and "How will we protect from it" on long duration space travel.

Lunar Nautics**:** This project is a compilation of hands-on activities hosted by Discovery Place museum. Students in grades 6-8 are asked to form their own aerospace company and embark on a mission regarding lunar exploration, a project which is ideal for after-school and outreach programs, workshops, and week-long camps. This project also works to inspire young people to consider careers in science, technology, engineering and mathematics.

NASA Fit Explorer: Managed by NASA in partnership with the President's Council on Physical Fitness and Sports, this project is a scientific and physical approach to human health and fitness on Earth and in space. Students in grades 3-5 train like an astronaut by completing physical activities modeled after the real-life physical requirements of humans traveling in space, and gain an understanding of the science behind nutrition and physical fitness by studying how these factors relate to space exploration.

The Space Exploration AP Project**:** This is a multi-center educational effort to develop, test and release space-related support material to Advanced Placement educators nationally and internationally in calculus, physics and chemistry.

The USA TODAY Collaboration: The national newspaper USA TODAY uses content provided by NASA to develop customized educational lessons from real-world articles appearing in USA TODAY and makes them available online to their network of educators. The collaboration also includes development of exploration-specific case studies for college students as well as a micro-web site and an electronic newsletter.

Problem-Based Units for Physical Sciences: This project is based on a scenario for a lunar outpost located at the South Pole of the Moon. The web-based module asks students to select a lunar-outpost site and a number of instructional activities are presented, including Rover Forces & Motion; Reduced-gravity Demonstrations; Inertial Balance; Rover Crater Peeking; and Orbital Mechanics. These activities are aligned with the National Science Standards, the NCTM Principles and Standards, the Technology Standards and the Ohio state academic standards.

Rockets: An Educator's Guide with Activities in Science, Mathematics, and Technology*:* NASA is updating this very popular publication for teachers. The last edition was published in 1995 and this new edition will contain activities related to human exploration of the Moon and Mars.

Informal (non-classroom) Activities to Inspire & Engage Students & the Public:

A Field Trip to the Moon: Managed by NASA in conjunction with the American Museum of Natural History, this project brings the U.S. Space Exploration Initiative to New York City school students who visit AMNH. NASA has also developed an after-school program to accompany the field trip and provide greater depth of instruction. This program focuses primarily on human exploration and includes a discussion of the space robotics program.

Girl Scouts Exploring in the 21st Century --- Promise Them the Moon and Mars: This program highlights many aspects of lunar exploration, including in-situ resource location through mineralogical mapping of frozen water and lunar minerals and ores; selection of safe landing sites for human and robotic missions; and characterization of lunar environmental hazards. NASA also present robotics connections to 21st century exploration including human-robotic interfaces, robotic-human assist systems, and vehicles for exploration on planetary surfaces. This project uses a train-the-trainer approach in which NASA personnel provide instruction to paid and volunteer GSUSA staff, who then return to their home areas and provide further training to troop leaders who then present the material to Girl Scouts.

Sports and Exploration: This project is a bilingual, hands-on educational program designed in collaboration with the Houston Dynamo Major League Soccer franchise and the Houston Independent School District (HISD), targeting STEM, Health, and Physical Education content in grades 3-5. The program relates national sports fitness standards to the laws of nature through fundamental physics, and emphasizes the message of life-long health and fitness needed for long duration space exploration.

Librarian Workshops: This project provides content related to lunar exploration to librarians and after-school providers who use the material in after-school and weekend programs.

Explore! Life Sciences – Health in Space: Managed by NASA JSC, the project includes development of modules for children ages 8 through 13 that stimulate children to think about life in space; the extreme conditions of the space environment (i.e. radiation and microgravity); how these conditions affect the human body; and what NASA researchers are planning to counteract these effects. Information is presented via a variety of methods, including presentation of the modules on an existing Web site for broader access; training of sixty after-school providers at workshops in Mississippi and Alabama; and involvement of the existing 'Explore!' community of trained librarians in the use of the new modules.

The Great Light Racer Championship*:* This competitive educational program is designed to allow middle school and high school students to participate in a plausible lunar exploration scenario – powering a robotic rover in the dark recesses of a permanently shadowed lunar crater – while learning about planetary science, physics, engineering, and exploration. Topics include why we want to reach the permanently shadowed lunar craters and the reasons why this is difficult; possible engineering approaches such as terrain navigation, in-situ resources utilization, etc.; and trade-offs such as power beaming between a rover on top of the crater to another at the bottom of a crater. The students design, build, navigate and race a remotely controlled rover vehicle.

In a May 2008 Gallup Poll, entitled: "Public Opinion Regarding America's Space Program," prepared for the Coalition for Space Exploration, one particular section dealt with the "Extent to which the Public Feels America's Space Program Inspires Young People." In particular, the poll question was worded as follows: *"To what extent do you believe America's space program inspires young people to consider an education in science, technology, math, or engineering fields? Would you say the space program inspires these students a great deal, some, very little, or not much at all?"* Results indicated that most (69%) of the adult public surveyed say they believe America's space program inspires young people to consider an education in science, technology, math or engineering fields at least to some degree. One in five (21%) believe the program inspires young people a great deal.

ESMD and the Constellation program agree with this assessment and strongly believe that education is the key to ensuring not only the continuation of NASA's exploration mission, but also the continuation of our country's leadership in discovery and innovation across all fields of science. As the United States begins the second century of flight, NASA believes the nation must maintain its commitment to excellence in STEM education to ensure that the next generation of Americans can accept the full measure of their roles and responsibilities in shaping the future.

DRAFT

Constellation Program Budget Development & Acquisition Strategy

Budget Development

The Constellation Program has been underway for three years, and thus the budget estimates have a fidelity of three years worth of annual evaluation. In the spring of 2006, the Constellation Program developed an unconstrained "bottoms-up" budget estimate for the purposes of establishing a "first cut" understanding of the drivers for costs and schedule from present to the lunar landing phase of the Program. This analysis provided the element break-down and the raw data for building a subsequent budget that was realistically constrained by Agency priorities and needs. By the summer 2006, the Program was able to establish the first budget baseline meeting Agency schedule commitments.

Completion of the Program's System Requirements Review in late 2006 and the Program's System Definition Review in 2008 provided a further level of requirements development that allowed for more refined estimates in the Agency's ~~FY07~~ budget development cycle. **Figure 4-4** shows a FY07 projection of Constellation NOA by project FY08 – FY13 ($M). Note that the early years of the Program are budgetarily constrained by the completion of the Space Shuttle Program. A ramp up to full manufacturing and production capabilities for the Orion and Ares I vehicles can be accomplished after successful transition of many of the Space Shuttle assets and facilities to the Constellation Program after 2010.

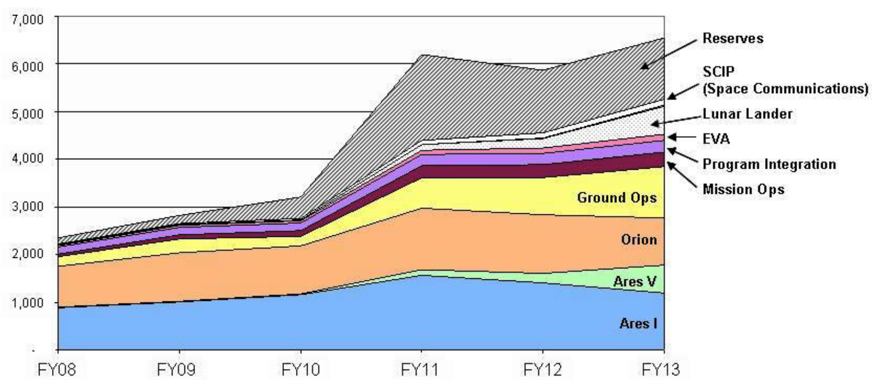

Figure 4-4. Constellation Near-Term Budget Allocation by Project[9]

Confidence Level

The history of human spaceflight is replete with examples of cost overruns due to confluence of under-funding, insufficient or poorly phased reserves, misunderstood risks and complexities, overly aggressive schedules, and difficulties meeting ambitious technical requirements. The Constellation Program ~~has no illusions that we will not continue to encounter~~will not be immune to ~~-~~these challenges; therefore the program is pioneering within NASA the implementation of probabilistic techniques to assess the confidence level expected that the program can achieve given schedule milestones within the budget allocated. Our guidance within the Agency is to maintain a confidence level of 65% that we can meet our schedule commitments within the allocated budget and technical base-line. Program confidence level is calculated incorporating project-level confidence levels, project-level risks, and program-level risks, along with assumptions on dependencies among the risks. The Program conducts confidence level assessments during the budget development process, and refines these during annual budget cycles. This analysis is key to assuring that we maintain our commitments to our stakeholders and have underpinning rationale for dialogue when requirements changes to the baseline are under consideration. While pioneering this technique, the program has learned that we must find efficient ways to incorporate our utilization of Space Shuttle heritage hardware, facilities and processes into our estimating tools. In general, we believe these to have a high cost confidence relative to new developments, and the tools in use today are unable to account for this. This is one more area in government where Constellation is leading the way.

Comment [j5]: Add citation here from my 2007 IAC paper. It was a GAO report.

~~During 2007, the Program was allocated less funding than planned in the Federal appropriation bill. Since the Constellation Program proceeds as a 'go as you can afford to pay' program, this resulted in a 6-month delay in our commitment to fielding the first Orion crew vehicle and Ares I launch vehicle for Initial Operating Capability (IOC). This date is now March 2015, rather than 2014.~~

Acquisition Strategy

As plans are made for the retirement of the Space Shuttle, NASA is assessing possible synergies to be gained between the contracts and acquisition strategies already in place. The Integrated Acquisition Roadmap Team (IART) has been chartered to map all existing and planned Space Shuttle, ISS and Constellation contracts and to identify opportunities to save costs, including life cycle costs, to utilize lessons learned and best practices, to address transitions across program phases, to maximize the effective use of both the existing civil service and contractor workforce, and to facilitate strategic competitive opportunities.

Where appropriate, the Constellation Program is utilizing current, proven technology in order to achieve safer, more reliable and affordable solutions. For example, the Ares I and the Ares V are based on proven systems from the Space Shuttle, Expendable Launch Vehicles, and the Apollo Saturn V programs, enabling NASA to reduce development costs compared to designing and building an entirely new launch vehicle. This approach maximizes the value of existing facilities, certified parts, production tools and expertise. Common propulsion elements help reduce operation costs for a more sustainable exploration program. The Constellation Program has entered into sole source production contracts for heritage-based elements; ATK Corporation for the Ares I first stage and Pratt & Whitney Rocketdyne for the J2-X engine.

Lockheed-Martin was selected as the prime contractor for the Orion development through full and open competition. The production contract for the Ares I upper stage was recently awarded to Boeing Corporation. Boeing also won a separate competition for the Ares I Instrument Unit. The Ares I and V first stage development has been awarded to the ATK Corporation. The EVA Systems prime contract award is planned to be completed in 2008.

The Constellation Program acquisition strategy places an emphasis on the criticality of reducing and controlling life cycle cost in each acquisition phase because NASA plans to produce and fly these vehicles for decades to come. Understanding and managing life cycle cost is pivotal to the overall long-term success and viability of the program.

Figure 4-5 shows a projection of the total Constellation program budget by project through the first human lunar landing in 2020 ($M).

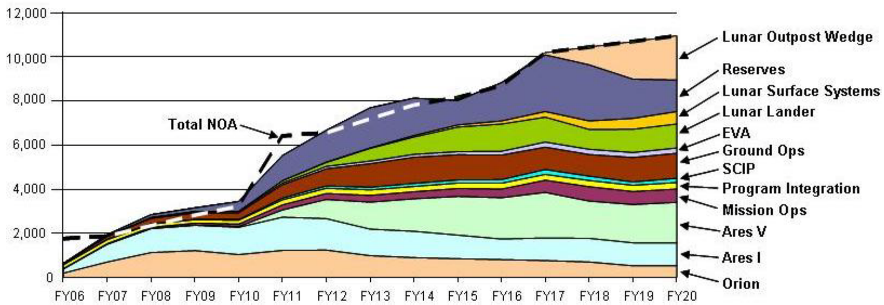

Figure 4-5. Constellation Long-Term Budget Allocation by Project[9]

Constellation Program Operational Philosophy

It is clear from past experience that the cost burden of Space Shuttle operations cannot be inherited by the Constellation Program if the lunar capability and the eventual Mars capability is to be developed concurrently with the program operations. While the Constellation program has the advantage of a much simpler system (from a purely engineering standpoint) to operate, this system is based on heritage hardware and its associated operational processes. ~~The program has undertaken a number of efforts aimed at life cycle cost reductions. Examples include:~~

To that end, the Program has designated a Program Operations Engineer to oversee the minimization of operational costs. Several initiatives are underway in support of this effort.

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Design for Affordability: Adapting a practice from military and commercial application, a design for affordability effort is underway to identify and ameliorate key drivers to operational costs. Currently, the baseline operational costs are being validated by an independent contractor. This contractor will~~plans to~~ deconstruct the operational cost estimates by phase of program (production, integration, and mission) and by 3 additional dimensions: product/platform; workforce, including crew, ground and mission operators; and ground based infrastructure. This is intended to drive out key cost drivers to define a path and architecture for operational cost reductions, as well as identify the risks and system-level trades necessary to achieve an affordability target.

Contracting Strategies to Reduce Operations Cost: The Program Operations Engineer manages~~initiated~~ a working group to address current contract strategies for operational cost reduction and recommended improvements. The working group is intended to engage senior procurement, project, and engineering management officials in strategic planning to produce the fundamental culture, process, and content changes achievable through contracting that must be realized to succeed in minimizing~~reducing~~ operations costs.

Stretch Requirements: The architecture requirements include 'stretch requirements' defined as those that enable ground and flight system supportability and reductions in operational life cycle costs. Modeled after the Boeing 777 development, stretch requirements specify a desired outcome believed to simplify operations. For instance, a 'clean pad' concept has been specified to challenge designers to minimize services and interfaces required at the launch pad as well as location/access on the vehicle. Each service or umbilical (e.g. cooling) attached to the launch vehicle is thus challenged for relevance or 'must have' capability. The Ground Operations Project and Mission Operations Project are focal to manage the stretch requirements; these are incorporated into flight design via negotiation of Interface Requirements Documents with each of the flight projects (Orion, Ares, Altair, and EVA).

'Con Ops' Development: Constellation has developed a Concept of Operations (Con Ops) for operation of the program through its mission phases, in order to drive out operational features that influence hardware, software and interface requirements. This is a typical best practice in large technical program development. Design reference missions have been developed for ISS missions, lunar sortie missions, lunar outpost missions, and a Mars mission so that operational design drivers are identified early.

Constellation has also initiated similar but perhaps unique con ops efforts for targeted processes that can influence life cycle costs. For example, the current practice of quality assurance in the Space Shuttle program is being bench-marked for efficiency improvements. By developing a con ops for how quality assurance is conducted through the life of the program, a more efficient path to quality assurance is being determined before it is needed for Constellation flight hardware manufacture.

Life Cycle Cost Evaluations: Change evaluations to the program baseline must include an assessment of the life cycle cost impact of each change to the baseline. Constellation procurements--both 'end-item' and 'award fee' types--include incentives to reduce life-cycle cost.

Lean Efforts: Lean six-sigma and Kaizen studies were conducted on early developments, such as the Ares 1-X test flight and Orion flight test program. This has proven successful and the Program is seeking further opportunities to gain process time reduction and simplification.

The 'handoff' between designers and the sustaining engineering and operational communities is being studied for efficiency improvements. Current practice includes overlapping responsibilities and designer involvement in post-design processes. Efforts are underway to identify and minimize this to ultimately reduce costs.

Industry and Experience Advice: The Ground Operations Project conducted feasibility studies under the Broad Area Announcement capability; requesting novel ideas from industry on how to streamline processing, launch and recovery operations. The concepts are intended to produce 'cleaner' techniques and processes in the belief that fewer anomalies are possible with simpler processes. Examples of concepts include new approaches to emergency egress system for the crew, isolation of the launch pad lightening protection system, and alternatives to hypergolic fuel loading to reduce processing time.

NASA also released a Broad Area Announcement regarding the Lunar Lander concept which requesteds industry approaches to minimizing Design, Development, Test, and Evaluation (DDT&E) and life cycle costs. In the past, NASA has utilized different approaches to the formation of the initial government-industry design team and transition to a prime contractor for its major development projects. With this BAA, NASA is seeking to identify the most effective option for Lunar Lander development, including assessing the option of maintaining an in-house NASA design team through the Preliminary Design Review and then transferring development responsibility to a prime contractor.

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~~Though NASA has considerable talent in its workforce, programs intended to carry humans to and from space are characterized by design, development and testing challenges which differ greatly from those encountered by the orbiting International Space Station or operational Space Shuttle. To reach back and capture launch and return vehicle experience, the Constellation Program created a ready resource – SAGES – Shuttle and Apollo Generation Expert Services. This contract provides a simple pathway to enlist the aid of recognized experts from NASA's past.~~

~~Beyond review and advice, SAGES was created to transfer knowledge through mentoring. It is based on relationships between Apollo and Shuttle-era program managers and discipline experts, and the Constellation team. SAGES provides mentors on an as-needed, targeted basis in areas ranging from technical design and analysis disciplines, to ground and flight operations, to program management. Twenty four tasks have been initiated to date, including margins management; relationship between Level II program office and the Level III project office responsibilities; lunar lander requirements; test and verification planning; and launch abort design and operations.~~

~~*Risk Informed Design & Probabilistic Risk Assessment:* It is clear from the operation of the Space Shuttle program that new emphasis and approaches to risk mitigation are~~

~~necessary in the next generation of human space exploration. In order to better meet this challenge the Constellation program has adopted a Risk Informed Design approach. The Risk Informed Design approach is based on the tenet that an understanding of the relative importance of risk drivers is essential in balancing risk across the design and controlling complexity, which has been found historically to be a significant feature of systems that fail. Understanding risk early in the design life cycle is useful in obviating or mitigating risk through careful selection of design alternatives based on risk. This limits the chance of having to "accept" risk later on in the vehicle or product life cycle.~~

~~The Risk Informed Design process developed for the Constellation program is based on the principle that risk is a design commodity like mass or power. Probabilistic risk analyses are performed during early design to understand the risk vulnerabilities of the current baseline design. Once a baseline has been established, design improvements are evaluated with a focus on enhanced functionality balanced with the basic risk of loss of mission and/or crew. The design is then evaluated to determine the best ways to mitigate risk. These methods may include adding a function (e.g., an abort capability), looking at a different method for performing the critical function, increased testing to improve reliability, selecting more reliable components, adding margin to the system or adding redundancy.~~

Summary

As the long-term objectives of U.S. space exploration evolve, the near-term goals remain the same: to develop the flight systems and ground infrastructure required to enable continued access to space and to enable future crewed mission to the ISS, the Moon, Mars and beyond. The program is evolving within this structure of organization, requirements and funding as its foundation.

The Constellation Program is a robust system, based on the best of NASA's heritage while incorporating the latest advanced technology and processes, and designed to evolve as a safe and cost-effective infrastructure that will allow America to maintain and enhance its leadership in space exploration, technical innovation and scientific discovery in the world community of the 21st century.

The Constellation Program is nearing completion of its preliminary design phase, beginning its flight test program, and undertaking critical design and manufacturing operations to support missions to the International Space Station in 2015, and human lunar exploration flights in 2020.

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