SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

A Review of NASA's Exploration Program in Transition: Issues for Congress and Industry

Wednesday, March 30, 2011
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Purpose

The subcommittee will examine 1) the accomplishments of the Constellation program, 2) NASA's transition toward development of the Space Launch System (SLS) and Multi Purpose Crew Vehicle (MPCV), and compliance with the FY2011 continuing resolution and the NASA Authorization Act, 3) the status of the 90-day SLS/MPCV report to Congress, and 4) examine the key challenges and risks in implementing the proposed changes including outstanding questions and issues for Congress from delays or other disruptions to the workforce or aerospace industrial base.

Witnesses

Mr. Douglas Cooke, Associate Administrator, Exploration Systems Mission Directorate, National Aeronautics and Space Administration;

Dr. Scott Pace, Director, Space Policy Institute, George Washington University

Mr. James Maser, Chairman, Corporate Membership Committee, The American Institute of Aeronautics and Astronautics.

Comparison of the NASA Authorization Act of 2010 (P.L. 111-267) with the FY2012 Budget Request

(millions of $)	FY10 enacted / FY11 C.R. *	Auth. FY12	Budget Request FY12	Request vs. Auth. FY12	Auth. FY13	Budget Request FY13	Request vs. Auth. FY13	Auth. Total FY12-13	Budget Request Total FY12-13	Request vs. Auth. FY12-13	Request vs. Auth. FY12-13
Human Exploration Capabilities	**3,287**	**4,050**	**2,810**	**(1,240)**	**4,050**	**2,810**	**(1,240)**	**8,100**	**5,620**	**(2,480)**	**-31%**
MPCV	*1,435*	*1,400*	*1,010*	*(390)*	*1,400*						
SLS/HLLV	*1,387*	*2,650*	*1,800*	*(850)*	*2,640*						
Integr'n & Ops	*465*										

* Values are for reference. Under the CR some numbers may vary slightly.

Issues

Exploration Capabilities in Transition; Issues for Congress and Industry

At issue is NASA's compliance with Congressional direction on extending and modifying the Constellation contracts, and the implications of NASA's actions for the continued, uninterrupted progress on the Multi Purpose Crew Vehicle (MPCV) and Space Launch System (SLS). Congressional intent, as reflected in authorization and appropriation language seek to utilize the existing workforce and assets in order to limit the damage to the nation's industrial base and workforce.

As the budget comparison above indicates, the FY2012 budget request does not adhere to the funding guidance in last year's authorization bill (PL 111-267). The administration's FY2012 budget request for Exploration systems is $1.24 billion below the amount specified in the Act. Exploration systems is **$2.5 billion below when comparing both FY2012 and FY2013**. In FY2013, the administration does not identify the funding specified for the two main components; the MPCV and the SLS.

In spite of the $2.5 billion reduction over two years in proposed funding for Exploration Capabilities, Administrator Bolden said, *"I am committed to try to make sure that the funding levels remain about the same, and one of the things…is beginning in 2013 I have asked and I have been granted…that we put human exploration in one budget line so that…we can move the funds around as necessary in each successive year so that we marry those programs up when we need them, you know, that being the 2020 timeframe…"*

Yet, section 302 of the NASA Authorization Act directs the agency to develop the heavy lift system in a way that permits early flight testing of the "core" stage elements with a goal of an operational capability to orbit by December 31, 2016.

The U.S. space industrial base that has supported the Constellation – now MPCV and SLS effort – has waited while the agency settles on a plan for human spaceflight, and unless the uncertainty is eliminated in the near future, there could be serious disruptions to the aerospace workforce and industrial base as key suppliers begin to exit the market.

Report due to Congress

The Authorization Act directed NASA to report back in 90 days on the design of the vehicle envisioned, and to provide the assumptions and cost analysis to justify the systems selected. On January 10th NASA provided a *preliminary report* containing no detailed cost or schedule assessments, yet concluding nevertheless that, "*to date our studies have shown that none of those options thus far appear to be affordable in our present fiscal conditions, based upon existing cost models, historical data, and traditional acquisition approaches*."

According to NASA it will provide an independent (outside of the Agency) assessment of cost and schedule for the SLS and MPCV design options, and make those assessments public this Spring or Summer.

According to the *preliminary report*, NASA is considering various acquisition strategies for the MPCV and SLS which could have significant impacts to the workforce and industrial base. Thus far, Congress has directed the agency to continue to extend (and modify if appropriate), the Constellation contracts to the maximum extent practicable (see background below).

NASA's future acquisition decisions could have wide ranging repercussions. The *preliminary report* states, *"While NASA will work as expeditiously as possible to meet the 2016 goal, NASA does not believe this goal is achievable based on a combination of the current funding profile estimate, traditional approaches to acquisition, and currently considered vehicle architectures."*

When asked by Senator Boozman at the March 15th, 2011 Senate Commerce, Science and Transportation Committee hearing on *The Challenges Facing NASA* whether NASA was basing its analysis on the funding in the Authorization Act, or the much lower administration proposal Associate Administrator Doug Cooke replied, *"we are looking at, in these studies, the president's requested budget."*

A decision to re-compete significant elements of the MPCV or SLS could result in delays of as much as two years while the Agency issues Requests for Proposals (RFPs), evaluates the proposals, awards contracts, adjudicates protests, etc.

Background

The Constellation program consisted of the Ares 1 crew launch vehicle and Orion crew exploration vehicle, the Ares 5 heavy-lift launch vehicle, and associated lunar systems. Constellation architecture had been established since 2004 as a replacement for the retiring Space Shuttle to deliver Americans and our International Partners to the International Space Station, and eventually to the Moon and other destinations beyond Earth orbit. Constellation was authorized in both the NASA Authorization Act of 2005 [P.L.109-155] and the NASA Authorization Act of 2008 [P.L.110-422] with a stepping-stone approach "*to ensure that activities in its lunar exploration program shall be designed and implemented in a manner that gives strong consideration to how those activities might also help meet the requirements of future activities beyond the Moon*" and a range of future destinations "*to expand human and robotic presence into the solar system, including the exploration and utilization of the Moon, near Earth asteroids, Lagrangian points, and eventually Mars and its moons.*"

The administration has presented various – and often conflicting – statements and goals for the U.S. Exploration Program. In his April 15, 2010 remarks at Kennedy Space Center, President Obama said: "*Early in the next decade, a set of crewed flights will test and prove the systems required for exploration beyond low-Earth orbit. And by 2025, we expect new spacecraft designed for long journeys to allow us to begin the first-ever crewed missions beyond the moon into deep space. We'll start by sending astronauts to an asteroid for the first time in history*." But at the March 2, 2011 House Science, Space, and Technology Committee hearing on NASA FY2012 budget proposal, in response to a question from Rep. Dana Rohrabacher, Administrator Bolden said, *"The International Space Station is the anchor for all future exploration. That is our Moon right now."*

Congress has supported NASA's exploration program and authorized $10.8 billion over three years (FY2011-FY2013). The Constellation system that the administration proposed canceling is developing an array of technologies and heavy lift capabilities applicable to the goals of exploration beyond low Earth orbit. Sections 203(a)(1) and 301(a) of the 2010 NASA Authorization Act expressed the sense of the Congress that, *"the ISS, technology developments, the current Space Shuttle program, and follow-on transportation systems authorized by this Act form the foundation of initial capabilities for missions beyond low-Earth orbit to a variety of lunar and Lagrangian orbital locations,"* and *"The extension of the human presence from low-Earth orbit to other regions of space beyond low-Earth orbit will enable missions to the surface of the Moon and missions to deep space destinations such as near-Earth asteroids and Mars."*

The NASA Authorization Act of 2010 directed the agency to develop a Space Launch System consisting of a heavy lift launcher (130 ton rocket, with 70-100 ton "core" capability that could be used to launch the crew capsule to the International Space Station by 2016) and multi-purpose crew vehicle (the Orion crew capsule). The system was envisioned to build upon the technologies and extensive capabilities of the Space Shuttle and Constellation systems, and to provide a backup capability to access the ISS by 2016 in case the Russian Soyuz, or commercial crew initiatives are unavailable. In order to limit termination liability costs and avoid disruptions to the workforce and industrial base, the 2010 Authorization Act directs NASA to, *"to the extent practicable, extend or modify existing vehicle development and associated contracts."*

<u>FY2010 Appropriations Direction: Extend or Modify Constellation Contracts</u>

In the Statement of Managers accompanying the FY 2010 Consolidated Appropriations Act, "*The conferees note that the Constellation program is the program for which funds have been authorized and appropriated over the last four years, and upon which the pending budget request is based. Accordingly, it is premature for the conferees to advocate or initiate significant changes to the current program absent a bona fide proposal from the Administration and subsequent assessment, consideration and enactment by Congress*." The Statement of Managers also states that "*Funds are not provided herein to initiate any new program, project or activity, not otherwise contemplated within the budget request and approved by Congress, consistent with section 505 of this Act, unless otherwise approved by the Congress in a subsequent appropriations Act. Funds are also not provided herein to cancel, terminate or significantly modify contracts related to the spacecraft architecture of the current program, unless such changes or modifications have been considered in subsequent appropriations Acts*." Similar language was included in the Act itself.

The Constellation program has racked up a series of impressive accomplishments including: 1) the full-scale Pad Abort Test of the crew escape system; 2) the near completion of the J2X rocket engine currently slated for testing at the Stennis Space Center in May or June; 3) the developmental test firings of five segment solid rocket motors; 4) the Ares 1X test flight in October 2008. (Please see Appendix 1 for a comprehensive list of Constellation program's achievements to date.)

The Constellation program's Orion spacecraft was intended to serve as a back-up for commercial cargo services envisioned by the Commercial Orbital Transportation Services (COTS) program to service the International Space Station. NASA's FY2009 budget request stated, *"It [Orion] will be capable of ferrying up to six astronauts (plus additional cargo) to and from the International Space Station if commercial transport services are unavailable."*

Delays in Commercial COTS Cargo Systems Led to Additional Shuttle Flights

Significant delays in the COTS commercial cargo development fuel concerns that NASA will be unable to provide the logistics support necessary to maintain and utilize the International Space Station, or to fulfill U.S. obligations to our international partners. (Please see the SpaceX and Orbital Sciences COTS milestone charts in Appendix 2.)

Congress was aware as far back as 2008 that delays in the COTS cargo program would likely result in the need for additional Space Shuttle flights to assure that adequate spares would be aboard the ISS. Thus, section 611 of the NASA Authorization Act of 2008 [P.L.110-422] added two additional logistics flights, *"In addition to the Space Shuttle flights listed as part of the baseline flight manifest as of January 1, 2008, the Utilization flights ULF–4 and ULF–5 shall be considered part of the Space Shuttle baseline flight manifest and shall be flown prior to the retirement of the Space Shuttle, currently scheduled for 2010."*

As Congress debated the NASA Authorization Act of 2010 [P.L.111-267] in the Fall of last year, no COTS provider had yet accomplished an initial demonstration flight. (SpaceX launched the first of three COTS demonstration flights of a Falcon 9/Dragon on December 8, 2010, and the other two test flights are tentatively scheduled for late 2011 and early 2012.) As a result of these concerns, the NASA Authorization funded another Space Shuttle flight (STS-135 will be the last mission of the program), *"The Administrator shall fly the Launch-On-Need Shuttle mission currently designated in the Shuttle Flight Manifest dated February 28, 2010, to the ISS in fiscal year 2011, but no earlier than June 1, 2011, unless required earlier by an operations contingency…"*

At the March 15th, 2011 Senate Commerce, Science and Transportation Committee hearing on *The Challenges Facing NASA,* Associate Administrator Bill Gerstenmaier explained how critical the STS-135 mission was given the concerns for commercial COTS schedule, *"We see that mission as extremely critical to us. What that mission provides for us is it gives us some margin that if the commercial providers are late and they don't fly in 2011 and 2012 as they plan, then we have got some time through 2012 that we will have enough supplies pre-positioned on Space Station that we can continue to do quality research, we continue to keep our crew size at six onboard station through that period of 2012 all the way until 2013. If we don't have that shuttle flight, then it's absolutely mandatory that the commercial cargo providers come on-line at the end of this year and early in 2012. I don't think that is a prudent strategy. We need some margin just as in the shuttle world, we thought we understood where we were going to go fly, then we had the tank problem that slowed us down a couple months. I would expect small problems to show up in the commercial providers as well. We need some margin to do that."*

Importance of MPCV and SLS as a Backup and as Assured Access to ISS

The impending retirement of the Space Shuttle and continuing delays in commercial COTS systems, reinforced the need for the backup assured ISS access capability envisioned for the original Exploration Systems development, as well as to lay the groundwork for exploration beyond low Earth orbit. Section 2(9) of the NASA Authorization Act of 2010 states, *"While commercial transportation systems have the promise to contribute valuable services, it is in the United States' national interest to maintain a government operated space transportation system for crew and cargo delivery to space."*

Many of NASA's international agreements with the Space Station partners were put in place before the decision to retire the Space Shuttle. As a result, even after the Space Shuttle has retired, NASA is still responsible for cargo delivery and transportation of our Canadian, European and Japanese partners to and from the International Space Station.

In Section 201(b) of the NASA Authorization Act of 2010, Congress, *"reaffirms the policy stated in section 501(a) of the NASA Authorization Act of 2005 (42 U.S.C. 16761(a)), that the United States shall maintain an uninterrupted capability for human space flight and operations in low-Earth orbit, and beyond, as an essential instrument of national security and of the capacity to ensure continued United States participation and leadership in the exploration and utilization of space."*

Appendix 1

Key Achievements of NASA's Constellation Program

The Constellation Program achieved notable maturity as a flight system, as evidenced by the successful completion of a Preliminary Design Review in March 2010. This review, following the successful Preliminary Design Reviews of the Ares-I launch vehicle and the Orion spacecraft, signaled the completion of a coherent Program technical approach that aligned content, budget and schedule for Phase I Capability, or LEO missions to the ISS. Key development flight and ground tests helped the Program to gauge programmatic risk by providing hard data in areas having the most uncertainty, providing confidence in the Agency's ability to execute the Constellation Phase I Capability development within cost & schedule commitments. Associated with this review, the Constellation Program also successfully completed the Phase I Safety Review, addressing all hazards that would lead to loss of life or loss of mission for the integrated system including the launch vehicle, spacecraft, and ground systems. Technical studies continued on the Constellation Program Phase II content, which would enable missions to the Moon & beyond, with technology maturation, trade studies, and programmatic planning scenarios all under concurrent development for the Altair Lunar Lander, the Ares V heavy lift launch vehicle, and Lunar surface habitats. The overall feasibility of the Constellation Program Phase II architecture was successfully demonstrated at the Lunar Capability Concept Review conducted in 2008. A listing of key achievements for the projects comprising the Constellation Phase I Capability is provided below.

Key Achievements of the Orion Project

The Orion Preliminary Design Review (PDR) was successfully completed in August, 2009. Both the ISS and Lunar variants of the Orion spacecraft were examined during the review. The Orion Project also successfully completed the Phase 1 Safety Review of the spacecraft. The review addressed all catastrophic loss of crew and/or vehicle, and critical loss of mission hazards for both the ISS and Lunar Sortie missions. Orion safety analysis integrated the results of hazard analysis, probabilistic risk assessment, failure modes analysis, and engineering design assessments to provide an integrated design and safety assessment consistent with the latest NASA human rating requirements. As a result, the Orion design has been more fully optimized to minimize safety risk while carefully balancing other project cost, schedule, and technical constraints.

Fabrication of the Orion crew module Ground Test Article, the first full scale Orion article designed and manufactured to NASA's rigorous human spaceflight specifications, continues. Construction of this article has validated many of the advanced production processes, equipment and tools necessary to manufacture Orion spaceflight hardware. The crew module pressure vessel and primary structure were manufactured at the Michoud Assembly Facility in Louisiana using friction stir welding, an advanced welding process that yields stronger bonds resulting in optimal structural integrity. The article was subsequently shipped to a Lockheed Martin facility in Colorado where final outfitting, including installation of the thermal protection system, secondary structure and spacecraft subsystem simulators is underway. Assembly will be complete by July, 2011 at which time environmental testing, including mechanical vibration and acoustic testing will be initiated. The article will subsequently be shipped to NASA's Langley Research Center for high fidelity water landing testing. Fabrication of similar Orion service module and launch abort system ground test articles is now also underway.

The first developmental flight test of the Orion Launch Abort System (LAS) was conducted at the White Sands Missile Range, New Mexico on May 6, 2010. During this test, the Orion LAS accelerated the crew module from a standstill to over 500 miles per hour in less than 3 seconds in a real flight environment exactly as would be required during a real launch contingency in order to save the lives of a human crew. The Orion LAS includes three newly designed solid rocket motors (an abort motor, a jettison motor and an attitude control motor) developed to optimize vehicle performance and improve the range of survivable abort conditions.

A thermal protection system (TPS) advanced development project was undertaken to address the low maturity level of TPS materials suitable for the Orion heat shield. Since the end of the Apollo program, NASA's focus on reusable TPS materials such as those used in the Space Shuttle eroded NASA's in-house research and development capability and left the ablative TPS industry in a state of neglect. The Orion project pursued a competitive phased development strategy with succeeding rounds of development, testing, and down selections. These efforts re-invigorated the ablative TPS industry, re-established a NASA competency to respond to future material needs, and transferred mature heat shield material and design options to the unmanned and commercial space industry, including TPS materials and technology information being used by the Mars Science Laboratory spacecraft and SpaceX Dragon capsule.

A new sensor technology has been developed that will allow easier and safer on-orbit rendezvous and docking. The Orion Vision Navigation System (VNS) is an advanced LiDAR based relative navigation sensor with performance specifications unmatched in today's relative navigation sensor market. A flight qualified version of the VNS is installed onboard the Space Shuttle Endeavour for the STS-134 mission. During the mission, the VNS will be operated in an experimental mode to characterize its performance and validate the technology for space operations. The VNS is a cross-cutting technology that has been developed in partnership with commercial vendors and is applicable for future spacecraft requiring rendezvous and dockings as well as other terrestrial commercial applications.

A new, high speed digital data bus protocol leveraging commercial developed standards while providing assured delivery of time critical data packets demanded by spacecraft command and control applications has been successfully developed for Orion. The protocol, referred to as Time Triggered Gigabit Ethernet, is an innovative technology employed that manages flight critical data as well as mission critical data, such as high definition video, over a single network to minimize weight and power. The Orion data bus network has been integrated and tested at the Honeywell labs in Phoenix, AR. The SAE approval of the Orion bus protocols is nearing completion, allowing for multiple vendors to supply this critical technology to a variety of commercial and government applications.

The Orion project successfully completed a Landing Systems advanced development project to trade, develop, test, and mature candidate systems to mitigate the loads imparted to the spacecraft and crew upon landing impact. Extensive analysis on the effectiveness of various technologies using sophisticated computer models and simulations was completed. The Project ensured the analysis was well-grounded by building and testing engineering development versions of the most promising alternatives, conducting a total of 117 drop tests. These efforts significantly advanced the state-of the art knowledge in this field and formed the basis for key Orion design decisions. These efforts have also provided the basis for the landing systems currently being considered by commercial human spaceflight efforts.

The Orion project successfully completed a formal Integrated Baseline Review to assess the adequacy of the integrated project baseline (cost, schedule, risk, and technical) following the system PDR.

Key Achievements of the Ares Project

The project completed its Preliminary Design Review in August 2008. Building on the successful Preliminary Design Reviews of the Upper Stage, Upper Stage Engine (J-2X), and First Stage, this review focused on integrated Ares-I launch vehicle design and performance. As a prerequisite for the Preliminary Design Review, the Ares Project successfully also completed the Phase 1 Safety Review. The review addressed all catastrophic (loss of crew/vehicle) and critical (loss of mission) hazards for the launch vehicle, integrating the results of hazard analysis, probabilistic risk assessment, failure modes analysis, and engineering design assessments to provide an integrated design and safety assessment consistent with the latest NASA human rating requirements.

In September 2009 and September 2010, NASA and ATK conducted successful tests of five segment development motors in Promontory, Utah. These tests were designated DM-1 and DM-2. Beyond validating the basic performance characteristics of the stage, the tests have enhanced modeling and understanding of key attributes that have historically been very difficult to predict analytically such as erosive burning, thrust oscillations and thrust tail off. Casting for DM-3 has been completed and the test is scheduled for later this year. This test will characterize and validate performance materials and processes applicable to future heavy lift launch systems utilizing solid propulsion stages.

In October 2009, the Ares I-X test flight took place at Kennedy Space Center in Florida. Data from more than 700 on-board sensors showed that the vehicle was effectively controlled and stable in flight. Thrust oscillation frequencies and magnitude data from the Ares I-X flight also were consistent with measurements from recent Shuttle flights that were instrumented, leading us to conclude that the oscillation vibration on the Ares I would be within the bounds that the Ares I was being designed to. In the end, this test flight provided tremendous insight into the aerodynamic, acoustic, structural, vibration, and thermal forces that Ares I would be expected to experience. A final report, Final Flight Evaluation Report for Ares I Use of Ares I-X Data (APO-1041), was completed in January 2011.

The Ares Project successfully completed development and demonstration on September 30, 2010 of a core end-to-end avionics and software integration and test capability. This capability included the integration of upper stage software development unit flight computers, an initial version of the Upper Stage flight software, a single string of First Stage engineering avionics hardware, prototype First Stage rock and tilt thrust vector control (TVC) actuators, and a Kennedy Space Center-developed Ground System (GS) Launch Control System (LCS) interface emulator. The team demonstrated prelaunch checkout and commanding, a complete closed-loop Ares vehicle ascent, and descent of the recoverable First Stage. State-of-the-art systems modeling & simulation capabilities that include hardware integration have broad government and commercial launch systems applicability.

In early 2011, the Upper Stage Element successfully completed functional testing and delivery of three lithium-ion (li-ion) battery development test units (DTUs). A total of eight additional battery DTUs will be delivered to the Marshall Space Flight Center in FY11 for further evaluation and testing. The flight unit batteries are designed to power launch vehicle avionics and various other

flight hardware components. Li-ion batteries are rechargeable batteries currently used in portable electronic applications. They are growing in popularity for military, electric vehicle, and now aerospace applications. The Ares I Project is working towards qualification of li-ion technology for human space flight.

The majority of the J-2X engine E10001 parts has been delivered to Stennis Space Center and engine assembly has begun with completion scheduled for May 2011. Static fire testing is currently slated to begin in the June/July 2011 time frame in Test Stand A2. J-2X Powerpack-2 Testing will begin in May 2011 in Test Stand A1. The J-2X offers a viable upper stage engine option in the development of government and commercial human and cargo launch systems.

Key Achievements of the Extra Vehicular Activity (EVA) Project

The EVA Systems Design Review was successfully completed in May of 2008. Successful completion of this review signaled completion of top-level EVA requirements and the associated technical feasibility of the design concept to meet the requirements.

In preparation for EVA Preliminary Design Review, the EVA Systems Project developed and delivered 5 prototype suits representing various design configurations and architectures to assess their respective merits in areas such as mobility, ease of donning and doffing, durability, reliability and safety.

The EVA Systems Project completed a formal Integrated Baseline Review in January of 2010.

Key Achievements in Ground Systems, Mission Operations, and Infrastructure

A two-year renovation of Kennedy Space Center's Operations & Checkout (O&C) building has been completed, resulting in a pristine new spacecraft "factory of the future." Built in 1964, the O&C building will continue its proud heritage of supporting every U.S. human spaceflight endeavor since the Gemini Program. Lockheed Martin and Space Florida partnered with NASA to create this state-of-the-art facility that will allow final assembly and checkout of the Orion spacecraft to be completed at the launch site.

At Kennedy Space Center in Florida, the deconstruction of Launch Pad 39B was initiated in October 2010 with the removal of the Rotating and Fixed service structures. Completion of the deconstruction is scheduled for April 30, 2011. These structures at the pad are no longer needed for NASA's Space Shuttle Program, so the pad is being renovated for future use. The new design will feature a "clean pad" for rockets to come with their own launcher, making it more versatile for a number of vehicles. The new lightning protection system, consisting of three lightning towers and a wire catenary system will remain.

In September 2010, four-year Launch Equipment Test Facility (LETF) renovation effort was completed at the Kennedy Space Center in Florida. The LETF includes a 600-ton test fixture used for tension and compression testing, a water flow test loop that tests valves, pumps and flow meters, two launch simulation towers and two 15,000-gallon cryogenic towers. The new Vehicle Motion Simulator, or VMS, simulates all the movements a vehicle will experience from rollout to launch.

At NASA's Kennedy Space Center in Florida, NASA's new mobile launcher (ML) support structure was completed in August 2010 and was moved from a construction site, north of the Vehicle

Assembly Building (VAB), to the Mobile Launcher east park site. The base of the launcher is lighter than space shuttle mobile launcher platforms so the crawler-transporter can pick up the heavier load of the tower and a taller rocket. Once there, the ML can be outfitted with ground support equipment, such as umbilicals and access arms, for future rocket launches. It took about two years to construct the 355-foot-tall structure, which will support NASA's future human spaceflight program.

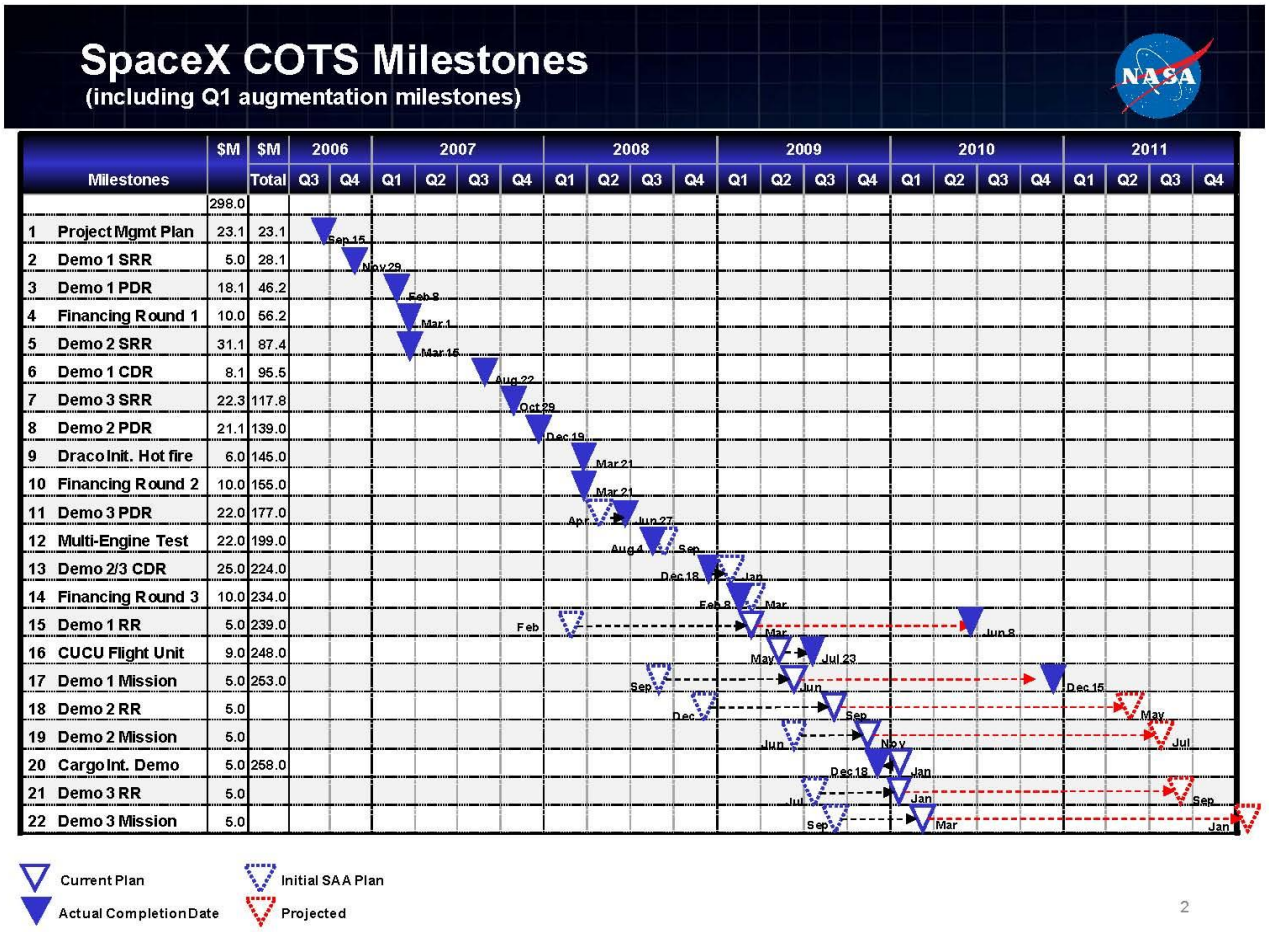
Construction of an advanced Space Environmental Test Facility (SET) at Glenn Research Center's Plum Brook Station in Ohio was initiated in 2007 and will be complete in the summer of 2011. Development of this facility will allow all Orion vehicle level qualification testing including mechanical vibration, acoustics, EMI and thermal vacuum testing to be accomplished in a single facility.

A hydro impact water basin was constructed at NASA's Langley Research Center in Virginia. This facility is available to support water landing impact testing of Orion and commercial spacecraft.

At NASA's Stennis Space Center in Mississippi, construction continues on a new engine test stand. The 300-foot-tall, steel-framed stand will be used to test the J-2X rocket engine. When completed in 2013, the A-3 test stand will allow engineers to evaluate the operating parameters of the J-2X engine by simulating conditions at altitudes as high as 100,000 feet. Construction on the stand began in August 2007At NASA's Johnson Space Center in Texas, architectures for the Mission Control Center-21 (MCC-21) project are being developed. The MCC-21 design features a modern architecture leveraging recent advances in technology to lower overall sustaining costs while increasing the flexibility and capability of the system. In concert with the MCC-21, the Training System (TS)-21 will provide a generalized simulation-based training capability for crew and flight controllers. This approach will support integration of a variety of future spacecraft rather than a single program or vehicle, develop simulation with integrated instructor tools that will provide common behavior across vehicle trainers; and create a simulation interface that supports a variety of vehicle-specific integration models. The Preliminary Design Reviews for MCC-21 and TS-21 will be held in the summer of 2011.

Several world-class manufacturing capabilities for liquid stage structures foaming, machining, and welding have been fabricated and installed at Alabama's Marshall Space Flight Center. These capabilities, the Vertical Milling Machine (the world's largest horizontal multi-axis milling machine), the Robotic Weld Tool, the Vertical Weld Tool, and the Spray-On Foam Insulation Booth, are adaptable and useful for a myriad of spacecraft applications.

Appendix 2


SpaceX COTS Milestones
(including Q1 augmentation milestones)
NASA
Milestones
$M
$M Total
2006
2007
2008
2009
2010
2011
Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
298.0
1 Project Mgmt Plan 23.1 23.1
2 Demo 1 SRR 5.0 28.1
3 Demo 1 PDR 18.1 46.2
4 Financing Round 1 10.0 56.2
5 Demo 2 SRR 31.1 87.4
6 Demo 1 CDR 8.1 95.5
7 Demo 3 SRR 22.3 117.8
8 Demo 2 PDR 21.1 139.0
9 Draco Init. Hot fire 6.0 145.0
10 Financing Round 2 10.0 155.0
11 Demo 3 PDR 22.0 177.0
12 Multi-Engine Test 22.0 199.0
13 Demo 2/3 CDR 25.0 224.0
14 Financing Round 3 10.0 234.0
15 Demo 1 RR 5.0 239.0
16 CUCU Flight Unit 9.0 248.0
17 Demo 1 Mission 5.0 253.0
18 Demo 2 RR 5.0
19 Demo 2 Mission 5.0
20 Cargo Int. Demo 5.0 258.0
21 Demo 3 RR 5.0
22 Demo 3 Mission 5.0
Sep 15
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Feb 8
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Aug 22
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Jun 27
Aug 4
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Jun 8
May
Jul 23
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Dec 15
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Dec
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May
Jun
Nov
Jul
Dec 18
Jan
Jan
Jul
Sep
Mar
Sep
Jan
Current Plan
Actual Completion Date
Initial SAA Plan
Projected
2

Orbital COTS Milestones
(including Q1 augmentation milestones)