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NASA's Launch Support and Infrastructure Modernization: Assessment of the Ground Systems Needed to Launch SLS and Orion

March 18, 2015

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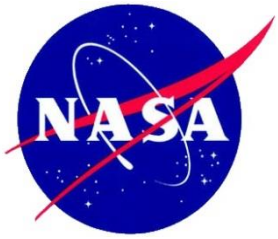

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RESULTS IN BRIEF

NASA's Launch Support and Infrastructure Modernization: Assessment of the Ground Systems Needed to Launch SLS and Orion

March 18, 2015 IG-15-012 (A-13-020-00)

WHY WE PERFORMED THIS AUDIT

More than 50 years after serving as the launch site for the storied Apollo Program, the Kennedy Space Center (Kennedy) is working to revamp decades-old infrastructure and transform itself into a multi-user spaceport to accommodate both commercial spaceflight companies and the Space Launch System (SLS) and Orion Multi-Purpose Crew Vehicle (Orion) NASA is developing for its next stage of deep-space exploration.

NASA has spent more than $975 million on modernization efforts at Kennedy over the last 5 years and anticipates spending an additional $2.4 billion over the next 5 to upgrade such infrastructure as the Launch Pad 39B, from which the Agency launched the Apollo and Space Shuttle flights; the Mobile Launcher built for the cancelled Constellation Program; one of the crawler-transporters NASA used to move spacecraft to launch pads for almost 50 years; the Vehicle Assembly Building (VAB) constructed in the mid-1960s to support the Apollo Program and which the Agency used to process Space Shuttle orbiters; as well as to develop the software necessary to integrate and launch the SLS and Orion. The Agency's Ground Systems Development and Operations (GSDO) Program is leading this effort.

In this review we evaluated whether the GSDO Program is meeting cost, schedule, and technical performance goals as it prepares Kennedy to launch the SLS and Orion on Exploration Mission 1 by the current target date of no later than November 2018.

WHAT WE FOUND

GSDO has made steady progress on the major equipment and facilities modernization initiatives needed to launch SLS and Orion, but significant technical and programmatic challenges remain to meet a November 2018 launch date. For the most part, these challenges originate from interdependencies between the GSDO, SLS, and Orion Programs. In short, GSDO cannot finalize and complete its requirements without substantial input from the other two Programs, and NASA is still finalizing the requirements for those Programs. Specifically, GSDO must overcome (1) a short timeframe for performing verification and validation testing between the Mobile Launcher, VAB, and Launch Pad 39B; (2) receipt of data and hardware regarding Orion later than planned; (3) the potential that integrated operations for Exploration Mission 1 may take longer than expected; and (4) most significantly, delays associated with development of command and control software.

At the time of our audit, GSDO was scheduled to complete a significant development milestone known as Critical Design Review in March 2015, several months before SLS (May 2015) and Orion (August 2015). The purpose of the Critical Design Review is to demonstrate a project's design is sufficiently mature to proceed to full scale fabrication, assembly, integration, and testing and technical aspects are on track to meet performance requirements within identified cost and schedule constraints. In our judgment, given the many interdependencies between the Programs, a schedule that has GSDO completing Critical Design Review prior to the other two Programs increases the risk GSDO may experience schedule delays or be required to perform costly redesign work.

Finally, coordinating and integrating development of the three individual Programs to meet a common milestone date presents a unique challenge, particularly since NASA historically has used a single program structure to manage similar efforts such as Apollo and the Space Shuttle. In lieu of central management, NASA established a cross-program integration structure that designates leaders from each Program to coordinate and align the Programs' development schedules. It is too early to say whether these substantial coordination challenges will result in cost or schedule issues for the Exploration Mission 1 launch. Moreover, new issues are likely to be uncovered during integration – the point at which most projects encounter technical problems that impact cost and schedule. Given these challenges, coordination efforts among the GSDO, SLS, and Orion Programs are essential to successfully meeting NASA's human exploration goals.

WHAT WE RECOMMENDED

In order to decrease the risk that the GSDO Program will experience cost increases or schedule delays, we recommended the Associate Administrator for Human Exploration and Operations reevaluate allowing GSDO to complete Critical Design Review before the SLS and Orion Programs. In response to a draft of our report, NASA management concurred with our recommendation and indicated it had changed the dates of the Programs' Critical Design Reviews so that the SLS and Orion reviews (currently planned for July and October 2015, respectively) will precede the GSDO review (currently planned for December 2015). However, NASA management noted a risk that the dates planned for SLS and Orion could slip and the GSDO review occur first. Accordingly, NASA should closely monitor the Programs to ensure any such risk is mitigated so as to avoid significant cost increases or schedule delays. The recommendation is resolved and will be closed upon verification and completion of the proposed action.

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TABLE OF CONTENTS

Acronyms

CT	Crawler-Transporter
EGS	Exploration Ground Systems
GSDO	Ground Systems Development and Operations
JCL	Joint Confidence Level
KDP	Key Decision Point
OSMU	Orion Service Module Umbilical
SCCS	Spaceport Command and Control System
SLS	Space Launch System
VAB	Vehicle Assembly Building

INTRODUCTION

For more than 50 years, the Kennedy Space Center (Kennedy) has served as the launch site for NASA's most storied space exploration programs, including Apollo and the Space Shuttle. Now, decades later, much of the infrastructure that supported those programs remains on the Center. As NASA prepares to enter a new stage of space exploration with its Space Launch System (SLS) and Orion Multi-Purpose Crew Vehicle (Orion) Programs, the Agency's Ground Systems Development and Operations (GSDO) Program is working to modernize and transform Kennedy into a multi-user spaceport capable of launching both Government and commercial spacecraft.

Modernization efforts at Kennedy began in October 2010, and as of the end of fiscal year 2014, NASA has spent approximately $975.84 million on the effort. NASA's budget requests for the next 5 years include roughly $2.4 billion for modernization efforts of existing infrastructure, to upgrade and develop software that will process launch vehicles and spacecraft, and to operate associated ground support equipment.[1] The infrastructure GSDO is adapting for new uses includes Launch Pad 39B, from which the Agency launched the Apollo and Space Shuttle flights; the Mobile Launcher built for the cancelled Constellation Program; one of the crawler-transporters (CT) NASA used to move spacecraft to launch pads for almost 50 years; and the Vehicle Assembly Building (VAB) constructed in the mid-1960s to support the Apollo Program and which the Agency used to process Space Shuttle orbiters.[2]

The GSDO Program is comprised of two components: Exploration Ground Systems (EGS), which focuses on preparing for launch of the SLS and Orion, and the 21st Century Space Launch Complex, which focuses on modernizing the infrastructure to support multiple users at Kennedy, including other Government agencies and commercial entities. In October 2014, we issued a report on Kennedy's efforts to encourage commercial space launch activities.[3] In this audit, we evaluated whether GSDO's EGS efforts are meeting cost, schedule, and technical performance goals. Details of the audit's scope and methodology are found in Appendix A.

Background

In August 2014, NASA committed to a first launch of the SLS – Exploration Mission 1 – by November 2018. Several issues make it particularly challenging for the GSDO Program to complete its SLS and Orion-related work by this date.[4] To begin with, the Program is working to modernize a diverse set of existing facilities and equipment, much of which is more than 50 years old. This is also the first time NASA is designing launch infrastructure intended to accommodate a variety of vehicles rather than a single vehicle like Apollo or the Space Shuttle. Finally, NASA is managing GSDO, SLS, and Orion as

[1] Ground support equipment refers to nonflight equipment, systems, or devices (such as pneumatic lines or pressure gauges) designed to interface with flight hardware.

[2] The Constellation Program was developing spacecraft to replace the Space Shuttle for trips to the International Space Station and enable human exploration beyond low Earth orbit. The Program was cancelled in 2010.

[3] NASA Office of Inspector General, "NASA'S Launch Support and Infrastructure Modernization: Commercial Space Launch Activities at Kennedy Space Center" (IG-15-003, October 23, 2014).

[4] NASA's original launch date for the SLS was December 2017.

three independent but coordinated programs. In contrast, for the Apollo, Space Shuttle, and Constellation Programs, NASA used a centralized approach with Headquarters assuming overall management responsibility. NASA is managing the three Programs in parallel – all with the same launch date and complex integration activities – through a cross-program integration structure. To this end, much of GSDO's work is heavily dependent on the final requirements of the SLS and Orion Programs, both of which are still in development.

Ground Systems Development and Operations

The GSDO Program is responsible for preparing Kennedy to process and launch the next generation of rockets and spacecraft in support of NASA's exploration objectives by developing the necessary ground systems, infrastructure, and operational approaches. To accomplish this mission, the Program must move launch vehicles to the launch pad, manage and operate the equipment required to safely connect a spacecraft with a rocket, and successfully send the integrated vehicle into space. In addition to mechanical aspects, such as propulsion systems and environmental control and life support, the Program is also modernizing related systems and bringing computers, tracking systems, and other networks up-to-date.

The EGS component of the GSDO Program is focused on developing and preparing the physical infrastructure and software necessary to integrate and launch the SLS and Orion. EGS is required to follow NASA Procedural Requirements 7120.5E, "NASA Space Flight Program and Project Management Requirements w/Changes 1-12," which establishes the process by which NASA formulates and implements space flight programs and projects.

The EGS budget consists of two primary components – Development and Program Integration and Support. Development contains four main elements:

- **Vehicle Integration and Launch** focuses on the equipment, management, and operations required to safely connect a spacecraft with a rocket, move the launch vehicle to the launch pad, and send it into space. The work entails many of the facilities unique to Kennedy, such as Launch Pad 39B and the 52-story VAB.
- **Offline Processing and Infrastructure** develops methods to handle the Orion spacecraft, rocket stages, and launch abort system before they are assembled into one vehicle. Work takes place at several facilities in Kennedy's industrial area, including the Operations and Checkout Building, the Multi-Payload Processing Facility, and the Launch Abort System Processing Facility.
- **Command, Control, Communications, and Range** element involves launching astronauts into space. In addition to modernizing existing computers, tracking systems, and other networks, this element creates systems that can handle several different types of spacecraft and rockets. The sophistication of the antennas, computers, and software under development are expected to reduce the size of launch teams compared to the staff that supported the Space Shuttle Program.
- **Project Management** includes safety and mission assurance, logistics, systems engineering, utilities, and facility operations and maintenance.

Program Integration and Support activities focus on the interfaces between the SLS and Orion Programs to ensure that the ground systems meet technical and safety specifications. This effort involves coordination and integration across all the GSDO, SLS, and Orion Programs to avoid potential design overlaps, schedule disconnects, and cost increases. Table 1 shows the GSDO Program's budget for the EGS component.

Table 1: EGS Budget

Budget Authority	Fiscal Year (dollars in millions)						
	2013 (actual)	2014 (enacted)	2015 (requested)	2016[b]	2017[b]	2018[b]	2019[b]
Development	$355.1	$318.2	$320.6	$390.9	$417.1	$425.9	$437.7
Program Integration and Support[a]	n/a	n/a	$30.7	$19.1	$15.3	$15.3	$15.3
Total Budget	**$355.1**	**$318.2**	**$351.3**	**$410.0**	**$432.4**	**$441.2**	**$453.0**

Source: NASA budget data.

[a] 2015 was the first year for this budget line item.
[b] Notional.

Major Kennedy Infrastructure and Equipment Modernization Initiatives

The major existing equipment and facilities GSDO is overhauling as part of their EGS component include Launch Pad 39B, the Mobile Launcher, CTs, and VAB. In addition to these projects, the Program is developing computer hardware and software for the Spaceport Command and Control System (SCCS) that will process launch vehicles and spacecraft and operate associated ground support equipment.

Launch Pad 39B

Originally built in the late 1960s for the Apollo Saturn V rockets, Launch Pad 39B was later modified to accommodate Space Shuttle flights. In 2007, as the Space Shuttle Program was winding down, NASA began modifying the Pad to accommodate rockets being developed as part of the Constellation Program. GSDO is currently preparing the Pad to serve as the launch site for the SLS rocket and Orion spacecraft, including demolishing and replacing the Shuttle-era flame trench with a new version and repairing the catacomb roof structure and water tank.[5] Between fiscal years 2013 and 2017, funding for Launch Pad 39B modernization efforts is $193.6 million. Major contractors are Vencore, Inc.; URS Corporation; Canaveral Construction Company, Inc.; Ivey's Construction, Inc.; Sauer, Inc.; Speegle Construction, Inc.; Vanguard Contractors; and Precision Mechanical, Inc.

Launch Pad 39B

Source: NASA.

Mobile Launcher

The Mobile Launcher, completed in 2010 at a cost of $234 million as part of the cancelled Constellation Program, is being structurally modified to meet requirements for the SLS rocket and Orion spacecraft. The Mobile Launcher consists of a two-story base, a 355-foot-tall launch umbilical tower, and facility ground support systems that include power, communications, and water. It is designed to support the assembly, testing, check out, and servicing of SLS and Orion and will carry the rocket and spacecraft atop the CT to Launch Pad 39B for Exploration Mission 1. Funding for the Mobile Launcher modernization is $335.1 million. Major contractors are Vencore, Inc.; JP Donovan Construction, Inc.; and Hensel Phelps Construction Company.

Mobile Launcher

Source: NASA.

[5] The NASA Authorization Act of 2010 directed the Agency, to the extent practical, to develop SLS and Orion using existing contracts, investments, workforce, and capabilities from the Constellation and Space Shuttle Programs.

Crawler-Transporter

Built in the 1960s to ferry the Apollo Saturn V rockets to Launch Pad 39B and used through the final Space Shuttle mission in 2011, Kennedy's CT-1 and CT-2 have collectively traveled approximately 4,167 miles in their lifetimes and are the largest self-powered land vehicles in the world. Bigger than a baseball field, each CT weighs 6.5 million pounds and travels at a speed of one mile per hour.

Crawler-Transporter

Source: NASA.

GSDO is upgrading and modifying CT-2 to increase its load capacity from 12 million to 18 million pounds to support the combined weight of the Mobile Launcher, SLS, and Orion. Work on CT-2 is scheduled to be completed in 2017.

NASA uses CT-1 to move the Mobile Launcher and to test basic crawler operations such as cylinders that lift and equalize loads and measure exhaust emissions. The Agency plans to retain CT-1 in a reduced operations and maintenance state until CT-2 modernization efforts are complete, at which time it will stop maintaining CT-1. Between fiscal years 2013 and 2017, NASA expects to spend $25.1 million on the CTs. Major contractors for the CTs are Vencore, Inc.; Jacobs Engineering Group, Inc.; and Ivey's Construction, Inc.

Vehicle Assembly Building

The 525-foot-tall VAB is the largest single-story structure and one of the largest buildings by volume in the world. Constructed in the mid-1960s, the VAB was first used to assemble the stages of the 363-foot Saturn V rockets that launched astronauts to the Moon. After the Apollo Program ended, NASA reconfigured the facility and used it for 30 years to stack orbiters with their boosters and store external fuel tanks for 135 Space Shuttle missions. Modifications to the VAB are once again required to service the SLS and Orion. Funding for the VAB modernization between fiscal years 2013 and 2017 is $233.2 million. Major contractors are Vencore, Inc.; Ivey's Construction, Inc.; Sauer, Inc.; Hensel Phelps Construction Company; and Met-Con, Inc.

Vehicle Assembly Building

Source: NASA.

Spaceport Command and Control System Software

Housed within Kennedy's Launch Control Center, the SCCS is at the heart of the activities involved with preparing and directing the launch of the SLS and Orion and operating associated ground support equipment. The GSDO Program is developing the hardware and software designs for the computers, displays, networks, applications, and simulation systems that will make up the SCCS. SCCS will provide the command and control infrastructure for the Program and is comprised of two subsystems: the Launch Control Subsystem, which provides the system software and hardware for the basic command, control, and monitoring capability, and the Ground Control Subsystem, which provides industrial control hardware infrastructure and interfaces and cabling between ground support equipment subsystems and the Launch Control Center.

Launch Control Center Firing Room

Source: NASA.

NASA's Project Life Cycle

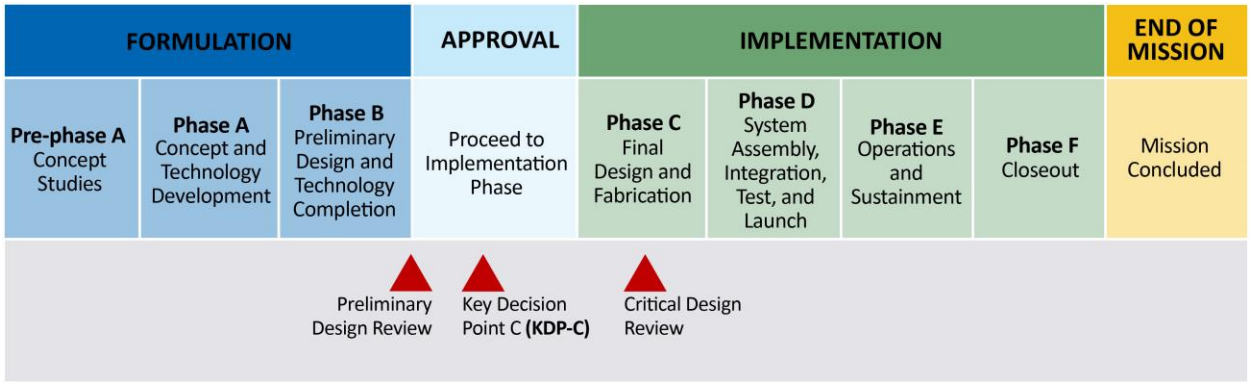
NASA policy provides overall direction for how project managers execute their responsibilities.[6] As shown in Figure 1, NASA divides the life cycle of its spaceflight projects into two major Phases – Formulation and Implementation – which are further divided into Phases A through F.[7] Phases A and B consist of Formulation and Phases C through F Implementation. This structure allows managers to assess the progress of their projects at Key Decision Points (KDP) in the process.[8] Generally speaking, projects that stay within the parameters of their plans and other governing agreements proceed to the next phase. Those projects that deviate significantly from these plans and agreements may undergo a Termination Review, which can lead to project cancellation.

[6] NASA Procedural Requirements 7120.5E, "NASA Space Flight Program and Project Management Requirements w/Changes 1-12," August 14, 2012.

[7] NASA defines the Formulation Phase as the period in which Agency personnel identify how a project supports the Agency's strategic goals; assess feasibility, technology, concepts, and risk; build teams; develop operations concepts and acquisition strategies; establish high-level requirements and success criteria; prepare plans, budgets, and schedules; and establish control systems to ensure performance to those plans and alignment with current Agency strategies. The Implementation Phase is the period in which personnel execute approved plans for the development and operation of the project and use control systems to ensure performance to those plans and continued alignment with the Agency's strategic goals.

[8] A KDP is defined as the point in time when the Decision Authority – the responsible official who provides approval – makes a decision on the readiness of the project to progress to the next life-cycle phase. KDPs serve as checkpoints or gates through which projects must pass.

Figure 1: NASA Life-Cycle Phases



Source: NASA Procedural Requirements 7120.5E.

During Formulation Phases A (Concept and Technology Development) and B (Preliminary Design and Technology Completion), projects develop and define requirements, cost and schedule projections, acquisition strategy, and project design and complete development of mission-critical or enabling technology. As needed, projects are required to demonstrate evidence of technology maturity and document the information in technology readiness assessment reports. Projects must also develop, document, and maintain a project management baseline that includes an integrated master schedule and baseline life-cycle cost estimate.[9]

The Formulation Phase ends with a Preliminary Design Review, during which project personnel are requested to demonstrate that the project's preliminary design meets all system requirements with acceptable risk and within cost and schedule constraints and establish the basis for proceeding with detailed design. At the Preliminary Design Review, the project is required to present full baseline cost and schedules, as well as risk assessments, management systems, and metrics. In addition, a Standing Review Board conducts an independent assessment of the readiness of the project to proceed to the Implementation Phase.[10] The Formulation Phase culminates in management approval to proceed to the next phase, which requires passage through KDP-C where an assessment of the preliminary design and a determination of whether the project is sufficiently mature to proceed to Phase C is made. In addition, as part of the KDP-C review process, cost and schedule baselines are established against which the project is thereafter measured.

During Phase C, the project prepares its final design, fabricates test units that resemble the actual hardware, and tests those units. A second design review – the Critical Design Review – occurs in the latter half of Phase C. The purpose of the Critical Design Review is to demonstrate that the design is sufficiently mature to proceed to full-scale fabrication, assembly, integration, and testing and that the technical effort is on track to meet performance requirements within identified cost and schedule

[9] The management baseline is an integrated set of requirements, cost, schedule, and technical content forming the foundation for project execution and reporting that is done as part of NASA's performance assessment and governance process.

[10] A Standing Review Board is composed of independent experts who provide assessments of the project's technical and programmatic approach, risk posture, and progress against the project baseline and offer recommendations to improve performance or reduce risk.

constraints. After the Critical Design Review, a System Integration Review takes place, which assesses the readiness of the project through system assembly, test, and launch operations. Depending on the results of that review, the project may be approved to continue into Phase D, which includes system assembly, integration, test, and launch activities. Phase E consists of operations and sustainment, and Phase F is project closeout.

Two of the three Programs – GSDO and SLS – have concluded life-cycle Phases A and B as well as the Preliminary Design Review and have entered into life-cycle Phase C for final design and testing. In August and September 2014, the SLS and GSDO Programs, respectively, completed KDP-C. Orion has completed Preliminary Design Review with KDP-C currently scheduled for March 2015. The GSDO Program Critical Design Review is scheduled for March 2015, with the reviews for the SLS and Orion Programs to follow in May and August 2015, respectively.

GSDO HAS MADE STEADY PROGRESS ON MODERNIZATION EFFORTS BUT INTERDEPENDENCIES AND RELIANCE ON SLS AND ORION DEVELOPMENT POSE CHALLENGES

GSDO has made steady progress on the major equipment and facilities modernization initiatives needed to launch SLS and Orion, but significant technical and programmatic challenges remain in order to meet the revised Exploration Mission 1 launch date of no later than November 2018. For the most part, these challenges originate from interdependencies between the GSDO, SLS, and Orion Programs. In short, GSDO cannot finalize and complete its requirements without substantial input from the other two Programs and NASA is still finalizing the requirements for those Programs. Specifically, GSDO must overcome (1) a short timeframe for performing verification and validation testing between the Mobile Launcher, VAB, and Launch Pad 39B; (2) receipt of data and hardware regarding the Orion Service Module Umbilical (OSMU) later than planned; (3) the potential that integrated operations for Exploration Mission 1 may take longer than expected; and (4) most significantly, delays associated with development of command and control software. As noted, GSDO is currently scheduled to complete the Critical Design Review several months before the other two Programs. In our judgment, given the many interdependencies between the Programs, this schedule increases the risk GSDO may experience schedule delays or be required to perform costly redesign work. Moreover, it will remain challenging to coordinate development of the Programs in the absence of a central management structure.

GSDO Completes Preliminary Design Review but First SLS Launch Date is Delayed

The GSDO completed its Preliminary Design Review in March 2014. As part of that process, GSDO and the Standing Review Board assigned to oversee the Program performed a Joint Confidence Level (JCL) analysis. The JCL process is an integrated analysis that examines a program's cost and schedule estimates and indicates the probability the program's cost will be equal to or less than the targeted cost and the schedule equal to or less than the targeted completion date.

The GSDO JCL analyses revealed less than a 3 percent confidence level that the Program would meet an SLS launch date of December 15, 2017. Accordingly, after further analyses and discussions and consideration of the status of the SLS and Orion Programs, NASA's Program Management Council issued a final KDP-C Decision Memorandum in September 2014 authorizing GSDO to proceed into Phase C and establishing an Agency Baseline Commitment (80 percent confidence level) date for Exploration Mission 1 no later than November 2018 and a revised life-cycle costs for GSDO of $2.8 billion. This represented an 11-month slip from NASA's original target for a December 2017 SLS and Orion launch and an increase of $208 million over GSDO's baseline cost estimate of $2.6 billion when the Program entered its Preliminary Design Review in February 2014.

GSDO Making Progress Modernizing Infrastructure but Software Development Remains a Challenge

GSDO has made progress modernizing infrastructure that will be needed to successfully launch and operate the SLS and Orion. However, the Program faces several risks that could impact its ability to launch Exploration Mission 1 by November 2018. Chief among these risks is the development of the command and control software necessary for integrated Firing Room applications and displays in support of SLS, Orion, and ground operations. The ability of the GSDO Program to mitigate many of these risks relies, in large part, on the success of the SLS and Orion Programs.

Infrastructure Modernization Efforts

In general, GSDO's modernization and reconfiguration efforts for Launch Pad 39B, the Mobile Launcher, CTs, and VAB are on schedule and close to budget.

Launch Pad 39B. As of December 2014, renovations to Launch Pad 39B were about 25 percent complete and meeting schedule projections. A million feet of cable, storage tanks for hypergolic fuels, and corrosive chemicals that powered the Space Shuttle's thrusters in space have been removed. Instruments that monitor and control the facility and ground and communications systems have been replaced with new state-of-the-art equipment. In 2013, GSDO finished demolishing the Shuttle-era flame trench and deflector (to be replaced with new versions in 2015), repaired the catacomb roof structure and a water tank, and replaced fire and potable water piping at the Pad. In 2014, NASA refurbished the Heating, Ventilating and Air Conditioning system and the Environmental Control System, and began construction on new systems for ground cooling, liquid oxygen vaporization, ignition overpressure, and sound suppression. Additional construction and verification testing at the Pad is scheduled for 2015 and 2016.

Mobile Launcher. As of December 2014, the Mobile Launcher was approximately 43 percent complete and experiencing cost growth under 2 percent. Major work for the Mobile Launcher includes modifying the base exhaust hole to encompass the various configurations in weight and size of the evolvable SLS architecture. Nearly all of the necessary demolition work around the original exhaust opening is complete and structural changes are underway. For example, the exhaust opening has been expanded from approximately 22-by-22 feet to 64-by-32 feet, and the massive steel support beams within the Mobile Launcher's platform have been reconfigured, with five newly fabricated pieces installed and the relocation and modification of another section. Work continues on the power, air conditioning, sprinkler, fire alarm systems, and a vehicle stabilizer subsystem.

CT-2. As of December 2014, the CT-2 was about 36 percent complete and on schedule for final readiness testing in 2016. GSDO has completed the removal of obsolete diesel engines, generators, and associated parts and is working to install new engines and connecting electrical, plumbing, and mechanical lines. Upgrades to the CT-2 include 88 new traction roller bearing assemblies, a modified lubrication delivery system, and a temperature monitoring system. Recently, the CT-2 passed the first phase of testing of the new traction roller bearings in half the vehicle.

VAB. As of December 2014, the VAB was about 14 percent complete and generally on schedule to meet an operational readiness date of September 2017. Major work to the VAB includes removing Space Shuttle-era platforms; extracting more than 150 miles of obsolete Apollo and Shuttle-era cabling; installing new structural, mechanical, and electrical systems; and replacing antiquated communications, power, and vehicle access.

Risks to Infrastructure Modernization Efforts

Despite the progress made on renovation and construction, the GSDO Program is monitoring a variety of significant risks identified through the JCL analyses, such as cross-program integration with SLS and Orion and verification and validation of ground support equipment. In general, the ability of the GSDO Program to mitigate many of these risks relies in large part on receiving timely and accurate information about requirements from the SLS and Orion Programs. Of the 42 program risks being tracked by GSDO, 19 (45 percent) are categorized as "cross-program risks," meaning that integration with the SLS and Orion Programs is needed to successfully mitigate the risk. More significantly, five of the eight top GSDO Program risks (63 percent) are reliant on the successful progress of the other Programs, as summarized below.

Insufficient Time for Verification and Validation Testing between the Mobile Launcher, VAB, and Launch Pad 39B. The time allotted by GSDO to perform verification and validation testing between the Mobile Launcher, the VAB, and Launch Pad 39B may be insufficient.[11] As a result, the GSDO may not be ready to process the SLS and Orion at the planned date, which could result in delays to the projected launch date. Currently, the GSDO, SLS, and Orion integrated schedule elements are broadly defined and do not include the level of detail required to completely encompass the testing required. In addition, there may not be enough contingency time in the schedules to deal with the issues identified during the testing. As a result, the Mobile Launcher timeframe for traveling to the VAB is expected to be delayed by 75 to 120 days.

Late Delivery of OSMU Data. The OSMU will provide electrical, data, and purging processes to Orion's Service Module until launch. The OSMU – 27-feet-long and 42-feet-tall – will attach to the Mobile Launcher and retract into a special structure on the Mobile Launcher as soon as the SLS's solid rocket boosters ignite. The OSMU cables, hoses, and lines connect to the side of Orion, which sits on the top of the SLS, through the OSMU plates. During the course of the audit, Orion Program officials provided some of the needed data and requirements for the OSMU. Specifically, GSDO received information on the exact points where the umbilicals will connect to the spacecraft. However the GSDO Program still requires additional detailed interface data to confirm final designs needed to either procure or fabricate hardware. The late delivery of the connection points delayed the OSMU setup inside of the Launch Equipment Test Facility by approximately 1 month. Late delivery of the interface data could impact the delivery of hardware needed for integrated operations which could delay two important design reviews by approximately 6 months each.[12]

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[11] Verification is the process of proving or demonstrating that a finished product meets design specifications and requirements, while validation is the process of showing proof that the product accomplishes the intended purpose based on stakeholder expectations and concept of operations. Verification and validation can be accomplished by any one, or a combination, of the following methods: testing, analysis, demonstration, simulation, and inspection.

[12] The Launch Equipment Test Facility provides NASA with a proving ground in designing and evaluating ground support systems and structures for the SLS rocket and Orion spacecraft. The facility includes workshops for rapid prototyping and precise manufacturing, along with huge launch support structures located outdoors.

Late Delivery of Flight and Ground Umbilical Plates to Support Testing. The OSMU plates are the contact point between Orion and the ground umbilicals where cables, hoses, and lines provide fluids, gases, power, and data to and from the vehicle. The GSDO Program may be unable to fully qualify the OSMU system if its plates are not received by June 2015. Late delivery could delay installation of five OSMU systems and the ground support equipment launch accessories for the Mobile Launcher by 90 to 180 days.

Integrated Operations for First Launch of SLS. Integrated operations for Exploration Mission 1 may take longer than planned, which could cause a launch delay. Based on historical experience, GSDO expects to encounter a "learning curve" during processing of the first launch. In addition, the Program is uncertain how long some integration tasks may take and expects others to take longer than planned. The current learning curve analysis shows a potential 6-month schedule delay. GSDO officials are analyzing risk factors and historical delays in the analysis to better estimate overall impact. Any of the risk factors identified during integration could delay the first launch by at least 1 month.

The JCL analyses identified a variety of significant risks to the GSDO Program, such as cross-program integration with SLS and Orion and verification and validation of ground support equipment. The risks were evidenced by the conclusion of the JCL analyses that the GSDO Program had less than a 3 percent confidence level that it would meet the initially planned SLS launch date of December 2017. The JCL analyses also concluded that the confidence level would increase from 3 percent to 80 percent if the SLS launch date was moved 11 months, from December 2017 to November 2018. Although this is a significant increase in confidence for the GSDO Program to meet the new launch milestone, the fact remains that nearly all the risks and issues identified through the JCL process have a significant element of cross-program integration associated with them, highlighting the fact that GSDO has limited control over many of the items that continue to represent risk to launching SLS by November 2018.

Software Development

Chief among the challenges GSDO is tracking is SCCS development, which is comprised of multiple projects, including the Ground and Control System, the Launch Control System, and the Ground-to-Flight Application Software. These systems work together to operate and monitor ground equipment, such as pumps, motors, and power supplies, in addition to equipment in the firing room needed to launch and communicate with the vehicle and range. SCCS is being developed iteratively, beginning with SCCS 1.0 and progressing to versions 2.0, 3.0, and 4.0. Each iteration builds on the previous version and is eventually integrated into the overall system that operates and monitors equipment managed by the GSDO, SLS, and Orion Programs. SCCS 4.0 will be the culmination of the software development process for Exploration Mission 1 and the software that will be used for the integrated ground operations. Although the software development effort is only 3 percent over budget, it is currently behind schedule. GSDO was scheduled to complete formal validation of SCCS 2.0 in February 2015, which is a 5-month slip from the previous date of September 2014.

Risks to Software Development

The GSDO Program is tracking several risks to SCCS development. Once again, the interdependency of the GSDO, SLS, and Orion Programs contributes to these risks. For example, the schedule for development of ground-to-flight software is at risk because the schedule for development of Orion flight software does not align with the GSDO development schedule. Additionally, SCCS 3.0 is planned to be used for ground support equipment hazardous testing. The purpose of those tests is to verify that the

hardware and software used to support hazardous operations is functioning properly. Hazardous testing of the ground support equipment may be impacted if SCCS 3.0 is not available by the scheduled testing date. Furthermore, because the GSDO Program has shifted work for some software requirements from 2014 into 2015, costs may increase.

Historically, software development efforts have been a source of significant cost and schedule overruns, and the complexity and highly interdependent nature of the GSDO effort combine to make software development one of the greatest risks to on-time and on-budget performance of the Program.

GSDO, SLS, and Orion Programs at Different Stages of Development

In our judgment, the current sequence of GSDO, SLS, and Orion development milestones increases cost and schedule risk for all three Programs. According to the Exploration Systems Development Division Master Schedule, GSDO will complete its Critical Design Review in March 2015, 2 months ahead of SLS and 5 months ahead of Orion (see Table 2).

Table 2: Milestone Reviews for GSDO, SLS, and Orion Programs

Milestone Review	GSDO	SLS	Orion
	Life-Cycle Phase A		
Key Decision Point A	January 2012	November 2011	February 2012
Systems Requirements Review	August 2012	July 2012	March 2007
	Life-Cycle Phase B		
Key Decision Point B	November 2012	July 2012	January 2013
Preliminary Design Review	March 2014	July 2013	August 2014
	Life-Cycle Phase C		
Key Decision Point C	September 2014	August 2014	March 2015[a]
Critical Design Review	March 2015[a]	May 2015[a]	August 2015[a]

Source: NASA Office of Inspector General representation of Agency information.

[a] Estimated.

As previously discussed, GSDO is already experiencing coordination challenges with the SLS and Orion Programs related to critical software development. The purpose of the Critical Design Review is to demonstrate that a program's design is sufficiently mature to proceed to full-scale fabrication, assembly, integration, and testing and that the technical effort is on track to meet performance requirements within identified cost and schedule constraints. Experience with past NASA programs such as Ares I (Constellation) and the Mars Science Laboratory has shown that moving forward prior to demonstrating that a design is sufficiently mature can result in costly reworking efforts.

Many of GSDO's development activities cannot be completed until the SLS and Orion Programs deliver flight hardware that will be assembled and integrated with the launch vehicle and spacecraft. In addition, GSDO must rely on SLS and Orion to provide needed data and software requirements to complete development of SCCS and to install and test the performance of the OSMU plate assemblies for the Mobile Launcher. While GSDO has received information from SLS and Orion Program officials on the exact points at which the umbilicals will connect to the SLS and Orion, there is still a risk that some

of the detailed interface information could be delivered late. Moreover, GSDO must perform extensive integration and verification tests before transporting the vehicle to Launch Pad 39B and before fueling can occur.

Given these factors, the maturity of GSDO's design is dependent, to a great extent, on the stable requirements and mature designs of the SLS and Orion Programs. However, these requirements and designs may not be sufficiently proven until those Programs complete their Critical Design Reviews. Consequently, having GSDO proceed to the Review prior to the other two Programs increases the risk of higher cost or schedule delays.

Lack of Central Management Structure Creates Challenges for Coordination of GSDO, SLS, and Orion Programs

Since June 2012, NASA has identified 462 interdependencies between the GSDO, SLS, and Orion Programs. To date, NASA has resolved 295 items (63.8 percent) with 167 remaining. Coordinating and integrating development of the three individual Programs to meet a common milestone date presents a unique challenge to NASA, which historically has used a single program structure to manage similar efforts such as the Apollo, Space Shuttle, and Constellation Programs.

In lieu of a central management structure, NASA has taken steps to coordinate and align the development schedules of the three Programs. Specifically, NASA has established a cross-program system integration structure that delegates authority to leaders in each of the Programs to make the majority of cross-program integration decisions. Teams from the GSDO, SLS, and Orion Programs communicate requirements and assess budget and cost implications of changing assumptions and configurations as their Programs evolve. The Programs have developed more than 30 product-focused task teams and a virtual System Engineering and Integration organization that conducts technical integration across all three Programs. The task teams report to a cross-program integration team comprised of senior managers from the Exploration Systems Division at NASA Headquarters and managers from the GSDO, SLS, and Orion Programs.

The task teams utilize a database to track issues that impact more than one of the three Programs and work together to develop mitigation plans and solutions. Issues that require extensive negotiations are elevated to the cross-program integration team for resolution. The cross-program integration team also works closely with the GSDO, SLS, and Orion Program task teams to develop a master schedule for the Exploration Systems Division that estimates development milestones for each of the three Programs.

It is too early to say whether the substantial coordination challenges will result in cost or schedule issues for the first launch of Exploration Mission 1. Moreover, new issues are likely to be uncovered during integration – the point at which, historically, most projects encounter technical problems that can result in cost increases and schedule delays. Given these challenges, NASA's coordination efforts among the GSDO, SLS, and Orion Programs are essential to successfully meeting the Agency's human exploration goals.

CONCLUSION

Along with SLS and Orion, the GSDO Program is a central component of NASA's future human exploration efforts. While GSDO has made steady progress in renovating launch-related infrastructure, the Program must overcome significant technical risks and interdependency issues with the SLS and Orion Programs to meet NASA's commitment for launch by November 2018. The evolving configuration requirements among the Programs necessitate close coordination and significant delays in any component will affect the overall timeframe. Some of the most serious challenges relate to GSDO's development of software for which the Program is awaiting firm requirements from SLS and Orion. Given these challenges and interdependencies, we believe NASA needs to closely monitor whether allowing GSDO to complete the Critical Design Review milestone before SLS and Orion accomplish their respective milestones poses an unacceptable level of schedule and cost risk to the Agency's human exploration goals.

RECOMMENDATION, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

In order to decrease the risk that the GSDO Program will experience cost increases or schedule delays, we recommended the Associate Administrator for Human Exploration and Operations reevaluate allowing GSDO to complete its Critical Design Review before the SLS and Orion Programs.

In response to a draft of our report, NASA management concurred with our recommendation and indicated it had changed the dates of the Programs' Critical Design Reviews so that the SLS and Orion reviews (currently planned for July and October 2015, respectively) will precede the GSDO review (currently planned for December 2015). However, NASA management noted a risk that the dates planned for SLS and Orion could slip and the GSDO review occur first. Accordingly, NASA should closely monitor the Programs to ensure any such risk is mitigated so as to avoid significant cost increases or schedule delays. The recommendation is resolved and will be closed upon verification and completion of the proposed action.

Management's full response is reproduced in Appendix B. Technical comments provided by management have also been incorporated, as appropriate.

Major contributors to this report include, Ridge Bowman, Space Operations Director; G. Paul Johnson, Project Manager; Jim Richards; Linda Hargrove; Greg Lokey; and Dimitra Tsamis.

If you have questions about this report or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at 202-358-1543 or laurence.b.hawkins@nasa.gov.

Paul K. Martin
Inspector General

APPENDIX A: SCOPE AND METHODOLOGY

We performed this audit from August 2013 through February 2015 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

This review evaluated NASA's progress at Kennedy to prepare the infrastructure for the processing and launch of the SLS and Orion. Specifically, we evaluated whether GSDO's efforts are meeting cost, schedule, and technical performance goals. Our review was conducted at Kennedy.

To accomplish this review, we interviewed key GSDO officials regarding the GSDO Program, the EGS component, and the 21st Century Space Launch Complex initiative. Additionally, we toured and observed the on-going modernization efforts at key Kennedy facilities during August and September 2013.

We obtained and examined applicable documents and verified compliance with the NASA Authorization Act of 2010 (Pub. L. No. 111-267, October 11, 2010), other Federal law and regulations, and NASA policy. The documents we examined included the following:

- GSDO monthly reports on cost, schedule, and technical performance for Launch Pad 39B, the Mobile Launcher, CTs, VAB, and software development activities
- GSDO risk management plan, program risk summary, risk reports, and program commitment agreement
- GSDO fiscal year 2014 budget documents and supporting data by detailed work breakdown structure for fiscal years 2013 to 2025
- Testimony of William H. Gerstenmaier, NASA Associate Administrator for Human Exploration and Operations, before the U.S. House of Representatives Subcommittee on Space and the Committee on Science, Space and Technology, December 10, 2014
- KDP-C Decision Memorandum for the EGS, NASA Agency Program Management Council, September 9, 2014
- GSDO Program Commitment Agreement, September 9, 2014
- GSDO KDP-C documents, including GSDO Standing Review Board assessments and GSDO self-assessments of the GSDO Program development before entering Phase C (Implementation: Final Design and Fabrication, May 2014)
- GSDO Preliminary Design Review Risk Ranking Charts (JCL "Tornado Charts"), February 2014
- GSDO Program Plan, June 12, 2012
- NASA Report to Congress: "NASA Launch Support and Infrastructure Modernization Program Report pursuant to Section 305 of the NASA Authorization Act of 2010 (Public Law 111-267)," April 2011

- "Independent Cost Assessment of the Space Launch System, Multi-Purpose Crew Vehicle and 21st Century Ground Systems Programs, Final Report," Booz Allen Hamilton, August 19, 2011

Use of Computer-Processed Data

We used limited computer-processed data to perform this audit. Specifically, we reviewed budget data from NASA's financial system and various schedule and technical performance reports. Generally, we concluded the data was valid and reliable for the purposes of the review.

Review of Internal Controls

We reviewed and evaluated internal controls, including applicable Federal laws and NASA policies and procedures. We considered the reviewed internal controls to be adequate.

Prior Coverage

During the last 5 years, the NASA Office of Inspector General has issued four reports and the Government Accountability Office has twice provided testimony of significant relevance to the subject of this report. Unrestricted reports can be accessed at http://oig.nasa.gov/audits/reports/FY15/index.html and http://www.gao.gov, respectively.

NASA Office of Inspector General

NASA's Launch Support and Infrastructure Modernization: Commercial Space Launch Activities at Kennedy Space Center (IG-15-003, October 23, 2014)

NASA's Efforts to Reduce Unneeded Infrastructure and Facilities (IG-13-008, February 12, 2013)

NASA's Challenges to Meeting Cost, Schedule, and Performance Goals (IG-12-021, September 27, 2012)

NASA's Plans to Modify the Ares I Mobile Launcher in Support of the Space Launch System (IG-12-022, September 25, 2012)

Government Accountability Office

Federal Real Property: Progress Made on Planning and Data, but Unneeded Owned and Leased Facilities Remain (GAO-11-520T, April 6, 2011)

Federal Real Property: The Government Faces Challenges to Disposing of Unneeded Buildings (GAO-11-370T, February 10, 2011)

APPENDIX B: MANAGEMENT COMMENTS

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

MAR - 9 2015

Reply to Attn of: Human Exploration and Operations Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator Human Exploration and Operations Directorate

SUBJECT: Response to OIG Draft Audit Report, "Launch Support and Infrastructure Modernization Efforts at Kennedy Space Center" (Assignment No. A-13-020-00)

The Human Exploration and Operations Mission Directorate (HEOMD) appreciates the opportunity to review your draft report entitled "*Launch Support and Infrastructure Modernization Efforts at Kennedy Space Center*" (Assignment No. A-13-020-00), dated February 11, 2015.

In the draft report, the OIG makes one recommendation addressed to the Associate Administrator for HEOMD to decrease the risk that the Ground Systems Development and Operations (GSDO) Program will experience cost increases or schedule delays.

NASA's response to the OIG's recommendation, including planned corrective actions, follows:

Recommendation 1: The Associate Administrator for Human Exploration and Operations reevaluate allowing GSDO to complete critical design review before the Space Launch System (SLS) and Orion Programs.

Management's Response: Concur. Exploration Systems Development's Critical Design Review (CDR) plan is changing to a model in which the flight programs' CDRs will precede the ground program CDR. The Exploration Control Board convened February 5, 2015, and baselined new CDR dates, which will have the Space Launch System (SLS) and Orion CDRs occurring prior to the Ground Systems and Development Operations (GSDO) CDR. There remains a risk that one of the flight program CDRs could slip its planned date and follow the ground program CDR.

Estimated Completion Date: Quarterly dates for the CDR Boards are as follows: SLS on July 22, 2015; Orion on October 15, 2015; and GSDO on December 3, 2015.

We have reviewed the draft report for information that we believe should not be publicly released. We have not communicated any concerns regarding the public release of information contained in your report.

Thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Michelle Bascoe at (202) 358-1574.

William Gerstenmaier

cc:
Kennedy Space Center/Mr. Cabana

APPENDIX C: REPORT DISTRIBUTION

National Aeronautics and Space Administration

Administrator
Associate Administrator
Chief of Staff
Associate Administrator, Human Exploration and Operations Mission Directorate
Center Director, Kennedy Space Center
Program Manager, Ground Systems Development and Operations

Non-NASA Organizations and Individuals

Office of Management and Budget
    Deputy Associate Director, Energy and Space Programs Division

Government Accountability Office
    Director, Office of Acquisition and Sourcing Management

Congressional Committees and Subcommittees, Chairman and Ranking Member

Senate Committee on Appropriations
    Subcommittee on Commerce, Justice, Science, and Related Agencies

Senate Committee on Commerce, Science, and Transportation
    Subcommittee on Space, Science, and Competiveness

Senate Committee on Homeland Security and Governmental Affairs

House Committee on Appropriations
    Subcommittee on Commerce, Justice, Science, and Related Agencies

House Committee on Oversight and Government Reform
    Subcommittee on Government Operations

House Committee on Science, Space, and Technology
    Subcommittee on Oversight
    Subcommittee on Space

(Assignment No. A-13-020-00)