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CONSTRUCTION OF TEST STANDS 4693 AND 4697 AT MARSHALL SPACE FLIGHT CENTER

May 17, 2017

Report No. IG-17-021

Office of Inspector General

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NASA Office of Inspector General
Office of Audits

RESULTS IN BRIEF

Construction of Test Stands 4693 and 4697 at Marshall Space Flight Center

May 17, 2017

IG-17-021 (A-16-016-00)

WHY WE PERFORMED THIS REVIEW

Test stands for large rocket propulsion systems are used to test system components under controlled conditions on the ground as part of the process to certify the systems for flight. Such stands cost tens or hundreds of millions of dollars to build or refurbish and may sit idle for many years after the programs for which they were built end. In August 2013, NASA entered into an agreement with the Army Corps of Engineers to plan and build two test stands at Marshall Space Flight Center to test the liquid hydrogen and liquid oxygen tanks that are part of the core stage of the Agency's new heavy-lift rocket, the Space Launch System (SLS). An essential component to achieving the Agency's goal of expanding human presence in the solar system, the SLS is designed to launch crews of up to four astronauts beyond low Earth orbit on the Orion Multi-Purpose Crew Vehicle (Orion), as well as cargo needed for NASA's future exploration missions. NASA spent approximately $76 million to build the two test stands.

We initiated this review to assess NASA's acquisition approach for the test stands; the cost, schedule, and performance of the construction project; the justification for placing the stands at Marshall; and plans for future use of the stands. We reviewed Federal and NASA policies, regulations, and plans; interviewed officials from NASA and Army Corps of Engineers; and reviewed contract documentation and various Agency studies concerning planning and construction of the test stands.

WHAT WE FOUND

In an attempt to meet a 2017 launch date for the SLS, NASA expedited construction of the test stands and paid the contractor a premium of approximately $7.6 million to complete construction on a compressed timetable. Moreover, because the stand designs were based on preliminary testing specifications, the requirements and testing capabilities that would be needed were not fully understood when the construction contract was awarded. As the testing requirements matured, NASA modified the contract to meet changing requirements, added additional features, and made other modifications that raised the contract price by $20.3 million. In addition, NASA did not establish adequate funding reserves to cover these changes and therefore had to secure $35.5 million in additional funding over the planned budget. Finally, because NASA did not adequately consider alternative locations before selecting Marshall as the site for the test stands, it cannot ensure it made the most cost-effective decision regarding where to build the stands.

WHAT WE RECOMMENDED

To improve the decision-making process for construction of test stands and facilities, we recommended NASA's Assistant Administrator for Strategic Infrastructure perform a comprehensive review of Program-funded construction projects to ensure adequate analysis, including all life cycle costs, is completed prior to project initiation, and develop additional construction project guidance for establishing unallocated construction reserves for program-direct construction facility projects to better account for significant expected risks. We also recommended NASA's Associate Administrator for Human Exploration and Operations ensure facility needs, such as construction of new facilities and/or modification of existing facilities, are appropriately included in program planning and scheduling and that testing requirements are adequately understood prior to committing the Agency to construction or modification of test facilities.

We provided a draft of this report to NASA management who concurred with each of the recommendations and described corrective actions the Agency plans to take. We consider management's comments to Recommendations 1 and 2 responsive; therefore, these recommendations are resolved and will be closed upon verification and completion of proposed actions.

Although NASA management concurred with Recommendation 3, the Agency's response did not adequately address the intent of the recommendation. NASA management agreed that modifying existing facilities or constructing new facilities to meet a specific program requirement should be included in program planning, and the driving requirements for those efforts should be clearly understood prior to committing Agency resources. However, the Agency considered this action to be complete since program planning and scheduling requirements are identified in "NASA Space Flight Program and Project Management Requirements," NASA Procedural Requirements (NPR) 7120.5E. We disagree. NPR 7120.5E, originally issued in 2012, was in place prior to the start of the test stand construction effort examined in this audit. As such, it was insufficient to prevent the concerns identified in this report and further action is needed to ensure the issues do not reoccur in future projects. Therefore, this recommendation remains unresolved pending further discussion with Agency officials.

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Acronyms

EM	Exploration Mission
GAO	Government Accountability Office
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
OIG	Office of Inspector General
SLS	Space Launch System

INTRODUCTION

Test stands for large rocket propulsion systems are used to test system components under controlled conditions on the ground as part of the process to certify the systems for flight. Such stands cost tens or hundreds of millions of dollars to build or refurbish and may sit idle for many years after the programs for which they were built end. In August 2013, NASA entered into an agreement with the Army Corps of Engineers to plan and build two test stands at Marshall Space Flight Center (Marshall) to test the liquid hydrogen and liquid oxygen tanks that are part of the core stage of the Agency's new heavy-lift rocket, the Space Launch System (SLS).[1] An essential component to achieving the Agency's goal of expanding human presence in the solar system, the SLS is designed to launch crews of up to four astronauts beyond low Earth orbit on the Orion Multi-Purpose Crew Vehicle (Orion), as well as cargo needed for NASA's future exploration missions. NASA spent approximately $76 million to build the two test stands.

We initiated this review to assess NASA's acquisition approach for the test stands; the cost, schedule, and performance of the construction project; the justification for placing the stands at Marshall; and plans for future use of the stands. See Appendix A for details of the audit's scope and methodology.

Background

The NASA Authorization Act of 2010 directed the Agency to develop the SLS as a follow-on to the Space Shuttle.[2] NASA is planning the first flight of the SLS – Exploration Mission-1 (EM-1) – for 2019.[3] NASA's current plan for EM-1 is to launch an uncrewed Orion capsule on a 25-26 day journey orbiting the moon. This will be followed by Exploration Mission-2 (EM-2), the first crewed mission of the combined SLS/Orion system, which NASA hopes to launch as early as 2021.[4] The SLS Program is managed by NASA's Human Exploration and Operations Mission Directorate, and the SLS Program Office is located at Marshall in Huntsville, Alabama.

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[1] NASA has a blanket interagency agreement with the Corps of Engineers that covers construction management and a variety of other facility-related services. In addition to the hydrogen and oxygen tanks, the SLS core stage includes an engine section, the intertank that connects the hydrogen and oxygen tanks, and the forward skirt that connects the core stage to the upper stage of the SLS rocket.

[2] Public Law 111–267 (October 11, 2010).

[3] NASA initially committed to a launch readiness date of no later than November 2018; however, that date has slipped and as of May 2017 the Agency was in the process of establishing a new target launch date in 2019.

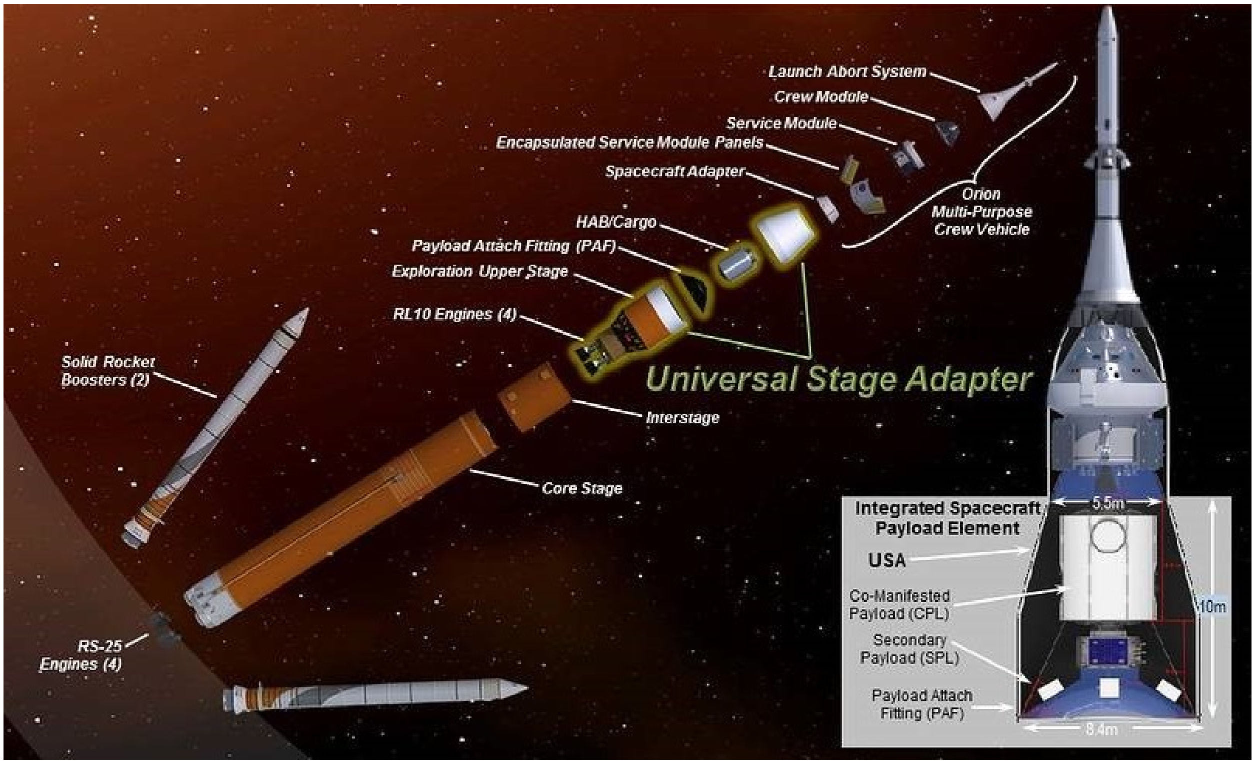
[4] Although NASA is working toward a 2021 launch date for EM-2, its Agency Baseline Commitment for a first crewed launch of Orion is 2023. The Baseline Commitment is the Agency's formal commitment to Congress for a program's launch readiness date and life-cycle cost estimates. NASA has not developed a Baseline Commitment for the other programs necessary to launch EM-2 – namely SLS and the ground systems program.

SLS Rocket and Core Stage

The SLS launch vehicle is designed to evolve into increasingly more powerful configurations and will be the most powerful rocket ever built. The initial configuration – Block 1 – will have a minimum 70 metric ton lift capability. At 322 feet, Block 1 will stand taller than the Statue of Liberty, weigh 5.75 million pounds fueled, and produce a maximum of 8.8 million pounds of thrust at liftoff – the equivalent of more than 160,000 sport car engines. Block 1 will provide 15 percent more thrust at launch than the Saturn V rocket NASA used to send astronauts to the Moon and will be capable of carrying more than three times the mass of the Space Shuttle.

The Block 1B configuration, which the Agency plans to use on EM-2, will have the capability to carry more than 105 metric tons. The Block 2 upgrade, expected to be completed by 2028, will replace the SLS's solid rocket boosters with more powerful boosters that will provide the capability to lift 130 metric tons to low Earth orbit and 41 metric tons to Mars. Figure 1 shows the various components of the SLS.

Figure 1: Depiction of NASA's Space Launch System



Source: NASA.

Marshall Test Facilities

Marshall has served as the testing site for many of NASA's iconic space programs, from the Saturn rockets to Skylab to the Space Shuttle to the International Space Station. The Center is home to a comprehensive set of structural and environmental testing facilities, including the Solid Propulsion Test Facility, which simulates solid rocket motor combustion environments, and the Hydrogen Cold Flow Facility, which provides low-pressure flow tests of hydrogen engine and subsystem components. It also has a full range of engineering support capabilities, including machine shops, test support and logistics services to supply consumables and instrumentation, and test planning support for budget analysis and risk management of test programs.

Vertical Assembly Center at Michoud

Source: NASA.

Marshall also manages the Michoud Assembly Facility (Michoud) in New Orleans, Louisiana, where the core stage of the SLS is being built using a unique set of tools, including the largest spacecraft welding instrument in the world – the 170-foot-tall, 78-foot-wide Vertical Assembly Center.

Test Stands 4693 and 4697

Before sending a rocket into space, NASA extensively tests its various components, simulating as closely as possible the environment in which the rocket will be expected to operate. Short of actual flight, this generally can only be accomplished with custom-built test stands.

In May 2014, Marshall began construction of two test stands NASA will use to test the structural integrity of the SLS core stage liquid hydrogen and liquid oxygen tanks to ensure they can withstand the stresses of launch. The test stands are identified by their corresponding building numbers – Test Stand 4693 and Test Stand 4697. Construction of Test Stand 4697, which will be used to test the liquid oxygen tank, was completed in September 2016 and construction of Test Stand 4693, which will be used to test the liquid hydrogen tank, was completed in November 2016.[5]

To accommodate testing of the 149-foot liquid hydrogen tank, Test Stand 4693 has a twin-tower configuration constructed of more than 3,560 tons of steel and stands at a height of 215 feet (about 23 stories). Engineers will hang the tank from the stand vertically, load it with enough liquid nitrogen to cover its critical areas, and apply stress by bending, twisting, compressing, and pulling on the tank.[6] The stand was built on the foundation of the now-demolished stand NASA used between 1965 and 1969 to test the Saturn V F1 engine.

[5] NASA performs these tests on tanks manufactured specifically for this purpose, which it refers to as test articles. For ease of reference, we simply use the term "tank" in this report.

[6] NASA officials prefer to use liquid nitrogen for structural tests because it is less expensive and less flammable than the liquid hydrogen used during actual launch.

Test Stand 4693 has a movable crosshead portion between the two towers that can be raised and lowered depending on the size of the article being tested. This feature gives NASA flexibility to test articles other than the SLS liquid hydrogen tank on the stand. NASA expects the SLS liquid hydrogen tank it will test on the stand to be ready for shipment from Michoud to Marshall in September 2017. After it arrives at Marshall, workers will spend up to six months integrating the tank in the stand and connecting the sensors and equipment required for testing. Test Stand 4693 is shown in Figure 2.

Figure 2: Test Stand 4693

Artist's Rendering of Test Stand 4693

Completed Test Stand 4693

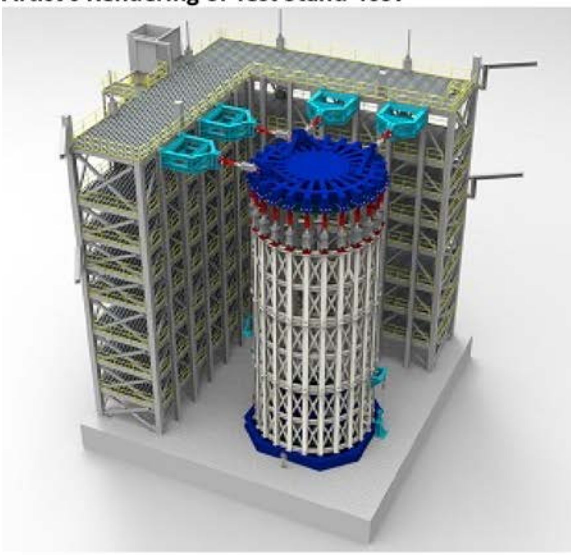
Source: NASA.

Test Stand 4697 is a more than 1,580-ton steel structure that stands 85-feet tall. For testing, the 28-foot-diameter, 70-foot tall liquid oxygen tank will be lifted and positioned inside a circle of three cage-like pedestals, with only about a foot of clearance on either side. The tank will sit atop a "spider" – essentially a support pedestal with arms to hold the tank in place – and a special ring that will be bolted into the stand's foundation. A similar spider and ring will be mounted to the top of the tank.

During testing to simulate different phases of an SLS launch and flight, the tank will be filled with varying amounts of liquid nitrogen and the hydraulic cylinders and "load lines" that will push, pull, and apply varying combinations of pressure to the tank will attach to the spiders' arms and the pedestals. NASA expects the liquid oxygen tank it will test on the stand to be ready for shipment from Michoud to Marshall in October 2017. After it arrives at Marshall, workers will spend up to four months integrating the tank into the stand and connecting the sensors and load lines required for testing. Test Stand 4697 is shown in Figure 3 below.

Figure 3: Test Stand 4697

Artist's Rendering of Test Stand 4697



Completed Test Stand 4697

Source: NASA.

Contract for the Construction Effort

In August 2013, NASA entered into an agreement with Corps of Engineers to execute the planning and construction of Test Stands 4693 and 4697. Pursuant to the agreement and subsequent modifications, NASA paid the Corps of Engineers $74.1 million to obtain and evaluate bids from construction contractors, select a contractor, award the construction contract, and oversee the construction, with NASA officials providing technical advice and assistance. In April 2014, the Corps of Engineers awarded a fixed price contract to build the stands to Brasfield & Gorrie of Birmingham, Alabama, one of the largest privately held construction firms in the nation.

The architectural firms Goodwyn Mills and Cawood, Inc. and Merrick & Company developed the designs for the stands in 2012-2014 under direct contracts with Marshall. The architectural design work cost approximately $3.3 million.

Prior OIG Reviews of NASA Infrastructure and Facilities

Over the last several years, the Office of Inspector General (OIG) has reported on NASA's test facilities and its decision making process regarding construction of another SLS test stand – the B-2 Test Stand at Stennis Space Center (Stennis). In a February 2013 audit, we assessed NASA's efforts to reduce unneeded infrastructure and facilities and identified 33 facilities – including wind tunnels, test stands, thermal vacuum chambers, airfields, and launch infrastructure – at NASA Centers across the country the Agency was not utilizing or for which NASA officials could not identify a future mission use.[7] In a January 2014 report, we found that in selecting the B-2 for SLS testing NASA may not have chosen the most efficient and cost-effective test site.[8]

NASA controls approximately 5,000 buildings and structures with an estimated replacement value of about $34 billion, making it one of the largest Federal Government property holders. While the Agency strives to keep these facilities operational, or at least in sufficient condition so they do not pose a safety hazard, NASA has not been able to fully fund required maintenance for its facilities for many years. In 2016, NASA estimated its deferred maintenance costs at $2.4 billion.

[7] NASA OIG, "NASA's Efforts to Reduce Unneeded Infrastructure and Facilities," (IG-13-008, February 12, 2013).

[8] NASA OIG, "NASA's Decision Process for Conducting Space Launch System Core Stage Testing at Stennis," (IG-14-009, January 8, 2014). NASA will use the B-2 Test Stand for "green run" testing of the SLS core stage. During this test, the engines will be assembled into a single configuration for the first time and the core stage fired at nearly full-power to test the compatibility and functionality of the system.

Compressed Schedule, Uncertain Requirements, and Design Changes Resulted in Significant Cost Increases

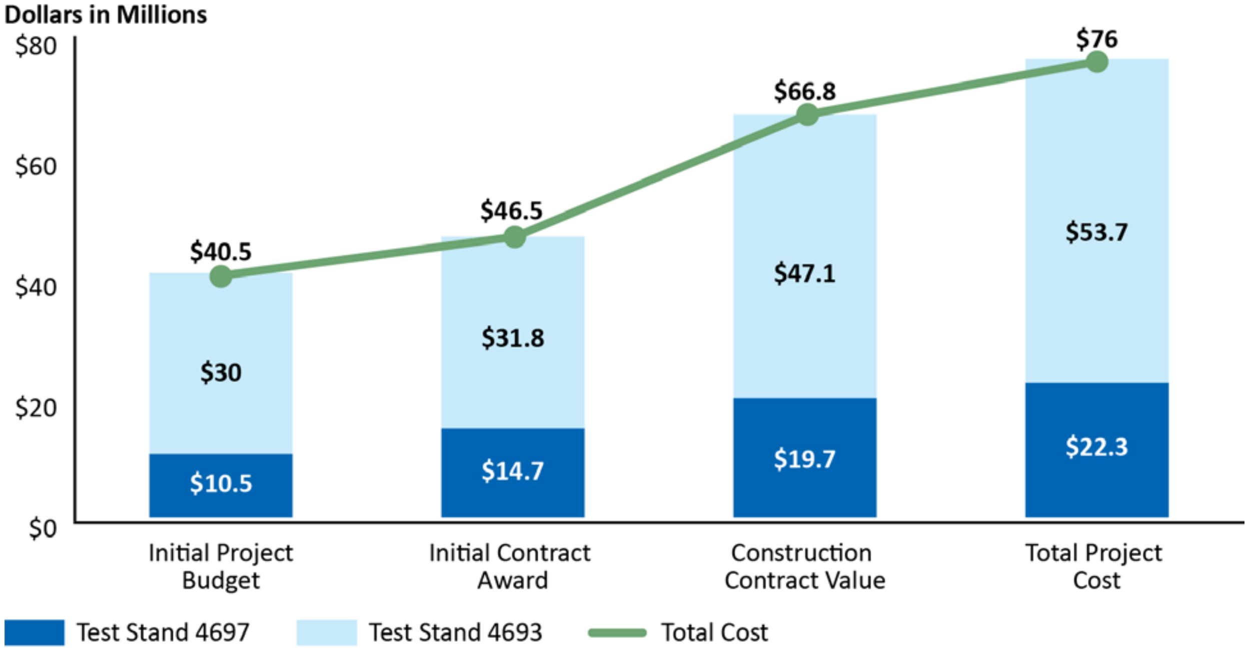
In an attempt to meet a 2017 launch date for the SLS, NASA expedited construction of Test Stands 4693 and 4697 and paid the contractor a premium of approximately $7.6 million to cover the expense of completing construction on a compressed timetable. Moreover, because the stand designs were based on preliminary testing specifications, the test stand requirements and capabilities needed were not fully understood when the construction contract was awarded. As testing requirements matured, NASA modified the contract to meet changing requirements, added additional features, and made other modifications that raised the contract price by $20.3 million. Finally, NASA did not establish adequate funding reserves to cover these changes and therefore had to secure $35.5 million in additional funding over the planned budget.

Construction of Test Stands

Although specifications and testing requirements for components of the SLS core stage had not yet been finalized, the SLS Program established an ambitious construction schedule for Test Stands 4693 and 4697. To meet this schedule, the initial designs were developed and the contract for the construction effort awarded before the requirements for the stands were finalized. As testing specifications matured, requirements evolved and the construction contract was modified accordingly.

The Program's initial budget for the test stands was $40.5 million – $30 million for Test Stand 4693 and $10.5 million for Test Stand 4697. Ultimately, the Agency spent approximately $76 million to construct the two stands – $53.7 million for Test Stand 4693 and $22.3 million for Test Stand 4697, an increase of nearly 88 percent to complete the modified designs. Budget and cost figures are shown in Figure 4 below.

Figure 4: Cost Increases for Test Stand Construction



Source: NASA Office of Inspector General analysis of cost data.

Note: Total Project Cost includes the construction contract value of $66.8 million, the cost of the Corps of Engineers' management services of $7.4 million, and NASA Marshall project management costs of more than $1.8 million but excludes design costs, which as noted above were covered by a separate contract. Costs are as of February 2017.

NASA Paid a Cost Premium to Expedite Construction

When the SLS Program was established in September 2011, NASA's goal was a first flight of the new rocket in December 2017. To meet this schedule, the SLS Program paid an estimated premium of $7.6 million for a compressed construction schedule for the test stands, requesting construction be complete for Test Stand 4693 by May 2015 and for Test Stand 4697 by September 2015. However, three months after construction began NASA committed to a first SLS launch readiness date of no later than November 2018, which largely obviated the need for the compressed construction schedule.

In July 2012, NASA engaged a design contractor to develop requirements for Test Stands 4693 and 4697 based on preliminary designs of the SLS and the anticipated testing requirements. Based on these designs, in September 2013 the Corps of Engineers announced a solicitation for proposals to construct the stands, requesting construction be completed in approximately 12 months. When the bids came in much higher than expected, the Corps of Engineers determined the independent government cost estimate developed in January 2013 did not adequately account for costs associated with a 12-month construction schedule.[9] Accordingly, in April 2014 the Corps of Engineers developed a revised cost

[9] An independent government cost estimate is developed by Government personnel to check the reasonableness of a contractor's cost proposal and ensure the offered prices are within the budget range for a particular program.

estimate $7.6 million higher than the original estimate, which accounted for the contractor having to work atypical hours to complete construction on the expedited timetable. The construction contract was awarded in April, and construction started in May 2014.

In accordance with NASA policy, the SLS Program underwent a key decision point milestone review which was approved in August 2014 to assess whether it was ready to move from formulation to implementation.[10] As part of this review, the Agency formally committed to an initial SLS launch readiness date of no later than November 2018. This schedule change pushed all planned testing to a later date, giving the SLS Program additional time to prepare for core stage testing on Test Stands 4693 and 4697 and alleviating the need to expedite construction. Because the Agency had awarded a fixed price contract for this effort, the contractor was not required to repay the compressed schedule premium. Although NASA officials told us the contractor agreed to take the premium payment into consideration when developing its costs for subsequent contract modifications, neither NASA nor the OIG could quantify how much of this money the Agency recouped in the form of reduced costs for the modifications.

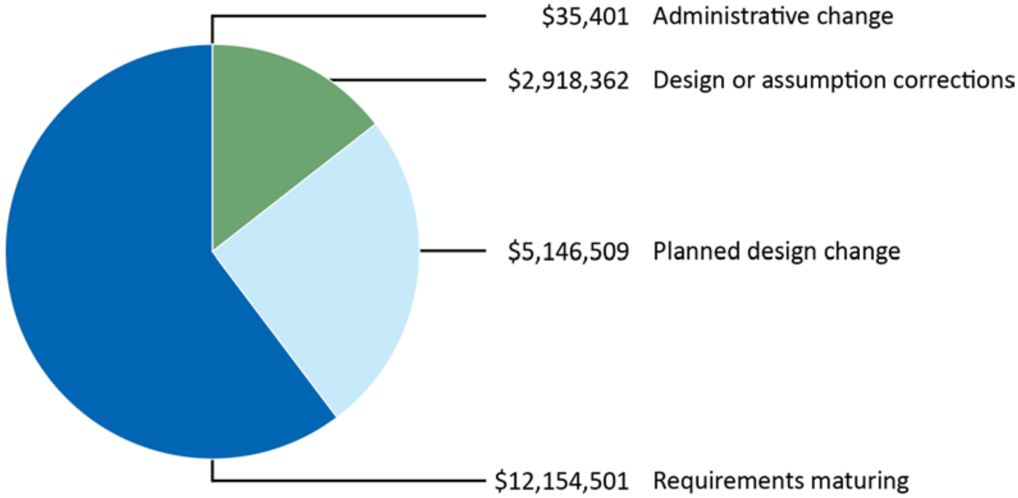
Contract Cost Increased Significantly Because Requirements and Designs for the Test Stands Were Uncertain at Contract Award

NASA has been operating on optimistic schedules for development of the SLS from the Program's beginning. The NASA Authorization Act of 2010 set a goal for operational capability for the core elements of no later than December 2016, and, as noted above, NASA's original goal for the first SLS flight was the end of 2017. To meet this ambitious schedule, NASA awarded the construction contract for the test stands before the Agency had settled on the final SLS testing requirements. As requirements matured, NASA had to modify the test stand designs accordingly. Indeed, the contract was modified 6 times to accommodate requirement changes, increasing the total contract cost by more than $12.1 million.

In addition to modifications driven by changing requirements, NASA made other changes that increased contract costs: $2.9 million for changes resulting from site conditions or unexpected design conflicts; $5.1 million for redesign of the crosshead to allow it to remain attached and move vertically in the stand; and $35,000 related to a minor modification that allowed the contractor to obtain a larger site trailer capable of accommodating all project personnel. Figure 5 below illustrates the sources of the increased costs to the construction contract for both stands. See Appendix B for summary of questioned costs.

[10] NASA Procedural Requirements 7120.5E, "NASA Space Flight Program and Project Management Requirements," August 14, 2012.

Figure 5: Sources of Increased Costs to the Construction Contract



Source: NASA Office of Inspector General analysis of construction contract modifications.

Design Corrections or Assumptions that Changed the Contract

It is not uncommon to incur design changes on large construction projects after contract award to accommodate actual site conditions or unforeseen design conflicts. We identified two such modifications to the test stand contract that substantially increased the contract price. The first modification was necessary because the design drawings for Test Stand 4693 did not clearly depict how connections between steel beams were to be made. After the contract was awarded, the Structural Engineer specified the method for making these connections, which differed from the method the contractor had proposed. NASA paid the contractor $880,000 to make the necessary adjustments. The second modification – also for Test Stand 4693 – was necessary because the Construction Project Office did not clearly communicate the weight requirements for the crosshead hoist to the designer and consequently the roof and truss system had to be redesigned to support additional weight. NASA paid the contractor $625,422 for this adjustment. Although the Agency anticipated these kinds of design corrections and set aside additional, unallocated funding at the start of the contract to cover such expenses, the high cost of the corrections significantly reduced the amount of reserve funding available for other changes required during the remainder of the contract.

Costs Increased as Testing Requirements Matured

As testing requirements matured, NASA modified the test stand contract six times to meet changing specifications, adding more than $12.1 million to the cost of the construction contract. For Test Stand 4693, the following modifications to the contract were made.

- One modification related to the contractor assisting with mounting the upper testing interface on the crosshead so as to avoid having to move the crosshead after construction was complete. Although this modification cost more than $186,000, it likely saved NASA money in the long run as it would have been more expensive to move the crosshead later.

- Another modification changed the requirements for the crosshead hoist that moves the test article up to the testing interface ring to accommodate a specialized hook and other necessary technical features. This modification cost more than $217,000.
- A modification related to the size of the strand jacks the contractor used.[11] The contractor originally planned on building the crosshead at ground level and lifting it to the desired location with strand jacks. However, the increased weight of the crosshead hoist and reinforcement of the crosshead necessitated the use of larger jacks. This $338,790 modification paid the contractor for the cost of renting larger jacks.
- Another modification added support to the crosshead to accommodate more defined testing requirements that put additional stresses on the test stand. This modification cost more than $7.1 million.

For Test Stand 4697, NASA made two modifications to strengthen the structure to support simultaneous horizontal and vertical stresses on the test article, a need that was not included in the original testing requirements. These modifications cost more than $4.2 million.

Design Change to Crosshead Increased Costs for Test Stand 4693

Before the contract was awarded, NASA decided to modify the design of Test Stand 4693 to make it easier to move the crosshead to a different height. Under the original design, NASA would have had to use cranes to detach and then reattach the crosshead at the desired height. The redesign allows the crosshead to move vertically within the stand and therefore to be moved using strand jacks rather than cranes. Although this is a somewhat less complex and expensive operation than using cranes, it will still require NASA to rent strand jacks and hire specialized personnel to complete each crosshead move. NASA personnel told us they made this change to make the test stand more flexible for future testing of different size tanks and to reduce the cost of crosshead moves. Based on our review of the original award documentation and the modified requirements, the change cost the Agency $5.1 million.

According to project personnel, the decision to change the crosshead design was not made until late 2013, after the request for proposals was issued but prior to actual contract award. NASA did not modify the solicitation to reflect the change. According to Agency personnel, modifying the solicitation would have delayed the contract award for several months so that the crosshead design could be completed, evaluated by bidders and considered in the award. At the time they did not believe the change would be as expensive or time consuming as it ultimately turned out to be, and feared that the cost of delays to the SLS Program downrange would be greater than any modification made. In our view, even with the initial schedule pressures, NASA may have saved a significant amount of money by revising the contract solicitation and asking the bidders to address the requested change in their submissions. By waiting until after the contract had been awarded, NASA lost any leverage it had to seek a lower price.

[11] Strand jacks are hydraulically operated lifting devices capable of lifting extremely heavy loads.

Agency officials told us they are considering using Test Stand 4693 to test the SLS exploration upper stage – testing that would require the crosshead be moved. However, beyond this possibility the Agency has no plans to move the crosshead for testing. Because it does not appear moving the crosshead will be a frequent occurrence, it may have been less expensive to maintain the original design and use cranes to move the crosshead when necessary.

NASA Did Not Establish Adequate Funding Reserves

NASA did not establish adequate funding reserves to cover anticipated contract and requirement changes to the test stands. Project personnel told us they established a 10 percent construction reserve for unanticipated cost increases, which is standard for most construction projects with known requirements. However, as discussed above, because testing plans were still evolving, construction requirements for the stands were not certain and, in any event, officials were planning the design change to the crosshead. In our view, the Agency should have anticipated the need to reserve significantly more than the normal 10 percent to cover the expected changes.

Funding reserves should be based on two factors: known risks with contingency plans and unknown risks. Projects should not underestimate funding reserves with the expectation of being granted additional cost and schedule allocations after project initiation. SLS officials told us they did not believe it was necessary to identify additional reserves for the test stand project because they had sufficient reserves in the overarching SLS Program account to cover the requirement changes. However, these funds had not been identified and set aside for the test stand project, and therefore may not have been available when needed. Given the significant risks associated with uncertain project requirements and a planned design change, we believe it would have been prudent for NASA to identify and set aside sufficient funds to cover the changes in excess of the 10 percent reserve.

The Project's initial budget was $40.5 million, of which $34.1 million was allocated for the construction contract, $3 million for supervision, and $3.4 million considered unallocated construction reserves. However, the reserve did not cover the $6 million difference between the actual contract award of $46.5 million and the initial budget estimate. Ultimately, the project needed an additional $15 million from the SLS Program to cover the higher contract price and to replenish reserves. Further, in 2015 the Project asked for an additional $20.5 million to fund requirements and design changes, for a total cost increase of $35.5 million.

ALTERNATIVE CONSTRUCTION SITES WERE NOT ADEQUATELY CONSIDERED

NASA did not adequately consider alternative locations before selecting Marshall as the site for construction of the test stands after it determined no existing facilities could meet the SLS Program's requirements. Without adequately assessing alternative sites, NASA cannot ensure it made the most cost-effective decision regarding where to build the stands.

Alternative Analysis for Facility Construction Projects

For facility construction projects with a cost estimate of $10 million or more NASA policy requires a life-cycle cost analysis of alternative approaches to determine the most cost effective option.[12] The analysis should identify and explain the problems and solutions with sufficient detail to make informed decisions and include discussion on the pros, cons, risks, and analyses for meeting project requirements. A life-cycle cost is an estimate of the total cost over the expected design life of a project and includes the cost of planning, design, and construction; energy consumption; periodic replacement of equipment or materials; operations; maintenance; and residual value. Decisions on program-funded facilities projects are made by the applicable program office in coordination with the NASA Headquarters Mission Support Directorate's Facilities and Real Estate Division.

Inadequate Site and Cost Analysis Completed for Construction of Test Stands

NASA chose to build Test Stands 4693 and 4697 at Marshall without adequately assessing life-cycle costs associated with other possible sites to make the most cost effective analysis. Indeed, Marshall was the only Center the Agency seriously considered for the stands.

Located within the boundaries of the U.S. Army's Redstone Arsenal in Huntsville, Alabama, Marshall has executed test programs for NASA's previous launch vehicles, including Saturn and the Space Shuttle.[13] However, construction of housing along the border of the Arsenal over the past few decades has necessitated a shift of NASA engine testing to test stands at Stennis, which has maintained a buffer zone adequate to protect the neighboring community from the intense sound generated during such testing. Despite this shift, much of the Agency's structural testing, which does not require similar buffer zones, has remained at Marshall.

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[12] NASA Procedural Requirements 8820.2G, "Facility Project Requirements," June 5, 2014.

[13] Redstone Arsenal has served for more than 60 years as the Army's center for missile and rocket programs.

No Alternative Construction Sites Considered for Test Stand 4697

Originally, NASA planned to use existing Marshall Test Stand 4699 to test the SLS liquid oxygen tanks.[14] However, officials subsequently determined Test Stand 4699 was not tall enough and did not have adequate anchors to support SLS load tests and that a new stand would be needed. According to Marshall officials, NASA made the decision in July 2012 to construct the new stand next to Test Stand 4699 to share testing infrastructure and meet the demands of the tight SLS development schedule. However, the SLS Program Office took another year to complete the design and consider how testing would be conducted, and NASA did not issue its request for proposal for construction of the new stand until September 2013. Despite taking more than year to finalize the test stand design, NASA officials did not revisit the location decision, stating the schedule did not allow for additional analysis. In our judgment, NASA had adequate time to conduct additional analysis between July 2012 and September 2013. Moreover, without this analysis we cannot determine whether NASA made the most cost effective decision regarding Test Stand 4697.

Only Construction Sites at Marshall were Seriously Considered for Test Stand 4693

Similarly, of three possible construction sites – one at Stennis and two at Marshall – NASA officially considered only the two Marshall locations for testing the structural integrity of the SLS's liquid hydrogen tank.[15] Although teams from both Marshall and Stennis proposed designs for possible test stands, only the Marshall designs were reviewed and listed as possible alternatives at the final decision review.[16] According to Marshall personnel, the Stennis design was eliminated because it would have cost 23 percent more than the highest-priced Marshall design – $39 million compared to approximately $30 million. However, this analysis was not documented in 2012 and had to be recreated by the SLS Program Office for our audit. Even if we assume the recreated analysis is accurate, most of the increase related to differences in the design and the teams' assumptions about other costs associated with the testing rather than to location. The long-term maintenance costs of the designs were not documented and could have significantly impacted the cost comparison.

Further, Marshall personnel stated the design ultimately chosen could accommodate different sized test articles and therefore provided more flexibility to accommodate testing of articles other than the SLS tank. However, no analysis was performed to determine if the Marshall design could have been constructed elsewhere. Although NASA officials noted that constructing Test Stand 4693 at Marshall enabled the reutilization of a previously built foundation, a significant amount of rework to the

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[14] Test Stand 4699 was originally constructed in 1967 to support Saturn V testing, and NASA plans to use the stand to test part of the SLS upper stage.

[15] Although NASA briefly considered Michoud as a possible site for the test stand, the location was quickly deemed unacceptable because of technical risks.

[16] Agency personnel stated that Marshall has long been recognized as the primary center for launch vehicle structural testing and cited this as a reason for constructing the test stands at Marshall. However, this explanation does not supersede NASA policy related to evaluation of alternatives and documenting the rationale for site selection. Further, the Agency made strategic decisions in November 2015 and October 2016 related to Marshall's role in propulsion testing; however, these decisions were made well after the construction contracts were awarded and construction for Test Stands 4693 and 4697 was underway.

foundation was necessary to support the new test stand, affecting the cost savings actually achieved. Further, because the Agency did not provide any evidence that a life-cycle analysis was completed, the actual cost savings compared to the cost of other potential sites could not be determined.[17] In our view, once the design that best met the SLS Program's needs was chosen, the Agency should have determined the most cost efficient location to build based on analysis of all potential locations.

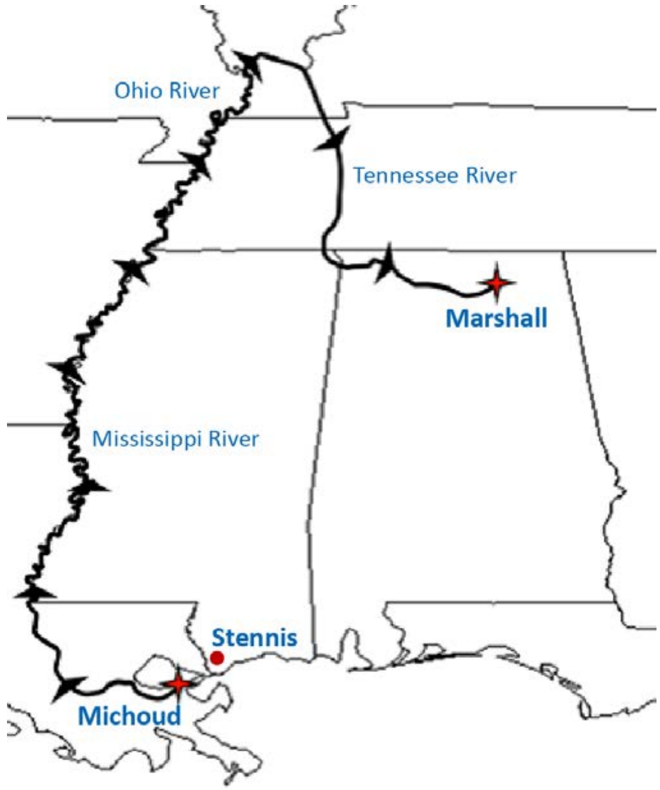
No Evidence that Life-Cycle Costs Were Considered as Part of the Construction Site Selection Process

Contrary to both NASA and Federal guidance, Agency personnel could not provide evidence that NASA considered the life-cycle costs associated with the selection of the Marshall site.[18] Although Agency personnel stated that life-cycle costs were considered as part of the construction site selection process, they could not provide any evidence of this assertion and could not explain why life-cycle costs were not documented in accordance with Agency policy. As a result, we question whether such costs as transporting the tanks to Marshall from Michoud were adequately considered as part of the Agency's analysis. This approximately 1,240-mile trip will entail shipment by barge along the Mississippi River, the Ohio River, and finally the Tennessee River; take about 2 weeks; and cost approximately $500,000 per tank (see Figure 6 below). Because each tank will need to be transported separately and the barge will need to return to Michoud between loads, the total transportation time for both tanks is 6 weeks. In contrast, transporting a tank from Michoud to Stennis would take less than one week and cost approximately $200,000.

[17] The SLS Program Office reviewed construction cost estimates as part of the Agency's analysis of alternatives; however, construction costs are only a part of the life-cycle costs of testing.

[18] Office of Management and Budget Circular A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," October 29, 1992.

Figure 6: NASA's Barge Water Route from Michoud to Marshall



Source: NASA.

The SLS Program funded construction of the Test Stands 4693 and 4697 to meet its near-term needs. However, after the SLS Program testing is complete NASA will have to maintain the stands if they are to be used in the future. Without a thorough analysis of alternative construction sites, including complete life-cycle cost analysis to include operations and maintenance costs, as well as transportation of test articles through the expected useful life of the stands, it remains unclear whether NASA made the most cost effective decision for the Program and the Agency in the long run.

CONCLUSION

To meet its ambitious schedule of an initial SLS launch in December 2017, NASA designed and initiated construction on Test Stands 4693 and 4697 based on preliminary testing specifications and before test stand requirements and capabilities were fully understood. As a result, the cost of the stands increased by $35.5 million from an original estimated cost of $40.5 million. More than $7.6 million of this additional expense was a premium to expedite construction to meet a deadline that only 3 months after contract award was extended by a year. Although NASA officials told us the contractor agreed to take this premium payment into consideration when developing its costs for subsequent contract modifications, neither NASA nor the OIG could quantify how much of the approximately $7.6 million the Agency recouped in the form of reduced costs for the modifications. Additionally, NASA modified the contract multiple times for a total increase in cost of approximately $20.3 million to meet changing requirements. We question the cost-effectiveness of one of these changes – the way in which the crosshead is moved – given that NASA failed to solicit bids for the design change and it is unclear how often the crosshead will be moved to accommodate testing. Finally, NASA failed to establish adequate funding reserves to cover anticipated contract and requirement changes or adequately document consideration of alternative sites for the testing. In short, rushing the decision regarding the test stands to support a December 2017 first flight raised the cost of constructing the stands by tens of millions of dollars.

RECOMMENDATIONS, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

To improve the decision-making process for construction of test stands and facilities, we recommended NASA's Assistant Administrator for Strategic Infrastructure:

1. Perform a comprehensive review of Program-funded construction projects to ensure adequate analysis, including all life-cycle costs, is completed prior to project initiation.

2. Develop additional construction project guidance for establishing unallocated construction reserves for program-direct construction facility projects to better account for significant expected risks.

In addition, we recommended NASA's Associate Administrator for Human Exploration and Operations:

3. Ensure facility needs, such as construction of new facilities and/or modification of existing facilities, are appropriately included in program planning and scheduling and that testing requirements are adequately understood prior to committing the Agency to construction or modification of test facilities.

We provided a draft of this report to NASA management, who concurred with each of the recommendations and described corrective actions the Agency plans to take. We consider management's comments to Recommendations 1 and 2 responsive; therefore, these recommendations are resolved and will be closed upon verification and completion of proposed actions.

Although NASA management concurred with Recommendation 3, the Agency's response did not adequately address the intent of the recommendation. NASA Management agreed that modifying existing facilities or constructing new facilities to meet a specific program requirement should be included in program planning, and the driving requirements for those efforts should be clearly understood prior to committing Agency resources. However, the Agency considered this action to be complete since program planning and scheduling requirements are identified in "NASA Space Flight Program and Project Management Requirements," NASA Procedural Requirements (NPR) 7120.5E. We disagree. NPR 7120.5E, originally issued in 2012, was in place prior to the start of the test stand construction effort examined in this audit. As such, it was insufficient to prevent the concerns identified in this report and further action is needed to ensure the issues do not reoccur in future projects. Therefore, this recommendation remains unresolved pending further discussion with Agency officials.

Management's comments are reproduced in Appendix C. Technical comments provided by management have also been incorporated, as appropriate.

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

Major contributors to this report include Laura Nicolosi, Mission Support Director; Karen VanSant, Project Manager; Troy Zigler; Rebecca Carpenter; Michael Beims; Sarah McGrath; and Matthew Ward.

Appendix A: Scope and Methodology

We performed this audit from July 2016 through May 2017 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.

We reviewed Federal and NASA policies, regulations, and plans to determine the criteria for identifying and assessing the Agency's construction and infrastructure requirements. The documents we reviewed included the following:

- Office of Management and Budget Circular A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," October 29, 1992
- NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements," August 14, 2012
- NASA Interim Directive 7120.99, "NASA Information Technology and Institutional Infrastructure Program and Project Management Requirements," December 22, 2011
- NASA Policy Directive (NPD) 8800.14E, "Policy for Real Estate Management," June 3, 2015
- NPR 8800.15C, "Real Estate Management Program," October 30, 2014
- NPD 8810.2A, "Master Planning for Real Property," December 2009
- NPD 8820.2D, "Design and Construction of Facilities," July 2013
- NPR 8820.2G, "Facility Project Requirements," June 2014
- NPR 8831.2F, "Facilities Management and Operations Management," October 7, 2015
- Marshall Procedural Requirements 8823.1E, "Design Control of Facilities," May 23, 2014

We interviewed NASA Headquarters and Center officials concerning the construction and requirements for the test stands, including officials responsible for the construction and operation of test facilities and the SLS Program at Marshall Space Flight Center, as well as officials from the Corps of Engineers, the NASA Headquarters Mission Support and Human Exploration and Operations Mission Directorates, and the Rocket Propulsion Test Program Office at Stennis Space Center. We also reviewed contract documentation as well as various Agency studies concerning planning and construction of the test stands.

Use of Computer-Processed Data

We relied on computer-processed data that tracked communications that clarified details of expected work. These communications between the Corps of Engineers, NASA, and the Contractor are tracked in a database and we were supplied an extract of that data. If we had any questions with the tracked communications, we verified the information with officials from the Corps of Engineers and NASA and from other relevant contract information. The communications appeared adequate for their purpose and we evaluated the reliance on this data as a low audit risk. From these efforts, we believe the information we obtained is sufficiently reliable for this report.

Review of Internal Controls

We reviewed and evaluated internal controls related to NASA's management of test stand construction at Marshall Space Flight Center in support of the Space Launch System. This included assessing the Marshall's compliance with the Agency's internal control requirements. We concluded that the Program's internal controls, except for those practices discussed in the report, complied with Agency requirements and were adequate to manage technical, schedule, and cost risks. The internal control recommendations discussed in the report, if implemented, should correct the weaknesses identified.

Prior Coverage

During the last several years, the NASA OIG and the Government Accountability Office (GAO) have issued 11 reports of significant relevance to the subject of this report. Unrestricted reports can be accessed at https://oig.nasa.gov/audits/reports/FY17 and http://www.gao.gov, respectively.

NASA Office of Inspector General

NASA's Management of the Orion Multi-Purpose Crew Vehicle Program (IG-16-029, September 6, 2016)

NASA's Decision Process for Conducting Space Launch System Core Stage Testing at Stennis (IG-14-009, January 8, 2014)

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

NASA's Infrastructure and Facilities: An Assessment of the Agency's Real Property Leasing Practices (IG-12-020, August 9, 2012)

Review of NASA's Plan to Build the A-3 Facility for Rocket Propulsion Testing (IG-08-021, July 8, 2008)

Government Accountability Office

NASA Human Space Exploration: Delay Likely for First Exploration Mission (GAO-17-414, April 2017)

NASA Human Space Exploration: Opportunity Nears to Reassess Launch and Ground Systems Cost and Schedule (GAO-16-612, July 2016)

Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk (GAO-15-596, July 2015)

Space Launch System: Resources Need to be Matched to Requirements to Decrease Risk and Support Long Term Affordability (GAO-14-631, July 2014)

NASA: Actions Needed to Improve Transparency and Assess Long-Term Affordability of Human Exploration Programs (GAO-14-385, May 2014)

Federal Real Property: National Strategy and Better Data Needed to Improve Management of Excess and Underutilized Property (GAO-12-645, June 2012)

Appendix B: Summary of Cost Increases, Including Costs Questioned by OIG

The following table summarizes the increased costs identified during our audit and discussed in this report (see discussion of added costs starting on page 7). Since these increases were due to NASA's schedule and requirements changes as discussed in the report, these costs are not recoverable from the contractor.

Additional Cost for 4693	Amount of Cost Increase	Amount Questioned by OIG[a]
Additional Contract Estimate Due to Compressed Schedule (recognized prior to contract award)	**$7,600,000**	**$7,600,000**
Additional Costs of Design Modifications (Post-Award)	**$2,918,362**	**$0**
• Change in specifications for steel beam connections (4693)	$880,000	--
• Increased weight requirements for truss and roof systems (4693)	$625,422	--
• Routine type changes in design or assumptions (covers multiple contract modifications) (both test stands)	$1,412,940	--
Changes Due to Maturing Requirements (Post-Award)	**$12,154,501**	**$11,968,500**
• Mounting of Testing Interface on Crosshead (4693)	$186,001	--
• Change Lifting Capability to Support Increased Weight of Test Articles (4693)	$217,193	$217,193
• Increased Size of Strand Jacks (4693)	$338,790	$338,790
• Additional Support for Crosshead (4693)	$7,150,000	$7,150,000
• Strengthening test stand to Support Simultaneous Vertical and Horizontal Stresses (4697)	$4,262,517	$4,262,517
Planned Change for Movable Crosshead (Post Award)	**$5,146,509**	**$5,146,509**
Administrative Change for Trailer Applicable to Both Test Stands (Post-Award)	**$35,401**	**$0**
TOTAL INCREASED CONTRACT COST (Post-Award)[b]	**$20,254,773**	**$17,115,009**

Source: OIG analysis of data provided by NASA and the Corps of Engineers.

[a] Questioned costs are expenditures that are questioned by the Office of Inspector General because of an alleged violation of legal, regulatory, or contractual requirements, are not supported by adequate documentation at the time of the audit, or are unallowable, unnecessary, or unreasonable.

[b] Totals include only post award increases in the contract. The totals do not include the estimated $7.6 million premium that was prior to the contract award.

APPENDIX C: MANAGEMENT'S COMMENTS

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

May 12, 2017

Reply to Attn of: Human Exploration and Operations Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Human Exploration and Operations
Assistant Administrator for Strategic Infrastructure

SUBJECT: Agency Response to OIG Draft Report, "Construction of Test Stands 4693 and 4697 at Marshall Space Flight Center" (A-16-016-00)

NASA appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "Construction of Test Stands 4693 and 4697 at Marshall Space Flight Center" (A-16-016-00), dated April 13, 2017.

In the draft report, the OIG makes three recommendations to the Associate Administrator for Human Exploration and Operations and the Assistant Administrator for Strategic Infrastructure intended to improve the decision-making process for construction of test stands.

Specifically, the OIG recommends the following:

To improve the decision-making process for construction of test stands and facilities, the OIG recommends NASA's Assistant Administrator for Strategic Infrastructure:

Recommendation 1: Perform a comprehensive review of Program-funded construction projects to ensure adequate analysis, including all life cycle costs, is completed prior to project initiation.

Management's Response: NASA concurs. NASA will strengthen the requirement for life-cycle cost analysis for Program-funded projects and budget estimation at project initiation. NASA notes that for these specific projects the Agency believes adequate analysis was performed to ensure these projects were absolutely required, and that improved life cycle analysis for Program-funded construction projects can contribute to well-considered future Agency decisions. Guidance will be developed and incorporated into the next revision of "Facility Project Requirements," NPR 8820 which expires June 2019.

Estimated Completion Date: July 31, 2019

Recommendation 2: Develop additional construction project guidance for establishing unallocated construction reserves for program-direct construction facility projects to better account for significant expected risks.

Management's Response: NASA concurs. NASA will strengthen the use of Project Definition Rating Index (PDRI) during design and develop recommendations for contingency reserves informed by PDRI scores. The PDRI identifies and precisely describes each critical element in a scope definition package and allows for the determination of factors impacting project risk. It is intended to evaluate the completeness of scope definition at any point prior to the time a project is considered for development of construction documents and construction. Additional guidance and processes will be developed and incorporated into the next revision of NPR 8820 which expires June 2019.

NASA's experience in managing projects, including test stand construction, taught us that, while having contingency funds available is critical, it can also remove the incentive for saving money. We have found that when managing to a tight budget, managers will work very hard to seek innovative solutions as problems are encountered. A greater contingency could lead to an incentive to spend all of the money versus trying to save as much as possible. Therefore we request that the OIG note that the NASA Mission Directorate programs typically maintain unallocated reserves outside of the Agency's Construction and Environmental Compliance and Restoration (CECR) account for construction contingency. These reserves could be transferred into the CECR account as needed (i.e., for cost growth of a construction project) through mechanisms such as an Operating Plan change or a Congressional notification. Maintaining this reserve outside of the CECR account enables greater flexibility for the mission directorates due to the Congressionally imposed transfer authority limits. Specifically, mission directorate program funds that have been transferred into the CECR account for a construction project and converted to six-year funds and, ultimately, not needed may not be transferable back to the mission as the funds revert back to two-year funds and may have expired. We believe that strengthening the use of PDRI may mitigate the need for these unanticipated transfers to/from the CECR account for contingency management.

Estimated Completion Date: July 31, 2019

In addition, the OIG recommends NASA's Associate Administrator for Human Exploration and Operations:

Recommendation 3: Ensure facility needs, such as construction of new facilities and/or modification of existing facilities, are appropriately included in program planning and scheduling and that testing requirements are adequately understood prior to committing the Agency to construction or modification of test facilities.

Management's Response: NASA concurs. Modifying existing facilities or constructing new facilities to meet a specific program requirement should be included in program planning, and the driving requirements for those efforts should be clearly understood prior to committing Agency resources. This action is completed as program planning and scheduling requirements are identified in "NASA Space Flight Program and Project Management Requirements," NPR 7120.5E.

Estimated Completion Date: Completed

We have reviewed the draft report for information that should not be publicly released. As a result of this review, we have not identified any information that should not be publicly released.

Once again, 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 on (202) 358-1574.

William H. Gerstenmaier

Calvin F. Williams

cc:
MSFC/Mr. May

APPENDIX D: REPORT DISTRIBUTION

National Aeronautics and Space Administration

Acting Administrator
Acting Deputy Administrator
Associate Administrator for Human Exploration and Operations
Associate Administrator for Mission Support
Assistant Administrator for Strategic Infrastructure
Director, Marshall Space Flight Center
Program Manager, Space Launch System

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 Competitiveness

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-16-016-00)