NASA Case Study *MSFC-CS1003-1*
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SLS Test Stand Site Selection

Finding a Field for Green Running

Test site selection is a critical element of the design, development and production of a new system. With the advent of the new Space Launch System (SLS), the National Aeronautics and Space Administration (NASA) had a number of test site selection decisions that needed to be made early enough in the Program to support the planned Launch Readiness Date (LRD).

This case study focuses on decisions that needed to be made in 2011 and 2012 in preparation for the April 2013 DPMC decision about where to execute the Main Propulsion Test that is commonly referred to as "Green Run." Those decisions relied upon cooperative analysis between the Program, the Test Lab and Center Operations.

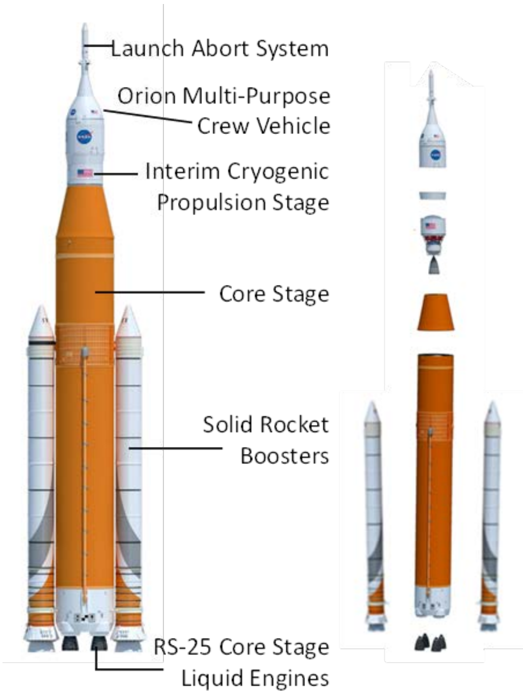

Figure 1 SLS Vehicle (Block 1) by Elements (NASA)

The SLS is a human spaceflight vehicle designed to carry a crew farther into space than humans have previously flown. The vehicle consists of four parts: the crew capsule, the upper stage, the core stage, and the first stage solid rocket boosters. The crew capsule carries the astronauts, while the upper stage, the core stage, and solid rocket boosters provide thrust for the vehicle. In other words, the stages provide the "lift" part of the lift vehicle. In conjunction with the solid rocket boosters, the core stage provides the initial "get-off-the-ground" thrust to the vehicle. The ignition of the four core stage engines and two solid rocket boosters is the first step in the launch portion of the mission. The solid rocket boosters burn out after about 2 minutes of flight, and are then jettisoned. The core stage provides thrust until the vehicle reaches a specific altitude and speed, at which point the core stage is shut off and jettisoned, and the upper stage provides vehicle thrust for subsequent mission trajectories.

The integrated core stage primarily consists of a liquid oxygen tank, a liquid hydrogen tank, and the four core stage engines. For the SLS program, four RS-25 engines were selected as the four core stage engines. The RS-25 engine is the same engine that was used for Space Shuttle.

The test plan for the integrated core stage was broken down into several segments: Component testing, system level testing, and element level testing. In this context, components are items such as valves, controllers, sensors, etc. Systems are items such as an entire engine, a tank, or the outer stage body. The core stage itself is considered to be an element. The rocket engines are also considered an element. At the program level, it was decided to perform a single green run test on the integrated core stage prior to shipment of it to Kennedy Space Center (KSC) for use in the EM-1 test flight of the SLS vehicle. A green run test is the first live fire of the new integrated core stage and engine elements – without boosters of course.

The SLS Program had to decide where to perform SLS green run testing.

Propulsion Testing at NASA

Historically, NASA's larger rocket and motor program infrastructure support has been generational. For example, the Apollo program spanned from the 1950s to the 1970s, with infrastructure development at Marshall mainly in the 1960's. Marshall's infrastructure was modified to also support the Shuttle program. Infrastructure work at Stennis Space Center (SSC) began in 1961 when it was known as the Mississippi Test Facility. The site was also named the Mississippi Test Operations and the National Space Technology Laboratories until 1988 when it was renamed for Mississippi senator and space program supporter John C. Stennis.

The test stands at SSC supported the Apollo/Saturn, and Shuttle programs. Much of the infrastructure needed to test Shuttle propulsion was designed and developed in the early years of the Shuttle program in the 1970s. During the early Shuttle period, the Agency had very limited data processing capabilities and learned much about applied physics relating to large rockets from the first Shuttle launch. Shuttle testing and development continued from the 1970s to the early 2000s, first at Marshall and then at Stennis. Shuttle propulsion testing was moved to Stennis around 1996. The Agency started to significantly reduce the quantity and expense of test support facilities to control costs as the Shuttle program drew to a close.

In interim years, between programs, maintenance of test facilities fell mostly upon Center Maintenance and Operations (CM&O) funding since program testing was complete. Starting around 2004, the Agency began to make a number of strategic decisions to help reduce the CM&O infrastructure cost after Shuttle. These decisions impacted the Solid Rocket Booster

(SRB) facilities and many others across MSFC, Santa Susanna Field Laboratory, and contractor facilities.

SLS facility decisions were made with insight from experience gained through support of the Constellation Program and the Ares project. The initial baseline for SLS was that the same tests envisioned for Constellation would be needed, since the rocket and missions were similar. SLS considered using the MSFC stand for main propulsion testing.

Running the Options

Once the number of hot-fires for the integrated core stage had been selected, the next step in the process was to select a test site. The decision process involved examination of several factors:

1. The enveloping characteristics of the integrated core stage, which encompasses core stage characteristics such as length, diameter, weight, static loads, and dynamic load interface locations, etc.
2. Loads: The overall loading applied by the integrated core stage to the test facility by weight, thrust generated, and thermal interactions
3. Resource capabilities: Evaluation of the test facilities ability to supply propellants, purges, water, and power to the core stage during the hot-fire testing
4. Personal and group access plus coordinated use by various people from program and support areas
5. Environmental impacts related to conducting the core stage test fire
6. Center Missions
7. Political impacts
8. Costs
9. Schedule availability
10. Risk
11. Transportation and ground support requirements
12. Infrastructure impacts

Very early in the decision process, the decision team discovered that there were only three facilities in the U.S. that had the potential to meet the needs of the core stage testing program: The Air Force Research Lab (AFRL) Test Facility L 1-125 1C located at Edwards AFB (not shown), the Saturn V Test Stand located at MSFC, and the B-Complex Test Stands located at SSC shown in Figures 2 and 3. The next step taken by the decision team was to determine what modifications would have to be made at each location in order to bring the specific facility capabilities into alignment with the core stage testing program needs. In this arena, each site was facing a different set of obstacles.

Air Force Research Lab (AFRL)

AFRL was operating in an inactive standby mode. Initially, AFRL could not support the SLS schedule. But with additional discussion, it was concluded that schedule requirements could be supported. Parties agreed that, following standard AACE (Association for the Advancement of Cost Engineering, now AACE International) practices for the initial Rough Order of Magnitude (ROM) that was prepared to bring the facility up to par with program expectations, an adjustment range of 35 percent to 70 percent uncertainty was within the realm of possibility.

It was also felt that the SLS design was in a fairly young stage and reliance on previous positions of Constellation and Ares would be beneficial. There were significant transportation challenges to move the core to AFRL for testing. Initial estimates included 5 days of ground transportation from the port to AFRL, but a transportation risk assessment was not completed.

Marshall Space Flight Center

At MSFC, it had been more than a decade since the MSFC propulsion test team had performed a full scale engine test, and several decades since the last full scale stage test, which was the Saturn V first stage, as shown in Figure 1. The MSFC stand was listed as “mothballed” and needed more than just mechanical modifications. Many years of minimized maintenance and upkeep meant that restoration of the facilities to baseline operable conditions was required. In fact, at the end of the Ares project, the entire West Test Area at MSFC had been mothballed, eliminating even preventative maintenance on it. Adding to the cost uncertainty, MSFC staff ceilings and attrition threatened the Center’s ability to provide full-time equivalent (FTE) civil service labor support.

In addition, performing the test at MSFC created logistical obstacles as the SLS program had created a Concept of Operations that required the RS25 engines as individual units to be assembled and tested at SSC in Mississippi, near Slidell, Louisiana; and the fabrication, assembly, stage-to-engine integration to be performed at Michoud Assembly Facility (MAF) in New Orleans, Louisiana. The core stage test tests the entire assembly of engines and propellant tanks in one test. This would mean that the operational portion of the cost estimate for the SLS core stage hotfire test would have to include the cost to transport the core stage by barge from MAF to the MSFC dock located on the Tennessee River.

Acoustical noise would impact new housing areas and schools closer to MSFC. The program analyzed the acoustical impacts, which indicated that the sound of rocket testing off the test site would affect nearby residents, rattling of windows and possibly other impacts. This would increase the number of damage claims due to population increase and urban encroachment.

Figure 2 MSFC Saturn V Test Stand with Saturn V First Stage being lifted into place

Figure 3 SSC B-Complex Test Facilities with propellant delivery barge in foreground

Stennis Space Center (SSC)

At SSC, the test stand status was “mothballed/ abandoned.” Previous static firings of first stages were conducted in the B-2 test position “B” Dual Position Test Stand for acceptance testing from early spring 1967 through early fall 1970. Fifteen S-IC static firings were conducted for a duration of about 1875 seconds. Testing at the B-2 for the Delta Common Booster Core Program was completed in FY2001.

To meet current program requirements, there were upgrades and repairs expected with the Booster Support Frame itself, various platform designated numbered levels (11, 8, and 7) characterized as both static and dynamic, the Aspirator and Flame Deflector. Test stand changes were anticipated for structural considerations relating to physically handling and maneuvering the core, structural support, and expected thrust. The Rocket Propulsion Test Program Office resides at SSC, and SSC is a short distance by barge from Michoud Assembly Facility where the SLS Core stage is assembled.

The independent cost estimate noted that 6 months of schedule margin for this magnitude of a project was tough and needed to be managed closely. The cost estimate grew through assessing various risk scenarios. Despite the unique challenges faced by each center, according to the Exploration Systems Development (ESD) B-2 Assessment, the cost estimates for performing the SLS core stage hotfire test at SSC was based upon a 2-year period of study. This was far longer than the time spent developing the other potential site cost estimates.

Early in the evaluation, the estimates were considered approximately the same at both MFSC and SSC. Additional project definition and refinement separated the cost estimates by about $100 million, with SSC being higher.

Another consideration for site selection was the Agency Level 0 strategic goals for capability alignment and maintenance cost reduction. For propulsion purposes, this task fell under the purview of the Rocket Propulsion Test Management Board (RPTMB), which managed the propulsion testing capabilities for the entire Agency. The RPTMB directed the use of the available facilities. The Agency made a strategic decision that SSC would be the NASA center for technical excellence in hot-fire propulsion testing.

The SLS program's assessment is based on cost, schedule, and risk impacts to the program as well as the maturity of the data provided. Another aspect of the decision assessment considered NASA's strategic decisions to align capabilities across the Centers and not duplicate costly facilities. Chart 1 shows the cost comparison for the three options as of April 2012. Since the test stand estimate costs where not known due the immaturity of the design, all the lower factors are shown as the same for each program. The uncertainty in the given estimates was very high, due to maturity of the SLS Program producing many unknowns.

- Are there other evaluation factors that should be considered?
- What factors are most important to you as the Program representative? The Test Lab representative? The Center Ops representative?
- Do you weight initial cost advantages of MSFC over SSC or logistics and strategic Agency level institutional alignment for selection of Core Stage green run testing?
- What site would you select?

Partial Test Stand Estimate Comparison Overview

Test Location	AFRL TS 1-125 1C	MSFC 4670	SSC B2	Independent Cost Estimate of SSC B2
Estimate Fidelity	3 Week Est. based on 3 large project est. in last 3 yrs	1 Week Est. Leverages CxP work done for J2X MPTA	2 yrs of Study	One Month Analysis
Test Stand Status	Active Standby	Mothballed	Mothballed / Abandoned	N/A
Facility and Test Costs	$158M	$92.5M	$191M	$246.3 M
FTE	Included in estimate	Included in estimate	89	89
STE	$ 28.3M	$ 28.3M**	$ 28.3M	$ 28.3M
Risk*	$ 58.4M	$ 58.4M***	$ 58.4M	$ 58.4M
Boeing	$ 74.0M	$ 74.0M**	$ 74.0M	$ 74.0M
Center Core Mission	NA	No	Yes	NA
Transportation Requirements	Significant Barge Operations	Significant Barge Operations	Near Production	NA
Total	$318.7M	$250.7M	$ 351.7M	$407.0M

*Some risk only applied to SSC but were left in the other estimates as representative of site specific risks until further analysis can be completed. Examples: impact of B1 testing, use of J-hook to lift test article.

** SLS is working with ICE to determine if some costs are being double-booked.

*** Risks could change because there is another 1.5 to 2 years more requirements definition before start.