MARSHALL SPACE FLIGHT CENTER,
SATURN VS-IC ~~SATURN V~~ STATIC TEST FACILITY
(Advanced Engine Test Facility)
(Marshall Space Flight Center,
Building No. 4670)
Redstone Arsenal
West Test Area
Huntsville Vicinity
Madison County
Alabama

HAER No. AL-129-K

BLACK & WHITE PHOTOGRAPHS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
Department of the Interior
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Washington, DC 20013-7127

ADDENDUM
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HAER ALA,45-HUVI.V,7K-
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PHOTOGRAPHS

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HISTORIC AMERICAN ENGINEERING RECORD

MARSHALL SPACE FLIGHT CENTER, SATURN S-1C STATIC TEST FACILITY
Advanced Engine Test Facility
(Building No. 4670, Marshall Space Flight Center)
(Facility 4670, Marshall Space Flight Center)

Location:	On Rte. 565 between Huntsville & Decatur. Madison Quadrangle, UTM 16. 531059. 3832160
Date of Construction:	1965
Builder/Fabricator	N.A.S.A.
Present Owner:	N.A.S.A.
Present Use:	Rocket Engine Development
Significance:	Engineers used the S-1C Test Stand to help develop the S-1C booster stage of the Saturn V rocket, and to test and qualify the stage's developing design. The tests conducted on the S-1C Test Stand also, however, validated the arrangements between NASA's engineers at MSFC and those of its major contractor for the rocket engine stage, The Boeing Aircraft Corporation, who together designed and built the S-1C rocket engine stage. The test stand was later used to test the External Tank and for the development and acceptance of the original and improved versions of the Space Shuttle Main Engines.

Project Information

Documentation of the S-1C Test Stand is part of the Historic American Engineering Record (H.A.E.R.), a long range program devoted to the documentation of the engineering and industrial heritage of the United States. The H.A.E.R. program is administered by the National Park Service. This project was funded by the Facilities Office of Marshall Space Flight Center (MSFC), with the assistance of Melvin D. Mckinstry, Master Planning Team Lead at MSFC.

Field work, measured drawings, and this historical report were prepared under the general direction of Richard O’Connor, Chief of H.A.E.R. The project was managed by Thomas M. Behrens, H.A.E.R. Architect; Historian, Douglas Jerolimov, University of Virginia; and John Wachtel, Architect.

ACKNOWLEDGEMENTS

This project would not have been possible without the help and support of our hosts at NASA's George C. Marshall Space Flight Center (MSFC). I am especially indebted to Mike D. Wright, NASA Historian, and Molly Porter, Archivist, both at the MSFC History Office.

We also acknowledge the help of Ron Tepool, test engineer at MSFC, for his many explanations of how tests were conducted at the S-1C Engine Test Stand.

Other Archivists also provided invaluable assistance in finding documents. We thank Anne Coleman, Archivist at the M. Louis Salmon Library's Special Collections, University of Alabama-Huntsville. We also thank Liz Suckow, Archivist at NASA's History Division in Washington, D.C.

Douglas Jerolimov

Project Historian

July 2013

Resource Description

The S-1C Static Test Stand, a towering steel-and-concrete structure used to hold down the Apollo Program's Saturn V rocket launch stage while NASA's engineers fired its enormous rocket engines, is located in the West Test Area at the Marshall Space Flight Center in Huntsville, Alabama. The structure sits among numerous vessels that stored pressurized gases and cryogenic liquids to fuel tests of the S-IC launch stage and, later, those of the Space Shuttle's External Tank (ET) and the Space Shuttle Main Engine (SSME). The test stand's outline encompasses four massive, reinforced-concrete piers, aligned in a square configuration. In addition to providing the foundational support for the structure, the interior of the piers house personnel support spaces, terminal rooms, staircases in the northwest and southwest piers and elevator shafts in the northeast and southeast piers. Each pier is an approximate 48-foot square at the base, hollow inside with approximately 4-foot thick walls. The piers are set approximately 68 feet apart from their opposing piers. The outside faces taper in as they rise in elevation and the inside faces remain parallel to the adjacent, opposing piers, rising vertically until the perimeter of the piers has been reduced to an approximate 30-foot square. The piers terminate at the load platform at 144 feet above the ground level. At this level a steel-truss superstructure is attached to and spans three sets of the piers, leaving the northeast face of the superstructure open to facilitate installation and removal of test articles in the test stand. The elevator shafts and stairs from the northeast and southeast piers continue up through the superstructure, clad with corrugated siding, terminating at the 267-foot level.

On the northeast corner of the northeast tower at the 74-foot level a 150-ton capacity, stiff-leg derrick is mounted on a concrete platform that projects from the base. This crane is used to assist in maneuvering, positioning and hoisting large test articles into and around the test stand. Occupying the entire inner area created by the four piers and opening out on the southwest side of the stand is a sloped, curved, steel flame deflector which redirects the force, flame and plume of test engines from vertical to horizontal, while also cooling itself and dampening acoustics with a massive deluge of water pumped through thousands of holes on its inside face. The flame deflector is supported by high-strength steel truss structures that rest on carriages that can lower their wheels to engage rails and displace the deflector to the southwest exterior of the stand to facilitate different test articles and testing programs. Additionally, at the 267 foot level, on the southeast corner of the superstructure, is a 200-ton capacity, stiff-leg derrick that is used as the primary hoist for the test stand. A major modification still evident from the stand's External Tank testing era is the large-diameter, corrugated, galvanized-steel ducting that wraps around the northwest, northeast and southeast elevations. The ducting was added to supply positive air pressure to the interior of the concrete piers to prevent the possibility of pockets of gaseous hydrogen accumulating in the piers during testing. The test stand was renamed as the Advanced Technology Engine Test Stand when converted back to testing rocket engines, and underwent additional modifications that are still in place, including run tanks mounted at the load platform level to for liquid hydrogen, liquid oxygen and RP-1 rocket fuel, and their associated piping, valves, actuators, sensors, telemetry equipment and work platforms.

Boeing had been used to working with Air Force contracts, working on their own. They had to learn how to deal with Marshall, and work with Marshall, which they had never done before. And we [Marshall] were in those days a pretty proud organization, too, because we knew what we were doing.…Boeing also had a very strong sense of accomplishment up to that point. They knew that they had built large airplanes before, and this [the S-1C Launch Stage] wasn't that much different. …there were some adjustments to make, getting the pecking order straight. –Matthew Urlaub[1]

A History of the S-1C Test Stand at Marshall Space Flight Center

On May 25th, 1961, John F. Kennedy asked Congress to commit funds to send a man to the moon "before this decade is out." Winning the race to land American astronauts on the moon, he argued, should be the United States' response to the successes of the Soviet Union's space program.[2] Kennedy's call to arms, directed this time at the United States' engineers and scientists, was part of a continuing effort to win the world's admiration and allegiance, part of the United States' "Cold War" with the Soviet Union.

The goal required a vehicle capable of lifting "payloads" of unprecedented weight into outer space. To launch such massive payloads from the ground, rocket engineers dedicated the bottom portion of the rocket, to a "booster stage" that would be jettisoned upon completing its task, landing in the Atlantic Ocean and leaving the remaining rocket "stages"—propulsive vehicles in their own right—to propel astronauts the rest of the way to the moon, and back.

NASA created the Saturn V rocket to transport humans to moon, and its "booster stage" would be known as the S-1C Launch Stage. The S-1C's developmental prototypes would be test-fired on the "S-1C Static Test Stand." The specifications of the test stand expressed the decision about whether the flight to the moon would be "direct" or involve some sort of rendezvous in space. Once built, however, the test stand's use revealed that NASA's engineers at the Marshall Space Flight Center (MSFC) took a leading role in the

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[1] Matthew Urlaub, Interviewed by Roger E. Bilstein, 29 July 1975. Available at http://libguides.uah.edu/content.php?pid=272087&sid=2243973.

[2] John F. Kennedy, "Urgent National Needs" (speech to Joint Session of Congress, 25 May 1961), John F. Kennedy Library, Boston, Massachusetts. Also available at http://www.jfklibrary.org/Asset-Viewer/xzw1gaeeTES6khED14P1Iw.aspx.

development of the S-1C launch stage, and used the S-1C test stand to identify and solve design problems.

The Boeing Company, which possessed tremendous expertise in the design and development of aircraft, was called upon to realize the design, and the manufacturing plans and processes that originated among Marshall's engineers. Boeing was responsible for managing production of the S-1C launch stage. That is, Boeing was called upon to make production units of the S-1C launch stage.

An examination of the S-1C test stand's use reveals the dominant relationship of Marshall's engineers to the engineers at Boeing in the prototyping phases of the vehicle design process, and in the planning of manufacturing processes. The last test-firing of the S-1C-T launch stage (the "T-Bird")—the S-1C-T was the developmental prototype of the launch stage, and only meant to be fired at MSFC—also marked the end of the design and prototyping of the launch vehicle. Marshall would soon relinquish control of manufacturing to Boeing—that is, after Marshall's engineers oversaw the manufacture of the first two production S-1C launch stages at Marshall.

A shift of test-fires from the S-1C test stand at Marshall to the S-1C Launch Stages at Mississippi Test Facility's S-1C Test Stand (which was designed and constructed under the supervision of engineers at MSFC, but was operated by Boeing), marked the transfer of complete responsibility for production of the S-1C Launch Stage to The Boeing Company. Subsequent uses of the MSFC's S-1C test stand in testing the Space Shuttle's External Tank (ET), and in testing the development of the Space Shuttle orbiter's Space Shuttle Main Engine (SSME), returned MSFC's engineers to prominence as both the developers of new spacecraft and as test engineers. MSFC's engineers shaped the S-1C test stand to meet the new requirements of the Space Transportation System (STS), also known as the "Space Shuttle Program."

*   *   *

This report will examine the development and uses of the S-1C Test Stand, facility 4670 at the Marshall Space Flight Center. The report will focus on the test stand's use, especially during the Apollo program. It will begin with a discussion of the context within which the S-1C test was created, a discussion of the American decision to enter the race to put humans on the moon, followed by a detailed discussion of the test stand as an artifact. The body of the report will then discuss the three major periods of the test stand's history: (1) The decisions about what "mode" of space travel to reach the moon, and how these decisions shaped the specifications of the test stand itself. Next, (2) the construction and uses of the S-1C Test Stand and, finally (3) a brief discussion of the test stand's use in designing and developing the Space Transportation System (STS) External Tank (ET), and its use to design and develop the Advanced Technology Engine of the Orbiter (the Space "Shuttle").

Background: The Decision to Go to the Moon, NASA, and The Boeing Company

A year after his address to a joint session of Congress, on September 12th, 1962, Kennedy gave a speech at Rice University's football stadium, and presented the goal of a lunar landing "in this decade" to the American people. The speech may have given pause to engineers of the recently created National Aeronautics and Space Administration (NASA), for only a little more than seven years remained in the decade of the 1960s.[3] The United States eventually committed more than $25 Billion to the effort, an enormous amount of money, but money alone did not put astronauts on the moon. It took the nation's full support, and it took expertise the United States would develop while undertaking the design and development of the spacecraft needed to transport astronauts to the moon.

Kennedy himself understood this, stating that "new money cannot solve [the problems of such a mission,] unless every scientist, every engineer, every serviceman, every technician, contractor, and civil servant gives his personal pledge that this nation will move forward, with the full speed of freedom, in the exciting adventure of space."[4] To motivate the American people, Kennedy looked to their most noble aspirations: "We choose to go to moon and do the other things," he said at Rice University, "not because they are easy, but because they are hard."[5]

To address the lack of expertise, especially in rocket engine and rocket stage design, the United States turned to Werner von Braun and the German rocket engineers who came with him to the United States at the conclusion of the Second World War—and who were later in the federal government's employ at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama. These engineers, in turn, looked for help from American contractors with experience building missiles and aircraft for the United States' military services. Until the space program, Americans had brought together their federal government and industry only in time of war. NASA began a peacetime engineering development project of unprecedented scale, collaborating with numerous aerospace companies to build and master the new technologies of propulsion, communication, and computerized control systems, that were needed for spacefaring. NASA employed the expertise of the German engineers at MSFC, to design and develop the Saturn V rocket, especially its systems of propulsion, including that of the S-1C launch stage.

The Saturn V was a three stage rocket of unprecedented complexity, measuring 363 feet in height and weighing 6,500,000 lbs. The payload of humans and equipment—and the additional rocket stages—required that NASA contract for the services of Rocketdyne Corporation to develop two new engines, the J-2 Engine for the second stage of the

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[3] John F. Kennedy, "We Choose to go to the Moon…" (speech given at Rice University, Houston, Texas, 12 September 1962).
[4] Kennedy, "Urgent National Needs" (speech to Joint Session of Congress, 25 May 1961).
[5] Kennedy, "We Choose to go to the Moon…" (speech given at Rice University, 12 September 1962).

Saturn V, and the F-1 Liquid Propellant Rocket Engine (LPRE) for the Saturn V's launch stage.

Generating 1,500,000 lbs. of thrust, the F-1 engine was—until the Soviet Union's developed its RD-170 engine in 1985, which generated 1,777,000 lbs. thrust—the most powerful liquid propellant rocket engine ever flown.[6] The F-1 engine still remains the most powerful rocket engine featuring a single combustion chamber, the RD-170 featured a more complicated staged combustion with four thrust chambers and two preburners.[7] To lift the Saturn V rocket from the ground required the S-1C launch stage carry a cluster of five F-1 engines, which together generated a total of 7,500,000 lbs of thrust. Designing and coordinating the engineering and manufacturing of the S-1C launch stage would require the engineering and managerial skills of von Braun's engineers. It would also require the work and expertise of colleagues at The Boeing Corporation, the contractor selected to build the S-1C Launch Stage.[8]

NASA and The Boeing Corporation

The Saturn V rocket began with the expertise of the German expatriate rocket engineers who conceived and built Germany's V-2 rocket during the Second World War. After the War, these rocket engineers built missiles for the Army Ballistic Missile Agency at Redstone Arsenal in Huntsville, Alabama. At NASA's founding, they entered the employ of NASA with Werner von Braun. But, while they were unmatched in skill and experience at designing rocket systems, they had neither the manufacturing nor development experience of American aerospace firms, nor did they hold the expertise of rocket engine developers in the United States.

To address these deficiencies, NASA selected The Boeing Corporation in December 1961 as the prime contractor to build and to help develop the S-1C launch stage.[9] In turn, NASA and Boeing looked to Rocketdyne Corporation to deliver engines for Saturn V's stages, the F-1 engine for the S-1C launch stage, and the J-2 engine for the S-II stage.[10]

Yet despite contracting with Boeing to build the S-1C launch stage, it was the engineers at NASA's Marshall Space Flight Center who maintained responsibility for the design of the rocket stage itself. NASA's engineering management at MSFC incorporated many of

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[6] George P. Sutton, *History of Liquid Propellant Rocket Engines* (Reston, Virginia: American Institute of Aeronautics and Astronautics, 2006), 303, 505.
[7] Ibid., 505.
[8] Ivan D. Ertel, Roland W. Newkirk, and Courtney G. Brooks, Appendix 7, "Apollo Program Budget Appropriations," *The Apollo Spacecraft: A Chronology* (Washington, D.C.: Scientific and Technical Information Division, Office of Technology Utilization, National Aeronautics and Space Administration, 1969-1978).
[9] National Aeronautics and Space Administration, News Release, "The National Aeronautics and Space Administration will negotiate with the Boeing Co., Seattle, Wash.," December 15, 1961, History Office, Marshall Space Flight Center, Huntsville, Alabama.
[10] Ibid.

Boeing's engineers at MSFC (Boeing already maintained a staff in Huntsville), placing Boeing's engineers under the direct supervision of NASA's engineering managers. Engineers at Marshall directly conducted the early design and development process, employing and supervising Boeing's contractor engineers.[11]

The supervisory relationship of MSFC engineers to the engineers at The Boeing Corporation extended geographically, to the Michoud Assembly Facility, which functioned as a satellite of the Marshall Space Flight Center, manufacturing some parts for, and assembling, the S-1C Launch Stage. The oversight of MSFC engineers even sometimes extended to the manufacturing facilities of Boeing's subcontractors. In spite of Boeing's vast experience in designing and manufacturing aircraft, the engineers at MSFC were the principal engineers of the S-1C Launch Stage and they were often the overseeing design agents for its manufacturing processes—hence, it was the Marshall Space Flight Center that maintained ultimate responsibility for both the design of the launch stage itself and for the design of manufacturing processes used to create the Saturn V's S-1C Launch Stage.

In this context, the S-1C Static Test Stand served as a means for engineers at MSFC to test and "de-bug" their designs, including their manufacturing designs, but also as an instrument of project management. The difficulties in finding solutions to the production problems of the launch stage, and the difficulty of bringing together the launch stage's different elements—such as the F-1 engines and other systems composing the S-1C launch stage—called for an instrument to test the S-1C stage's performance under circumstances closely approximating flight conditions. New project management techniques were also needed to track and supervise the design and development process. The S-1C Static Test Stand, however, performed an essential function: engineers used the test stand to generate the data needed to make—and to gain confidence in—design and production decisions shaping the S-1C launch stage.

The S-1C Engine Test Stand: Origins

The 5 October 1960 issue of the *Marshall Star*, the newsletter of Marshall Space Flight Center, announced NASA's plans to build a facility for static testing the new Saturn launch vehicle in the West Area of MSFC. The facilities were expected to cost $10.8 million. The newsletter included an artist's conception of the envisioned test stand, one showing a booster stage mounted undergoing testing on the test stand. In the artist's conception, an East Area test stand appeared in the background (see Figure 1).[12] The 2 November 1960 issue of the facility newsletter revealed that MSFC selected Aetron division of Aerojet General Corporation, of Covina, California (near Los Angeles), to

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[11] Andrew J. Dunar and Stephen P. Waring, *Power to Explore: A History of Marshall Space Flight Center, 1960-1990*, 86.
[12] "New Static Test Facility," *Marshall Star*, 5 October 1960, p. 1.

"initially perform only the design and engineering phase" of a test stand which was to be used for "captive firing of space boosters in the Saturn class."[13]

In June 1962, Aetron completed the initial drawing package for the "Saturn Static Test Static Test Facility," as it was labeled in the drawings themselves. The test stand was constructed and underwent "checkout" by 8 March 1965.[14] The first test of 9 April 1965 was undertaken on the "test" build of the launch stage, "S-1C-T," with a "great number of [its] parts and installations … made using sketches rather than first class documentation."[15] The original drawings of the test stand appear to have been initially drawn in September 1962, but revised and approved to conform to the structure as it was actually built in April 1965.[16]

S-1C Static Test Stand: Specifications

The size and thrust of the S-1C Launch Stage necessitated an enormous static test facility. The test stand needed to withstand the 7.5 million pounds of thrust generated by the launch stage's 5 F-1 Rocket Engines. To put this into perspective, the S-1C Launch Stage produced at least as much thrust as the totals of NASA's earlier rocket booster stages. The launch stage of the Atlas D/Mercury rocket, for instance, produced 341 thousand pounds force (lbf) of thrust, the Atlas/Agena produced 369 thousand lbf, the Titan II produced 430 thousand lbf. Before the Saturn V, NASA's largest rockets were the Saturn I and Saturn IB, which each featured launch stages that produced 1.296 million lbf of thrust—this is less than the thrust of a single F-1 Engine of the S-1C stage.[17] The Saturn Static Test Facility, Building 4670, would need to test-fire a launch stage that included 5 F-1 Engines, or 7.5 million lbf thrust, more than five times the thrust of earlier NASA launch stages.

A guide to the MSFC's Test Laboratory Facility capacity, published only a month before the structure's drawings were finalized, stated that the stand "has full capability for static firing 7.5 million pound thrust stages for full duration of 150 seconds, and is designed with a potential capability, with minimum modification, of handling larger stages with higher thrust in support of stage acceptance tests and research and development

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[13] "Stand to Be Used for Captive Firing of Space Boosters," *Marshall Star*, 2 November 1960, p. 7.
[14] Karl Heimburg, "Weekly Notes to Wernher von Braun," 8 March 1965, MSFC History Office, George C. Marshall Space Flight Center, Huntsville, Alabama.
[15] William Kuers, "Weekly Notes to Wernher von Braun," 1March 1965, MSFC History Office, George C. Marshall Space Flight Center, Huntsville, Alabama.
[16] See R. P. Lovin [Designer], "Saturn Static Test Facility," Drawing No. 60-09-08, Sheet 3 of 33. April 1965, George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama.
[17] National Aeronautics and Space Administration, *Skylab Saturn IB Flight Manual*, Document NASA-TM-x-70137 (Huntsville, Alabama: George C. Marshall Space Flight Center, September 30, 1972), pp. 1-5.

programs."[18] Ron Tepool, test engineer at Marshall Space Flight Center's S-1C Test Stand from its first firing in 1965, later becoming Branch Chief of the Test Division during the External Tank Structural Test and then Division Chief of the Test Laboratory, stated that the test stand was said to withstand launch stages generating 10 million lbs-force.[19]

The test stand features a steel-and-concrete construction, a steel skeleton atop a four-pillared concrete foundation. The S-1C Static Test Stand rests on a square area of 163 feet on each side, with the structure's pillars at its corners, and with a protruding flame deflector "apron" to deflect the flames of the S-1C launch stage's rocket engines. It is 267 feet at its highest platform, with derricks extending upward to nearly 400 feet. The structure's foundation extended at least 40 feet downward, below the concrete-walled base (below ground), reaching bedrock.[20]

Designers at Aetron hollowed each of the test stand's four concrete and rectangular pillars, using the pillars to enclose ladders, staircases and elevators, and habitable rooms. All of the four pillars rose to the structure's main level (Level 15), at 155 ft. The pillars facing West stop abruptly at Level 15. Upon the pillars facing East were constructed elevator shafts, which allow test engineers and technicians to comfortably reach the structure's highest level, Level 27, at 267 ft. The base of the derricks, which were used to lift and place the launch stage in its test position (and to return the launch stage to the ground after a test), may be found on this level. The test stand is a relatively simple-looking structure because the S-1C launch stage, held its fuel and oxidant in spherical tanks nearby, as well as in its own tanks. That is, the two tanks of liquid oxygen (LOX) and the engine's liquid propellant, a kerosene-based propellant, designated "RP-1," were already within the launch stage itself.

Just as for many of the rocket engine test, visitors to the S-1C Test Stand were captivated by its most visually striking feature, its flame deflector, or "flame bucket," as test technicians and engineers called it. Engineers oriented the launch stage vertically when testing it, just as the rocket would be oriented when beginning astronauts on their flight to the moon. The flame deflector redirected the rocket engines' exhaust from a downward direction to a horizontal direction. Shaped like a playground slide, the deflector rested between the test stand's pillars, directly below the launch stage when mounted into the

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[18] Technical Support Division, Test Laboratory, George C. Marshall Space Flight Center, *Test Laboratory Facilities and Capabilities* (Huntsville, Alabama: George C. Marshall Space Flight Center, January 1, 1966), p. 6.
[19] Ron Tepool, interview with author, 11 March 2013.
[20] Although the available drawings did not reveal the depth to which the columns extended, the S-1C launch stage test stand shares many commonalities with the nearby F-1 Engine Test Stand—except it is much larger and is expected to withstand at least five times the thrust load. Columns of the F-1 engine test stand extend downward 40 feet to bedrock, and it so the larger test S-1C test stand would be expected to extend downward at least to bedrock. See R.A. Zimmerman, "General Arrangement, F-1 Test Facility Test Stand," Drawing No. 60-09-09, Sheet 49 of 172. November 1966, George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama.

test stand. The deflector measures 1 foot in thickness, but is actually of a hollow welded construction, composed of one inch thick steel plate. Internal braces of 1 inch thick steel plate divided the deflector into a manifold of rectangular cells, or tubes.[21]

To prevent the deflector from melting under the exhaust of the 5 rocket engines under test, 300,000 gallons of water per minute, or 668 cubic feet per second (cfs), were forced through the deflector manifold.[22] The amount of water was not supplied from a single source—the East Area Pumping Station supplied about 40,000 gallons of water per minute, while the West Area Pumping Station supplied about 260,000 gallons per minute.[23] To coat and cool that part of the deflector's surface making direct contact with the F-1 rocket engine's flames, the walls of the deflector itself also featured a number of holes—many thousands of holes—through which water was forced. The test stand also included provisions to store addition LOX, RP-1, Nitrogen (GN_2), and Helium (GE_2).[24]

The test-stand also contained telemetry facilities to maintain an enormous flow of data. According to the Test Facilities Handbook, "Data acquisition equipment include[d] 112 Channels of analog tape units, 296 channels of oscillograph recorders, 375 channels of digital systems, 117 channels of strip chart recorders and various additional special instrumentation capabilities."[25] The control center was located in a "blockhouse" near the test stand, yet protected by an earthen bunker. The "engine exhaust gases are directed away from the blockhouse," notes the Test Facilities Handbook, "permitting good visibility during static firing," connected by a control tunnel 8 feet high and 8 feet wide.[26]

General Arrangements Among Nearby Test Facilities

The test-stand structure was nestled among a complex of test facilities and buildings used to support the test operations. S-1C Launch Stage Static Test Tower, Building 4670, was situated near the F-1 Engine Test Stand, Building 4696, and together they were near a number of buildings that supported test-fires at each test stand.

The complex of facilities dedicated to supporting test fires at 4696 and 4670 included a "blockhouse," a site protected by a mound of earth from which engineers and technicians controlled and recorded data derived from stage and engine tests. The blockhouse connected to both test stands through tunnels to each test stand, and the tunnels were used to run cable between the blockhouse and test stands, which also allow individuals to

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[21] See R. P. Lovin [Designer], "Saturn Static Test Facility Deflector: Deflector Elevation Back & Section at Centerline," Drawing No. 60-09-08, Sheet 7 of 33. April 1965, George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama.
[22] Test Laboratory. *Test Laboratory Facilities and Capabilities* (NASA History Office, Marshall Space Flight Center, Huntsville, Alabama, January 1, 1966), 6.

[23] Ibid.
[24] Ibid.
[25] Ibid.
[26] Ibid., 6, 10.

travel between blockhouse and test site. The "Block House," Building 4674, measures 128'(l) x 107'(w) x 44'(h), houses offices, rooms for equipment, instrumentation, and control panels and communications devices.[27]

A "Pump House," Building 4667, may also be found nearby to supply water to the test stands. Building 4667 can pump water to each test stand in the West Area (as well as to test stands in the older East Area) at 260,000 gallons per minute (600 cubic feet per second). This pump station measures 394'(l) x 54'(w) x 59'(h), and contains 13 ALCO Products Inc. diesel engines that ran the water pumps to cool each test stand's flame deflector, to operate the aspirator, and to supply water to fire extinguishing systems. As stated above, the Pump House, however, did not provide enough water for an S-1C Launch Stage test-fire—an additional 40,000 gallons of water per minute were needed, drawn from another pump house.

Building 4667 drew water from two nearby man-made reservoir holding tanks, Facilities 4668 and 4669. These cylindrical, above-ground holding tanks each measure 127 feet in diameter and 80 feet tall, and hold approximately 32,000 cubic feet of water (240,000 gallons) each.[28]

Loading and Testing the S-1C Launch Stage

Two sets of derricks atop the test stand were used to hoist the launch stage to its test position. A cable from a derrick on the test stand's highest level was attached to the forward end of the rocket stage (when fully assembled and upright within a Saturn V rocket). Another cable originating from a derrick that rests on Level 8, at 74 feet in height, was connected to the aft end of the launch stage. In one motion, operators lifted the launch stage while re-orienting the launch stage's central axis from the horizontal to the vertical (see Figure 2). Technicians positioned the assembly into the test stand and began the long process of attaching it to the test stand, setting up instrumentation, and making preparations for test.

Rocket Test-Fire Noise

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[27] Karen J. Weitze, "Appendix B: Buildings and Structures Historic Data Summary," *National Assessment of Marshall Space Flight Center, National Aeronautics and Space Administration* (Huntsville, Alabama: National Aeronautics and Space Administration, February 2007).

[28] Karen J. Weitz, *Historical Assessment of Marshall Space Flight Center, National Aeronautics and Space Administration* (Huntsville, Alabama: Marshall Space Flight Center, National Aeronautics and Space Administration, November 2003), 89.

Rocket engines produce a great deal of noise. Among scientific and engineering investigators, "noise" is understood to be a signal or output that obscures the output or signal of interest to investigators. In common parlance, noise is usually understood as unwanted sound. The sound of a particular tone or frequency, meanwhile, is really just the movement of air that pulses at one frequency (a particular "tone"), or many different frequencies simultaneously (which is often called "static," and which people usually interpret as "noise").

Sound exerts force on all structures that come into contact with its associated variations in air pressure, and thus causes structures to vibrate at the same frequency as the variations in air pressure. But if the frequency of the pulsing air matches the "natural frequency" of a structure, or matches the "natural frequency" of a structure's element, it is said to create a "resonance" in the structure, which is exhibited by disproportionately large deflections in the structure that can cause damage. Shattering some types of windows, for instance, moderately loud sound only needs to be at the window's natural frequency to deflect the glass enough to break glass.[29] The test-firing of an S-1C Launch stage created "noise"—sound at many different frequencies, simultaneously.

The test-fire records of MSFC include records of "Acoustic Claims" filed as a result of the damage caused by rocket engine test firings. In January 1961, for instance, Bruno Helm of Dill Street in Huntsville, filed a claim.[30] In response to the threat of damage as a result of the test firings of the F-1 Engine, and especially that of the S-1C Launch Stage (which carried 5 F-1 Engines), the timing of engine and stage test firings were planned carefully to minimize the travel of sound.

Engineers at MSFC created a system that relied on climatological data to select times at which test-fire noise would travel the least distance into Huntsville and to its surrounding community. A test-horn was sounded before each test, and sound sensors at varying distances around the test stand recorded the sound levels produced from the sounding of the test-horn. Initially, before the S-1C and F-1 Engine Test Stands were built in the "West Area" of MSFC, at least one test firing of the F-1 Engine was postponed at the Static Test Tower, its West position (STTW), located at the MSFC's East Area. Karl Heimburg, Director of Test Engineering at MSFC wrote in his Weekly Notes on 16 December 1963 that "The firings planned for last week were canceled, due to unfavorable sound focus prediction. The estimated noise level at the Parkway Shopping Center would

[29] Wernher von Braun, "Saturn the Giant," in Edgar M. Cortright, ed., Apollo Expeditions to the Moon. Washington D.C.: U.S. Government Printing Office, 1974, 52.
[30] "Acoustic Claims," *History of Static Firings Conducted at Saturn Static Test Facility, 1960-1970: S-1C-T, S-1C-1, S-1C-2, S-1C-3* (4572-SA-T STATIC TEST.pdf). NASA History Office, Marshall Space Flight Center, Huntsville, Alabama, 21.

have been 118 db (Wed., 12/11).”[31] Test Fire Logs reveal that the next test at STTW was conducted on 17 December 1963.[32]

Engineers at MSFC also experimented with a “sound suppression” device—a lengthy tunnel appendage positioned at the flame deflector outlet. It muffled the noise of the test by slowing the velocity of the expanding gases exiting the engine’s nozzle.[33] Engineers at the Marshall Space Flight Center were especially worried about the sound generated by the impending S-1C launch stage static test-fires, because the power of the S-1C launch stage was unprecedented. MSFC engineers also worried about the extent of damage and complaints generated by the F-1 Engine Tests. MSFC officials decided, however, to postpone construction of the “proposed suppressor for the MSFC S-1C,” and they did not include the project in Fiscal Year 1964 “due to lack of funds.”[34] Experimentation continued with the sound suppression devices. However, on 16 and 17 September 1964, engineers at MSFC tested the “sound suppression” device on the H-1 engine, an engine of 205,000 lbf thrust, “to gather sound data for comparison with previous H-1 engine tests” (See Figure 3).[35] Ultimately, however, it seemed that MSFC officers resigned themselves to a reliance on an earlier strategy of waiting for climatic conditions that minimized the projection of sound (noise) from test stands.

According to the records of “Acoustic Claims,” however, the careful timing of tests did not always work. The records of the claims list the names of claimants, dates, and the claimant’s locale (if in Huntsville) or city of residence. There were two claims listed for 1965 (one in November and one in December), 6 claims listed for 1966 (two for March, and one each for May, December, September, and October), and 9 claims for 1967 (two for January, four for February, one each for March, April, and June).[36]

The dates do not generally coincide with the months of S-1C tests, but the dates may actually be the date the claims were filed, or perhaps they were dates the claims were settled. Two of the listed claims, however, specifically reference S-1C tests. An entry was recorded for Elmer Jansen’s claim, with the date listed as December 1966—and an attached note stating, “280° [and] 6 KM from S-1C.” The most recent test to precede that

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[31] Karl Heimburg, “Weekly Notes to Wernher von Braun,” 16 December 1963, MSFC History Office, George C. Marshall Space Flight Center, Huntsville, Alabama.
[32] “F-1 ENGINE TEST - EAST AREA,” Test-Fire Logs, *History of Static Firings Conducted at Saturn Static Test Facility, 1960-1970: S-1C-T, S-1C-1, S-1C-2, S-1C-3* (4572-SA-T STATIC TEST.pdf). NASA History Office, Marshall Space Flight Center, Huntsville, Alabama.
[33] David S. Akens, *History of the George C. Marshall Space Flight Center, From January 1 Through June 30, 1963*. MSFC Historical Monograph No. 7 (Huntsville, Alabama: MSFC Historical Office, November 1963), 138.
[34] Heimburg, “Weekly Notes,” 5 August 1963.
[35] Karl Heimburg, “Weekly Notes,” 21 September 1964, See also Heimburg’s “Weekly Notes” for suppression tests conducted in June 1964. Ibid., 13 July, 20 July 1964.
[36] “Accoustic Claims,” *History of Static Firings Conducted at the Saturn Test Facility, 1960-1970: S-1C-T, S-1C-1, S-1C-2, S-1C-3*. Huntsville, Alabama: History Office, George C. Marshall Space Flight Center. 4572-SA-T STATIC TEST.pdf., 21.

date took place on November 15th, 1966, for a duration of 121.7 seconds. A second entry was recorded for the claim of a "Mrs. Marks," January 1967, with the accompanying note, "320º @ 10 KM from S-1C." The test most recently preceding the listed date is the same S-1C test, that of November 15th, 1966.[37] Test-fires of S-1C Stages at the Mississippi Test Facility would lead to similar damage claims from local residents, despite the site's location in rural Hancock County, Mississippi, on the banks of the Pearl River.[38]

Lunar Landing Mission "Modes" and the S-1C Test Stand

The idea of going to the moon required a decision about the mission "mode"—that is, a planned sequence of events to get to the moon. The decision shaped the design of the S-1C Test Stand because a decision about "mode" also determined the specifications of the launch stage. What amount of thrust should the test stand be able to withstand? What size (diameter) should the test stand be able to hold? The answers to these questions turned on decisions about the mode of travel and the corresponding launch vehicle used to lift the spacecraft and payload from the ground. Three different "modes" of travel to the moon were imagined, two "modes" involved a rendezvous maneuver, either while the astronauts were in orbit around the Earth or in orbit around the Moon. These different rendezvous modes were contrasted with a "direct ascent" mode, which required a larger rocket. The two rendezvous modes were assigned their own acronyms, Earth Orbit Rendezvous or "EOR," and Lunar Orbit Rendezvous or "LOR." Different vehicles were associated with each of the "modes" of travel to the moon.

In 1961, the different kinds of vehicles envisioned to undertake a moon landing changed frequently, reflecting changing ideas about the goals and their associated mission profiles. Changes in mission profiles entailed changes in payloads, in the schedules needed design and produce the different vehicles associated with the payloads, and in the amount of money associated with the different mission profiles. As such, they were widely debated among engineers at MSFC, the Space Task Group (STG) at Langley, and among administrators at NASA's Headquarters in Washington, D.C.

Roger E. Bilstein wrote that, in January 1961, the C-1 vehicle "changed from a three-stage to a two-stage booster," then returned to a three-stage booster in May. The updated Saturn C-2 began as a three-stage vehicle that featured the S-II second stage, but was superseded in consideration by the C-3 in June. Plans for a C-4 were considered later in the year. Solid rocket engine boosters were considered and, at the year's end, there was the C-5. The "direct ascent" mode of travel was associated with the C-5, "which

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[37] Ibid.

[38] See for instance, Jackson L. Balch, "Weekly Notes to Wernher von Braun," 20 March 1967, in which, after Balch reported that "two additional claims for damages caused by the S-1C-T static firings [at the Mississippi Test Facility] have been received," he went on to mention "A press release designed to dispel erroneous opinions as to the effects of noise generated by static firings."

permitted only the thinnest of margins in weight allowances for the spacecraft," and so was rejected,[39] and the NOVA, which would require a launch vehicle of 12 million pounds lift-off thrust minimum, a cluster of eight F-1 Engines.[40] The NOVA also posed difficult technical problems associated with its size, which would have elicited requirements beyond NASA's existing capabilities of fabrication.[41]

Despite its difficulties, however, officials at NASA headquarters and engineers at MSFC favored the direct ascent approach using the NOVA rocket. Robert R. Gilruth, Head of the Space Task Group in 1961, wrote to Nicholas Golovin, a NASA reliability expert and proponent of the direct ascent approach that, "I feel that it is highly desirable to develop a launch vehicle with sufficient performance and reliability to carry out the lunar landing mission using the direct approach." Gilruth viewed the rendezvous modes as a "crutch to achieve early planned dates for launch vehicle availability, and to avoid the difficulty of developing a reliable NOVA Class launch vehicle."[42]

Bilstein wrote that MSFC "refused to give up on NOVA."[43] All things equal, many at MSFC preferred the "direct ascent" mode, as evidenced by Future Projects Office exploration of the direct ascent using the C-5 configuration.[44] Perhaps they refused to let go of NOVA in order to gain a vehicle with great promise to serve as a foundation for future NASA projects. It is clear that important figures at MSFC looked to the NOVA program for its capacity to underlay future projects. Heinz-Hermann Koelle of the Future Projects Office, for instance, explored the "growth potential for all Apollo modes" and reported on it on 16 April 1962. The research effort sought to "give us an indication of the growth potential of each mode for the lunar base build-up."[45]

Von Braun and others at NASA looked beyond Apollo to the creation of a space station, a permanent lunar base, and to interplanetary travel. NOVA was surely viewed as important to making such future plans appear possible, in anticipation of the greater payloads required. But in a NASA press release of July 11, 1962, NASA announced "Saturn C-5 configuration chosen; NOVA deferred." The NOVA program was expected to continue to draw funding for studies of future NASA programs, the "objective" of which "would be a NOVA with a weight lifting capability at least two to three times that of SATURN C-5 which could be used for possible missions beyond APOLLO."[46]

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[39] Bilstein, 67.
[40] Wernher von Braun, "Saturn the Giant," in Edgar M. Cortright, *Apollo Expeditions to the Moon*. Washington, D.C.: U.S. Government Printing Office, 42.
[41] Bilstein, 67.
[42] Robert R. Gilruth to Nicholas E. Golovin, 12 September 1961. Cited in Bilstein, 63.
[43] Bilstein, 59.
[44] Heinz-Hermann Koelle, Director, Future Projects Office, "Weekly Notes to Wernher von Braun."16 April 1962. MSFC History Office, George C. Marshall Space Flight Center, Huntsville, Alabama.
[45] Ibid.
[46] NASA Press Release: "Saturn C-5 Configuration Chosen; NOVA deferred," 11 July 1962, University of Houston-Clear Lake Archives #2002-0003, Box 5.

Although NOVA had difficult to ignore drawbacks, directors of various divisions at MSFC worked hard to hold on to the NOVA vehicle, and to associate it with the C-5 vehicle. In the months leading up to the decision to go with the Saturn C-5 configuration, MSFC's William A. Mrazek (Director of MSFC's Propulsion and Vehicle Engineering Division), Hans Maus (Director of MSFC's Central Planning Office), and Heinz-Hermann Koelle (Director of the Future Projects Office at MSFC), and Oswald H. Lange (Director of the Saturn Systems Office) provided reports to Wernher von Braun about the progress of their thinking on integrating or combining the Saturn C-5 and NOVA programs.[47] On 19 February 1962, for instance, Lange wrote in his weekly summary to von Braun that "Exploratory meetings … for the purposes of establishing a coordinated C-5/NOVA plan and schedule has resulted in 1) task of identifying common hardware development, 2) reconciling ground rules for scheduling and funding, 3) correlating the Golovin Committee funding with updated assumptions."[48] Officials at MSFC, despite their advocacy of the NOVA rocket, appeared to view the C-5 and NOVA in parallel—both projects, in their thinking, should and would proceed. NOVA studies persisted well into 1964, after which Marshall's engineers were unable to gather funding for future research studies.

The S-1C Test Stand on Hold

While NASA's leaders debated among themselves about the "mode" of travel and vehicle configuration, engineers at MSFC made proposals and prepared for every eventuality. They prepared designs and plans for test stands to test-fire the different vehicles. On 30 October 1961, for instance, Karl L. Heimburg, the Director of the Test Division of MSFC, for instance, reported on "model tests with C-4 configuration at 1/59 scale" to design the flame deflector, should this configuration be chosen.[49]

As late as 20 November 1961, however, discussions had not yet begun about budgeting for the S-1C launch stage test stand in the Construction and Facilities budget for 1963 at the Marshall Space Flight Center. According to Heimburg, verbal commitments had already been made to him, and in the budget were other West Area test facilities, such as $4,500,000 allotted to the F-1 engine test stand and another $4,500,000 allotted to "Component Test Facilities," all in the "West Area" of MSFC, where the future S-1C Test Stand would be constructed.[50] By 26 March 1962, however, Test Facilities Director

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[47] See, for instance, Heinz-Hermann Koelle, "Weekly Notes," 12 February 1962, NASA History Office, Marshall Space Flight Center. Huntsville, Alabama; Hans Maus, Director, Central Planning Office, "Weekly Notes to Wernher von Braun," 12 February 1962, NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.
[48] Oswald H. Lange, Director, Saturn Systems Office, "Weekly Notes to Wernher von Braun," 19 February 1962, NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.
[49] Karl L. Heimburg, Director, Test Division, "Weekly Notes to Wernher von Braun," 30 October and 6 November, 1961, NASA History Office, Marshall Space Flight Center, Huntsville, Alabama.
[50] Heimburg, "Weekly Notes," 20 November 1961.

Heimburg had received an "Advice of Allotment" for Fiscal Year 1962 Construction of Facilities projects that included the "Saturn Static Test Facility, C-5, West Area."[51]

As far as the development schedule of the S-1C Launch Stage itself, the construction of the S-1C test stand at MSFC was tied to the construction of another S-1C Test Stand at the Mississippi Test Facility, and to the development of a test stand for the NOVA vehicle—in case a direct ascent approach employing that vehicle were to be chosen. Also included in Heimburg's report of 26 March 1962 were layouts of the future Mississippi Test Facility (MTF), which displayed prominently a site that was set aside for NOVA launch stage test facility—this in addition to site associated with S-1C testing. Boeing was expected to carry on qualification testing of production S-1C stages at MTF, and to produce the launch stages themselves at the Michoud Assembly Facility. Since the decision to reject the NOVA configuration in favor of the C-5 configuration was not made until July of 1962, MSFC officials continued to plan for a NOVA-class static launch stage testing facility. Heimburg's report of 9 April 1962 revealed drawings of the S-1C test stand.[52]

MSFC had decided to build its own development test stand for the S-1C launch stage. It appeared that a lack of funding held up the design of the S-1C Test Stand at the Marshall Space Flight Center, further delaying the testing of the developmental prototypes of the S-1C Launch Stage. Heimburg reported construction schedules for the C-5 static fire test facility "were predicated on FY 1963 design funds being available on or about 4/1/62. They have not been received and no information from Washington," he wrote, "can be obtained as to when funding of these items will be consummated."[53]

By the end of 1961 the general characteristics of the S-1C launch stage had been set, but there is some dispute over how the fifth engine was added. Engineers at MSFC designed the Saturn booster with 4 engines, located at the ends of two cross members at the bottom of the vehicle. Bilstein reports that it was Milton Rosen who "took the lead in pressing for the fifth engine."[54] Courtney G. Brooks, James M. Grimwood, and Lloyd S. Swenson, look to Milton W. Rosen's report to D. Brainerd Holmes on 20 November 1961, in which Rosen recommended the Lunar Orbit or Earth Orbit Rendezvous, though he himself preferred the direct ascent approach with the NOVA vehicle.[55] Brooks , Grimwood, and Swenson make no mention of whether it was Rosen who recommended adding a fifth engine. In an interview that Wernher von Braun gave in 1971, Von Braun said that the

[51] Heimburg, "Weekly Notes," 26 March 1962.
[52] Heimburg, "Weekly Notes," 9 April 1962.
[53] Heimburg, "Weekly Notes," 30 April 1962.
[54] Bilstein, 193.
[55] Courtney G. Brooks, James M. Grimwood, and Lloyd S. Swenson, Jr., *Chariots for Apollo: A History of Manned Lunar Spacecraft*. Washington, D.C.: National Aeronautics and Space Administration, 1979, 56-59.

idea for the fifth engine was his own, claiming that "we felt still a bit uncertain about the ultimate weight of that LEM [Lunar Excursion Module]."[56]

So the decision to use the S-1C launch stage became somewhat settled, but the details of the test stand remained unsettled by the change in thinking about the vehicle configuration. In his report on the state of the test facilities department at the end of 1961, Karl Heimburg wrote of the "Saturn Static Test Facilities" that "The first phase of construction (phase one), the excavation for foundation, was begun on July 1, 1961, and completed on August 21, 1961, on schedule." However, he wrote, "The design for the stand was suspended and new criteria was established for redesign of the stand and support items for the C-4 and C-5 booster configuration. The design completion date is May 1962."[57] The design phase would take somewhat longer.

On 25 June 1962, some word on the tentative specifications of the S-1C test stand had been made available to Heimburg, who had contracted with a company called Sverdrop and Parcel to initiate "the preparation of design criteria of the S-1C test stands and support facilities at MTF [Mississippi Test Facility]."[58] To support the effort, Heimburg initiated the construction of a 1:58th scale model deflector to aid in designing the test stand's deflector.[59] As for MTF, by 23 July 1962 Heimburg felt comfortable enough to go ahead with von Braun's recommendations that they establish the design criteria of the S-1C test stand for the Mississippi Test Facility, but also "begin additional studies on [the] effect of various sound suppression methods for MTF facilities."[60] The efforts also meant that work on the S-1C facility at MSFC could proceed—if there were funds available to proceed. This meant that, upon receiving funding, Heimburg could also proceed with the design and construction of an S-1C static test stand at MSFC. Heimburg wrote in a report dated 4 September 1962 that NASA headquarters in Washington finally approved funding for the West Area C-5 (S-1C) static test stand.[61] With funds approved, it would be nearly another two years before the S-1C Test Stand would become operational. Work on the stand happened in fits and starts, and problems with the test stand's design and construction would need to be solved.

Building the S-1C Test Stand

As stated above, the drawings of the test stand appear to been initially completed September 1962, but revised and approved to conform to the structure as it was actually

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[56] Von Braun Interview, MSFC History Office, 17 November 1971, 10-14. Quotation from page 11 of the transcript.
[57] Karl Heimburg, "Test Division's Historical Report: July 1, 1961 – December 31, 1961," p. 3, In David E. Akens, *History of the George C. Marshall Space Flight Center, July 1 –December 31, 1961, Volume Two, Supporting Documents* (March 1962).
[58] Heimburg, "Weekly Notes to Wernher von Braun," 25 June 1962.
[59] Heimburg, "Weekly Notes," 9 July 1962.
[60] Heimburg, "Weekly Notes," 23 July 1962.
[61] Heimburg, "Weekly Notes," 4 September 1962.

built in April 1965.[62] Building the S-1C stand at Marshall proved time consuming. The record is characterized by relatively large gaps in the record—which was generally documented by Karl Heimburg, Director of the Test Division at Marshall Space Flight Center—about the progress of the stand. For instance, on 3 June 1963, Heimburg wrote that "adverse weather and a short strike by the iron workers" would hold back "concrete work" that was planned for completion on 15 June, but "will not be met," while a "[n]ew date has not been established."[63] The record is silent until 15 July 1963, when Heimburg wrote that "Erection of steel was started last week on the S-1C test stand in the West Area."[64]

Very little was said for months about the development of the test stand, as engineers (including those of the Test Division), worked on the problems of the F-1 Engine. The F-1 engine remained the primary component and the primary worry associated with the S-1C launch stage—that, and the problems of Boeing in manufacturing the launch stage, and in getting vendors to deliver parts in time, kept the assembly of the S-1C-T test prototype launch stage months behind schedule. A reference to the S-1C test stand on 27 April 1964 gave the impression that reports of the test stand's construction were progressing well enough to not warrant mention since the previous entry Heimburg made about it in October 1963.

In a report of late April 1964, Heimburg wrote that the "Joint Occupancy Date (JOD)" was expected on 1 July, 1964, that his staff was "presently installing the measuring system in the east legs of the tower," and that "Various increments of the stand will be released to MSFC as they are completed."[65] Heimburg wrote, optimistically, "First hot firing [of the launch stage,] (single engine)—February 1965."[66] A week later, however, on 1 June 1964, there were indications that construction of the test stand was not proceeding smoothly, and that delays were to be expected. The trouble may not have bothered Heimburg, perhaps because the S-1C-T launch stage (the test article) was months behind schedule, but "NASA Headquarters did take issue on the apparent schedule slippage," according to his report.[67]

By August 1964, Heimburg reported that "Aetron and Aerojet-General" were visiting on the 25th and 26th of August "to discuss the design shortcomings of the S-1C test stand; specifically, the lox loading system, which has to be redesigned completely."[68] And the problems with the lox loading system were only the beginning. The cranes of the S-1C Test Stand and F-1 Test Stand (both designed by Aetron) and located at Marshall's "West

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[62] See R. P. Lovin [Designer], "Saturn Static Test Facility," Drawing No. 60-09-08, Sheet 3 of 33. April 1965, George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama.
[63] Heimburg, "Weekly Notes to Wernher von Braun," 3 June 1963.
[64] Heimburg, "Weekly Notes," 15 July 1963.
[65] Heimburg, "Weekly Notes," 27 April 1964.
[66] Ibid.
[67] Heimburg, "Weekly Notes to Wernher von Braun," 1 June 1964.
[68] Heimburg, "Weekly Notes," 31 August 1964.

Area," were exhibiting problems with their "stiff-leg derricks," which were used to install and remove test articles from the respective test stands. MSFC lacked "adequate funds to correct these deficiencies," wrote Heimburg on 21 September 1964, and "These funds are needed immediately to prevent a slip in the activation dates of both the S-1C and F-1 stands."[69] The Corps of Engineers "estimated that approximately $650,000.00 will be needed," continued Heimburg. A "proposal," he wrote, sought to "provide these funds by cancelling some of the FY 1965 projects in this area and applying a portion of this money to resolve these deficiencies."[70] Unexpected problems, such as this, required deft financial maneuvers to continue working within existing budgets and to maintain the timed allocations of money.

Before long, however, more problems appeared, associated with the "holddown arms" of the S-1C Test Stand, which were used to hold down the test article. Heimburg reported on 14 December 1964 that "3 major cracks have developed in the welds for the holddown arms," and that the "cause of these cracks and the solution therefor <sic> are presently being investigated."[71] The repairs were urgent, they were undertaken immediately, and extended between Christmas and New Year's Day, when Heimburg wrote that "Work is progressing on the repair of the cracks found in the load platform welds"; the cracks were "gouged out, rewelded, and stress relieved."[72] Heimburg wrote that the holddown arm repairs and design "will be verified by the load test scheduled early in 1965."[73]

Heimburg wrote on 18 January 1965 that an attempt to test the repaired and, perhaps, redesigned, holddown arm was "delayed because of the cold weather," anticipating the next possible date for a test of the holddown arm on 25 January 1965.[74] Unfortunately, the load test was delayed still further, he reported on 1 February 1965—a date that approached the earlier planned date for the first "hot fire" of the launch stage on its test stand—because of cold weather: "The temperature has to be 35^0 F. or more."[75] Despite the "modernity" of the Apollo program, designers and engineers were still beholden to the weather and the natural environment, which could influence schedules and events (just as it did in pre-modern societies).

"Load testing" of the holddown arms began on Wednesday, 3 February 1965 and revealed still more problems. "Cracks," wrote Heimburg on 8 February 1965, "have occurred during thrust loading, and a major crack occurred during rebound loading"—presumably a load exerted in the opposite direction to the expected loads during a static

[69] Heimburg, "Weekly Notes," 21 September 1964.
[70] Ibid.
[71] Heimburg, "Weekly Notes," 14 December 1964.
[72] Heimburg, "Weekly Notes," 14 December 1964.
[73] Heimburg, "Weekly Notes," 28 December 1964.
[74] Heimburg, "Weekly Notes," 18 January 1965.
[75] Heimburg, "Weekly Notes," 1 February 1965.

test fire. Heimburg characterized the test as “65% complete, disregarding future cracks.”[76] But an analysis of the holddown arm design revealed a few troubling problems.

Heimburg wrote that the “design of the holddown arm attachments is not good.” “Heavy welds,” he wrote were made on “relatively thin girder webs” which, when combined with “loading across the weakest axis of the material” led to concern among engineers at the Test Division. The design had led to a “redesign of the method of holddown arm attachment,” wrote Heimburg.[77] To further improve the safety of the weld connection, engineers added “tension rods … to the arms at MSFC,” which served to transfer the “critical rebound load … from the weld, through the rods,” and “to the top of the platform.

Compounding the design problems of the holddown arms were the problems in the quality of their fabrication. “Out of tolerance fabrication,” were serious problems, according to Heimburg. He wrote that, “In one position, the load transfer diaphragms … were located as much as 1-3/16 of an inch out of optimum position,” which “resulted in high stress in some parts of the diaphragms.”[78] The solution for this problem was reinforcement of “critical areas with added stiffeners.”[79]

In the S-1C design and manufacture, the engineers at MSFC used their own prototypes and manufacturing process to establish designs and processes for Boeing to follow in their manufacturing of the launch stage. The design of the S-1C Test Stand served as the model for the production checkout S-1C test stand being built at the Mississippi Test Facility, which Boeing would use to test fire and qualify the launch stages that it would build at the Michoud Assembly Facility. The test stand was used to develop the S-1C launch stage, but it was also a means for engineers at MSFC to learn more about how best to design and construct a static fire test stand for the S-1C launch stage at MTF. What they learned about the MSFC’s test stand design and fabrication of the S-1C test stand changed their thinking about the test stand under construction at the Mississippi Test Facility (MTF).

The experience of the test stand design and construction led to a rethinking of the design and construction of the S-1C test stand at MTF. The faulty design of the holddown arms led engineers at MSFC’s Test Division to a “re-evaluation of the situation at MTF and a redesign of the method of holddown arm attachment to be used there.”[80] Perhaps still more troubling to engineers at Marshall was the quality of fabrication. “Developments at the S-1C Stand here at MSFC have shown,” wrote Heimburg, “that we received poor welding in the fabrication of our load platform.”[81] In response, wrote Heimburg, “action has been initiated with the Mobile District Corps of Engineers to insure good quality

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[76] Heimburg, “Weekly Notes,” 8 February 1965.
[77] Heimburg, “Weekly Notes,” 15 February 1965.
[78] Ibid.
[79] Ibid.
[80] Ibid.
[81] Ibid.

control during fabrication there," in order to ensure that "the same mistakes do not come up to plague us again."[82] But this problem of design and construction held still more serious implications for the Apollo program.

The S-1C test stand was designed to replicate the environment within which the launch stage would be mounted and monitored on the launch pad at Kennedy Space Center. Engineers sought to come as close as was possible to testing the launch stage under the conditions that it would encounter during an actual launch. Doing so, of course, improved the reliability of any evaluations of the launch stage's performance. Hence the holddown arms at MSFC were not only prototypes for the soon-to-be-operational production test stand being built at the Mississippi Test Facility, the holddown arms also replicated the holddown arms to be used at Kennedy Space Center's launch pad—as did many other features, such as the "valve panels that applied purges to tanks and engines" in the process of preparing for a launch, as well as the "deflector hole panels" used to redirect the flames that emerged from the F-1 rocket engines, and the apparatus used to monitor the performance of the launch stage during an actual launch.[83]

The hold-down arms, during an actual launch, hold down the Saturn V rocket until engines have reached full power. "Lift-off" actually begins when the hold-down arms release the rocket. Karl Heimburg and his engineers at MSFC's Test Division, therefore, closely investigated problems associated with the hold-down arms. Indeed, the Test Division tested and analyzed the design and performance of the actual hold-down arms to be used on the launch pad at Kennedy Space Center, creating a test stand dedicated to the testing of these hold-down arms themselves.

On 22 March 1965, "a second Saturn V hold-down arm failed structurally while undergoing a preload test," wrote Heimburg.[84] As Von Braun's annotations to Heimburg's report testify, this news elicited an exasperated "Incredible!" from Wernher von Braun.[85] Heimburg noted that, "indications are that the material was defective," as "microscopic cracks were found to be distributed throughout the casting[,] and yield and ultimate strengths were considerably lower than design values."[86] "Yield strength" refers to the amount of load a material under tension may resist before deforming permanently—it is measured in pounds per square inch (defined as "stress"). "Ultimate strength" measures the load in tension that a material may withstand before breaking. In this case, the process of casting was the likely culprit, as the strength of the material was "considerably lower than design values," wrote Heimburg. Nevertheless, while it may have been a problem of the casting process (or a problem of the material itself), Heimburg reported that "KSC personnel are redesigning the upper link" of the hold-down

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[82] Ibid.
[83] Conversation with Ronald Tepool, Former Engineer and Division Chief of the Test Division, 6 June 2013.
[84] Heimburg, "Weekly Notes," 29 March 1965.
[85] Ibid.
[86] Ibid.

arm in response.[87] The S-1C test stand was an element that helped compose a highly integrated process of designing, constructing, and flying the Saturn V rocket.

Just as the S-1C Launch Stage needed to be tested to ensure that the design functioned correctly, so too would the test stand itself need to be tested. The cranes on the test stand, for instance, had their "check out on 12/22/64," wrote Heimburg on 28 December 1964, "and no major problems were encountered."[88] The physical characteristics of the S-1C Launch Stage itself, for instance, influenced the environment within which the Test Stand and its associated systems operated. Hence, while the test article S-1C-T was mounted, but before it was fired, engineers subjected the test stand to "Lox system cold shock tests." "Lox" is the way in which engineers referred to liquid oxygen, the catalyst for the rocket fuel. Lox has a boiling point of -297^0 F, and was stored at a temperature lower than its boiling point. This test verified operation of the fuel and liquid oxygen distribution system, it verified the procedures for loading fuel and liquid oxygen into the test article, as well as the integrity and strength of the storage tanks.[89] The cooling and safety systems were also tested. "The emergency fail-safe system of the deflector and the firex system were checked out on 2/20/65," wrote Heimburg on 23 February 1965.[90]

Engineers also needed to verify the test stand's structural characteristics, to ensure that the test stand itself did not affect the performance of the S-1C launch stage and, also, that the test stand did not change measurements they planned to undertake in the course of their tests. Heimburg wrote that "shaking" tests were undertaken "to determine the natural frequency of the empty test stand."[91] Rocket engineers, for instance, are very careful to ensure that a resonant or natural frequency in the launch stage itself (and, especially, the rocket engine) did not lead to a "Pogo" effect, or cyclically variable thrust levels, which would shake the Saturn V like a pogo stick, increasing and shortening its length along the rocket's cylindrical axis. Similarly, engineers investigated the possibility that the test stand itself exhibited a resonant frequency that would affect the rocket's performance, perhaps leading to a "Pogo" condition. This was a possibility that needed to be eliminated to gain confidence that engineers' measurements of launch stage performance actually recorded measurements of the performance of the launch stage itself, rather than recorded measurements corrupted by interactions between the launch stage (the test article) and the test stand. But, as stated above, an important goal of the test stand designs at the Test Division was that the test stand reproduce, to the extent possible, the context within which the S-1C stage would function in its final performance context—the launch of a flight to the moon. If interactions between the test stand and test article produced suspect data, then tests undertaken during developmental static test-fires of the S-1C launch stage provided a more desirable time and place to understand such interactions, so that the launch pad itself might be better designed.

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[87] Ibid.
[88] Ibid.
[89] Conversation with Ronald Tepool, Former Engineer and Division Chief of the Test Division, 6 June 2013.
[90] Heimburg, "Weekly Notes," 23 February 1965.
[91] Heimburg, "Weekly Notes," 11 January 1965.

At 4:20 p.m. on 9 April 1965, the S-1C test stand was first used for a static-fire of the S-1C-T launch stage, the "T-Bird." Test No. S-1C-01 was a static test-fire planned for 7 seconds in duration, but the record shows that the test was "terminated by observer inadvertently" at 3 seconds.[92] Only a single F-1 engine, F2003 was installed in the launch stage for the test fire, located in the fifth position, the center position—F-1 engines were not installed in the other four positions.[93] The test marked the official completion of the test stand. From this moment on, the test stand and the S-1C launch stage would enter a developmental phase, one in which engineers tested and improved the operation of the S-1C-T, a prototype launch stage that would not be used in flight. The S-1C-T launch stage was tested on the S-1C Test Stand in order to examine and "de-bug" the launch stage design, as will be discussed in the next section.

Designing and Developing the S-1C Test Stage: MSFC and Boeing

With less than 8 years to develop a space program to land astronauts on the moon and return them home safely, NASA required decisive leadership, it required resources, and it required expertise. It had the resources, apparently, for the Apollo program brought together a national effort, contractors and universities joining with the rocket engineers at NASA. The program encompassed 300,000 individuals, 20,000 contractors, and 200 universities. The far-flung individuals and institutions toiled in 80 nations.[94] The lack of time also necessitated a change in how MSFC's engineers typically went about designing and building rockets, which was a sequential approach, one that coordinated the rocket's design, testing, and production (see Figure 4). To collapse the typical design and testing cycle required thinking "outside the box," leading engineers and project managers to a new "concurrent engineering" approach, one that overlapped the different phases of design, prototyping, and testing.[95]

"Concurrent engineering" first appeared in the Air Force, and was employed to speed the design cycle for weapons development projects.[96] It was built upon the principles of

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[92] "S-1C Static Test History," *History of Static Firings Conducted at the Saturn Test Facility, 1960-1970: S-1C-T, S-1C-1, S-1C-2, S-1C-3*. Huntsville, Alabama: History Office, George C. Marshall Space Flight Center. 4572-SA-T STATIC TEST.pdf., 25.
[93] Ibid.
[94] Stephen B. Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore: Johns Hopkins University Press, 2002), 5.
[95] In addition to Johnson, *The Secret of Apollo* (2002), see also Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore: Johns Hopkins University Press, 1993), Joan Lisa Bromberg, *NASA and the Space Industry* (Baltimore: Johns Hopkins University Press, 1999), W. Henry Lambright, *Powering Apollo: James E. Webb of NASA* (Baltimore: Johns Hopkins University Press, 1993), Phillip K. Tompkins, *Organizational Communication Imperatives: Lessons of the Space Program* (Los Angeles: Roxbury, 1992), Irving Brinton Holley Jr., *Buying Aircraft: Materiel Procurement for the Army Air Forces*, vol. 7 of Stetson Conn, ed., *United States Army in World War II* (Washington, D.C.: Dept. of the Army, 1964).
[96] See Stephen B. Johnson, *The United States Air Force and the Culture of Innovation, 1945-1965* (Washington, D.C.: Air Force History and Museums Program, 2002). See also Benjamin Bellis, "The

systems engineering, which provided a more formal control of engineering analysis and design in order to control cost, schedules, and the reliability of complicated new projects, such as rockets and missiles. As Stephen B. Johnson put it, "systems engineering and systems management" were characterized by "a set of organizational structures and processes to rapidly produce a novel but dependable technological artifact within a predictable budget."[97] The concurrent approach emphasized "systems engineering" and testing, disciplines and practices that were important to define and control the interfaces among rocket systems and components, and to ensure that design efforts among hundreds of contractors were not at odds with one another, causing confusion and delay (see Figure 5). What concurrent engineering added to the systems approach was the idea that the different phases of the engineering design cycle could be overlapped, in order to speed up the process, it employed the same types of information that systems engineers employed in order to optimize the schedule—which, in turn, often minimized the cost of a program because time and cost were related (more time spent developing a system almost invariably meant greater cost).

The "systems engineering" approach and the "concurrent engineering" approach, therefore, were complementary, and both required reliable information about the artifact's performance and development—both systems engineers and program managers required information about ongoing testing and evaluation, and careful tracking of changes. In so complicated a program as Apollo, however, program managers required more. They required up-to-the-minute knowledge of the relationships among component development and delivery schedules for supplying vendors, and they required knowledge of what "critical paths" of project activities, and of component and systems development, shaped a program's overall schedule. The practice of systems engineering and concurrent engineering at NASA were realized through careful configuration control of the systems and components that together composed the Apollo program. References in weekly managerial reports to the director of the Marshall Space Flight Center, Wernher von Braun, provide evidence of the perceived need to employ computerized means of configuration controls, especially through the use of the Program Evaluation and Review Technique (PERT), which was realized through computer programming.[98]

Requirements for Configuration Management During Concurrency," AFSC Management Conference, May 1962, Air Force Systems Command, Andrews Air Force Base, Washington, D.C. 5.24.1 – 5.24.14.

[97] Stephen B. Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore: Johns Hopkins University Press, 2002), 17. See also Stephen B. Johnson, "From Concurrency to Phased Planning: An Episode in the History of Systems Management," in Agatha C. Hughes and Thomas P. Hughes, eds., *The Systems Approach in Management and Engineering, World War II and After* (Cambridge, Massachusetts: MIT Press, 2000), 93-112.
[98] For references to the proliferation of training in PERT at MSFC, see Hans Maus, "Weekly Notes to Wernher von Braun," 5 August 1963, NASA History Office, George C. Marshall Space Flight Center, Huntsville, Alabama. Also R.G. Smith, "Weekly Notes to Wernher von Braun," 30 October 1961, 6 November 1961, 4 December 1961, 18 December 1961. NASA History Office, George C. Marshall Space

It was when considering the complexity of Apollo program, given the limited time given to engineers and administrators to achieve the goal of landing an astronaut on the moon, that the S-1C Launch Stage revealed its importance. Building the S-1C Launch Stage required numerous tests to learn the effectiveness and reliability of its components and systems, and the S-1C Test Stand (among other tests stands) served this very important purpose. But the S-1C Test Stand's significance went beyond its use as an instrument to test the various performance criteria of the launch stage itself.

Given the rapidly approaching deadline set forth by President Kennedy, the S-1C Test Stand became more important as a tool of management and systems engineering in the development of the S-1C launch stage. This was all the more true because the actual process of developing the S-1C launch stage did not conform to the ideal model of "concurrent engineering." In the case of the S-1C launch stage, each of the design cycle phases—design, prototyping, development, and production—overlapped to a far greater extent than in the idealized model, shown in Figure 5, illustrating the practice of "concurrent engineering." Boeing's management, and the record shows, that more than two phases of the design cycle were ordinarily "concurrent" in the development of the S-1C Launch Stage. In 1968, Boeing presented to the U.S. House of Representatives Committee on Science and Astronautics a more true representation of the design cycle of the S-1C Launch Stage, here shown in Figure 6. The diagram, which shows that nearly all phases happened simultaneously, punctuates the importance of effectively monitoring the development of systems and components which, in turn, places great importance on testing.[99]

The Marshall Space Flight Center in the time of Apollo was well known for the expertise of its engineers and for its advocacy of the "Arsenal System," in which the government agency takes on a "hands-on" role in designing, testing, manufacturing, and operating its systems and equipment, a tradition of the U.S. Army dating at least since the early-nineteenth century.[100] This approach is often contrasted to the "Air Force System," which gave contractors a great deal of freedom to both propose and evaluate the technical quality of projects. That is, in the Air Force System, the Air Force administrators did not maintain the expertise to evaluate, technically, the proposals they received. Instead, they relied on competition among contractors to ensure the quality of proposals and work submitted.

Flight Center, Huntsville, Alabama. Arthur Rudolph, "Weekly Notes to Wernher von Braun," 25 May 1964, NASA History Office, George C. Marshall Space Flight Center, Huntsville, Alabama.

[99] U.S. House of Representatives, Ninety-First Congress, First Session, *Apollo Program Management: Staff Study for the Subcommittee on NASA Oversight of the Committee on Science and Astronautics*. Washington, D.C.: U.S. Government Printing Office, 1969, 15-34.

[100] See for instance, Merritt Roe Smith, *Harpers Ferry Armory and the New Technology: The Challenger of Change*. Ithaca, New York: Cornell University Press, 1977. See Roe Smith's dissertation, also. Merritt Roe Smith, "The Harper Ferry Armory and the 'New Technology' in America, 1794-1854." Ph.D. Dissertation: Pennsylvania State University, 1971.

Marshall's engineers, as Andrew J. Dunar and Stephen P. Waring argue, believed that the arsenal system "improved quality, accelerated progress, and contained costs."[101] For the case of the S-1C launch stage of the Saturn V rocket, in most matters relating to the design, manufacture, and testing of this crucial vehicle, this was certainly true. Marshall performed the initial design of the stage, they established the initial manufacturing processes at Marshall Space Flight Center, as well as testing procedures for the launch stage. As Georg F. von Tiesenhausen recalled, "Boeing knew exactly what they were doing, but they watched and then we turned over the specifications and drawings, blueprints, and they made theirs exactly like ours." Von Tiesenhausen acknowledged the contribution of Boeing, however, "That doesn't mean that they did not later improve here and there." He attributes the power of MSFC's engineers in the relationship to their expertise, saying that "we could afford to do that, because we had a 'hands-on' approach in-house." But he regretted that MSFC's engineers were "maybe authoritarian."[102]

The report of Boeing's officials to the US House of Representatives' Staff Study for the Subcommittee on NASA Oversight of the Committee on Science seemed to echo this characterization, albeit in terms more favorable to the company. In a chart (see Figure 7) presented to the subcommittee, the Boeing's management acknowledged the leading role that Marshall's engineers took in the design and initial manufacture of the launch stage, but emphasized the total responsibility they eventually secured for the design and manufacture of the launch stage.

This transfer of responsibility, and the emphasis on its importance, was also acknowledged by Matthew Urlaub, MSFC's Manager for the S-1C Stage, who distinguished between the roles of MSFC's engineers and Boeings engineers, leaving a more favorable—and perhaps more accurate—impression of Boeing's contribution to the development of the S-1C launch stage. As far as the "Preliminary concept," Urlaub recalled, "why did you choose this diameter, factor of safety, pressure requirements, general layout—that's all Marshall." But he argued, "When you talk about converting an idea to a producible item, the detail drawings that you can contract on and specifications that you can contract on, and assembly techniques that are repeatable, give you repeatable results … that was all Boeing." He applauded their effort, saying, "They did a tremendous job in an area where they had the expertise and we didn't. You get in to building airplanes…and the whole process, of drawing generation, quality, tool design, and how you make the parts come together in a repeatable fashion"—these very important dimensions of manufacturing the S-1C launch stage were Boeing's contribution.[103] Nevertheless, it is clear that Marshall's engineers were the "principal" engineers in the effort to design and initially manufacture the S-1C launch stage, as well as in the development and testing of the launch stage, as shown below.

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[101] Andrew J. Dunar and Stephen P. Waring, *Power to Explore: A History of the Marshall Space Flight Center, 1960-1990*. Washington, D.C.: National Aeronautics and Space Administration, 1999, 42.
[102] Georg F. von Tiesenhausen Interview, 29 November 1988.
[103] Matthew Urlaub, Interviewed by Roger E. Bilstein, 29 July 1975.

S-1C Test Stand: Development Phase

Testing of the S-1C "T-Bird" launch stage—NASA engineers referred to their vehicles as "birds," though the "T-Bird" was never actually used on a flight mission—would begin with static firings that ensured the basic operation of both the vehicle (the test article) and that of the test stand. Hence, the first test, Test No. S-1C-01 on 9 April 1965 at 4:20 p.m., fired the S-1C-T launch stage for 2.55 seconds, and was closely followed by a second test, Test No. S-1C-02 at 5:10 p.m., which attained a "scheduled duration of 15 seconds mainstage," or full power, for the lone F-1 engine installed in the S-1C launch stage.[104] The first five-engine test of the "T-Bird" took place on 16 April 1965, "successfully for 6.5 seconds mainstage," which produced data—including data on acoustics, which had concerned NASA.[105] In addition to efforts to de-bug and develop the S-1C launch stage, engineers also sought to develop the test stand itself.

Always concerned that the "Pogo" effect variations in thrust would appear, Test No. S-1C-05 of 6 May 1965 was conducted for 15.5 seconds on the S-1C-T. Test engineers lowered the setting for the "fuel tank pressurizing switch" by 2 p.s.i.g. (pounds per square inch gage) in order to "further investigate the 30-cycle oscillations" that were "evident" at each engine's "fuel pump inlet and outlet [but] with no apparent harmful vibrations being excited in the stage hardware."[106]

On 17 May 1965, Heimburg reported that the test stand's deflector was modified. He called it a "major modification [which] involves support of the deflector sidewalls," one that was "accomplished by a 24-inch-diameter pipe installed across the deflector opening and pin connected to the outside girder near the top." Such changes were undertaken in addition to plans made for the "four outboard engines" of the S-1C launch stage to be "gimbaled [pivoted] during the 40-second test scheduled for 5/20."[107] As shown in Heimburg's report, both the S-1C Launch stage and the test stand itself were tested and improved through analyses of the tests conducted. In the test undertaken on 20 May 1965, engineers from the test division conducted "a successful 41-second mainstage duration test," and "gimbaled" all four outboard engines ±2 degrees, while noting the 30-cycle oscillations (30 cycles per second) that were "evident in the fuel system for all engines." "[S]ustained oscillations," recorded Heimburg appeared "only in engines at stage positions 1, 4, and 5."[108]

The development phase of the S-1C Launch Stage meant, more than anything, that less reliable components of the S-1C launch stage and its F-1 engines were replaced with more reliable components. On 20 September 1965, for instance, Heimburg wrote that "Only one [electrical] distributer was received from MEL [Manufacturing Engineering

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[104] Heimburg, "Weekly Notes to Wernher von Braun," 12 April 1965.
[105] Heimburg, "Weekly Notes," 12 April 1965.
[106] Heimburg, "Weekly Notes," 10 May 1965.
[107] Heimburg, "Weekly Notes," 17 May 1965.
[108] Heimburg, "Weekly Notes," 24 May 1965.

Laboratory] last week, leaving 10 others to be delivered. These were supposed to have been installed last week."[109] A bigger problem were the individual "pre-valves" for the LOX and Fuel lines for each F-1 engine. Heimburg noted on 27 September 1965 that "Five prevalves are yet to be installed. Two prevalves, 1 fuel and 1 lox, have not been received to date."[110] The problem of prevalve replacement would reappear as Marshall sought to replace all such prevalves on existing and already-built production S-1C Launch Stages. The problem of replacing the prevalves is an example of the difficulty that Boeing confronted in procuring components on schedule for the S-1C program.

Recurring problems associated with the F-1 engine components also appeared at the S-1C Launch Stage development phase. For instance, upon removing F-1 engine F-4T21 from Position No. 1 of the S-1C-T Launch Stage on 10 November 1965, for the purposes of "exchanging the thrust chamber injector," technicians found that "the injector was found cracked during post test inspection on 11-5-65."[111] The F-1 engine provides an excellent example of "concurrent engineering" for the S-1C project—the F-1 engine developers at Rocketdyne and Marshall struggled with the F-1 engine, constantly replacing its components, even as production units were already delivered and installed in production S-1C Launch Stages both at Marshall and at the Michoud Assembly Facility.

Checkout Procedures; Training Boeing for S-1C Checkout Tests

The Test Division at MSFC also used these tests to develop an "automatic" testing procedure for "checkout" tests, tests designed to determine whether the performance of completed production launch stages were ready for Apollo missions. The first "automatic" test was scheduled at MSFC's S-1C test stand for 5 October 1965.[112] The Test Division performed "initial checkout of the automatic checkout equipment" for the S-1C's Ground Equipment Test Set (GETS).[113] Test Division engineers celebrated Test No. S-1C-11 (conducted on the S-1C-T Launch Stage) on 8 October 1965 at 4:41 p.m.: "The first S-1C-T test," wrote Heimburg, "using the automatic ground support equipment was successfully conducted."[114]

Heimburg described the automatic checkout further on 18 October 1965, suggesting the complicated and involved nature of the task and the "work-in-progress" character of the testing equipment and procedures. "During the first 'automatic' firing of the S-1C-T on October 8, 1965," he wrote, "77 out of 80 pieces of the new ground support equipment were used." For the next "operation," he wrote, "all 80 will be used and some computerized checkouts will be made as time allows."

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[109] Heimburg, "Weekly Notes," 20 September 1965.
[110] Heimburg, "Weekly Notes," 27 September 1965.
[111] Heimburg, "Weekly Notes," 15 November 1965.
[112] Heimburg, "Weekly Notes," 9 August 1965.
[113] Heimburg, "Weekly Notes," 20 September 1965.
[114] Heimburg, "Weekly Notes," 11 October 1965.

The success of the "automatic" testing procedures he wrote about signaled a change: test engineers began looking forward to the first S-1C production units. The first two of these flight stages, designated S-1C-1 and S-1C-2, were to be produced at MSFC, by Marshall's own prototype production facility, not by Boeing's team at the Michoud Assembly Facility. Heimburg wrote of the work remaining for the "automatic" test procedure and hardware, including the Ground Support Equipment, "All programs and equipment will be de-bugged prior to S-1C-1 operations."[115] For the next test to be undertaken on the S-1C test stand, 28 October, 1965, Heimburg wrote that "Approximately 550 telemetry channels will be active."[116] That is, data was gathered from 550 sources that measured the performance of the rocket stage under test.

The development phase of the S-1C-T neared completion, the problem components identified and solutions determined. The task of developing the S-1C-T Launch Stage depended on a related process of development for the S-1C Launch Stage itself, for which engineers also identified problem components and also determined working and reliable test processes to checkout production launch stages. Now the Test Division's attention turned to training Boeing personnel to undertake the task of testing of the first production units of the S-1C, a task to be undertaken on the S-1C Test Stand. When ready, Boeing's staff would test production launch stages at one of Marhall's own satellite facilities, the Mississippi Test Facility.

Test engineers at Marshall's S-1C test stand also trained Boeing personnel to conduct qualification test procedures in preparation for the transfer of this function to the Mississippi Test Facility. The MTF would receive production launch stages from the Michoud Assembly Facility, the site where Boeing produced the production launch stages. On 18 October 1965, Heimburg reported that "pre-test checkouts are progressing slowly due to problems associated with GSE [Ground Support Equipment] and, partially, as expected, from operating with Boeing personnel for the first time in certain areas."[117] On 8 November 1965, for instance, Heimburg wrote that, for Test No. S-1C-12 on 3 November 1965, "Boeing personnel" conducted an "automatic" test "under the supervision of Test Laboratory." He also noted that the "major part of the test objectives were attained."[118] The S-1C-T would undergo one more test, Test No. S-1C-15 on 16 December 1965, and then the test stand would be subjected to a "general refurbishment prior to additional static tests."[119]

Testing the First Three Production S-1C Launch Stages

The "additional static tests" were tests of the first three production units of the S-1C Launch Stage. The tests themselves were, in effect, a "checkout" of both the first two

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[115] Heimburg, "Weekly Notes," 18 October 1965.
[116] Ibid.
[117] Heimburg, "Weekly Notes," 18 October 1965.
[118] Heimburg, "Weekly Notes," 8 November 1965.
[119] Heimburg, "Weekly Notes," 20 December 1965.

production units (which were produced at Marshall, not Michoud) and a “checkout” of the prototype manufacturing process (also a product mainly of Marshall’s engineers, with the help of Boeing’s resident engineers). The first test-fire, Test No. S-1C-16 on launch stage S-1C-1 (this would soon become the first S-1C launch stage to fly), was successfully completed with 40.8 second duration mainstage. A problem was found with the “lox flowmeter in the suction line to engine position No. 2.” Heimburg wrote that “the bearing seized to the shaft and, therefore, a decision was made to remove the lox flowmeters for the next test.” The report states later that “Repairs are being made to correct deficiencies found in the actuator on each lox prevalve.”[120]

A pattern emerged in that repairs to the production S-1C launch stages continued even after the launch stages emerged from manufacturing. For the S-1C-1 launch stage recently tested, and soon to be part of Saturn V rocket AS-501, of *Apollo 6*, the Lox prevalve would be replaced. Heimburg wrote that “The replacement of the S-1C-1 Stage AiResearch Lox Prevalve with Whittaker should be completed on March 8, provided the valves are delivered on schedule.”[121] This stage would be removed on 14 March 1966 from the test stand, without another test fire, despite the replacement of the Lox prevalve.[122] According to Ron Tepool, the Lox and Fuel prevalves were “line replaceable units,” and qualified to a much higher level of reliability, and were already tested at the component level, thus the engineers replaced lox prevalves confident that another launch test-fire would not be required.[123]

Providing evidence of the practice of “concurrent engineering,” launch stage S-1C-2 had been completely assembled, but not meeting the requirements for checkout testing. It would undergo “checkout” testing anyway, as reported by Heimburg on 11 April 1966. He wrote in his report that “The stage will be updated to as near flight configuration as hardware and documentation permits prior to post-manufacturing checkout during April 25 through May 10 by R-QUAL.”[124] Indeed, this production launch stage—which would become the booster stage for the Saturn V rocket AS-502, of *Apollo 7*, exhibited problems with “cables,” “distributers,” “prevalve timers” and “the electrical circuit for the LOX flowmeters.”[125] Moreover, Heimburg also reported the plan to “change-out” the launch stage’s “center engine thrust structure bolts, total of 16,” while the launch stage was on the stand and propellant load tests were undertaken.[126] One of the 16 bolts had apparently failed, he reported on 16 May 1966.[127] A successful firing of the second production launch stage and its emergence from manufacturing at Marshall, S-1C-2, happened on 7 June 1966. This launch stage was removed from the test stand on 16 June

[120] Heimburg, “Weekly Notes,” 21 February 1966.
[121] Heimburg, “Weekly Notes,” 7 March 1966.
[122] Heimburg, “Weekly Notes,” 21 March 1966.
[123] Conversation with Ron Tepool, 6 June 2013.
[124] Heimburg, “Weekly Notes,” 11 April 1966.
[125] Heimburg, “Weekly Notes,” 18 April 1966.
[126] Heimburg, “Weekly Notes,” 9 May 1966.
[127] Heimburg, “Weekly Notes,” 16 May 1966.

1966.[128] So, while the production units appeared at the test stand for "checkout," in actuality the "development" phase actually continued, for the engineers at MSFC continued to replace parts and to learn about—and solve—the apparent problems of the S-1C launch stages.

Heimburg, Matthew Urlaub, and others, initiated a reinstallation of the S-1C-T launch stage onto the S-1C test stand at MSFC in order to continue development on the launch stage but, on orders from General Edmund F. O'Connor, Marshall's Director of Industrial Operations, the S-1C-T launch stage was removed. "We will reluctantly remove the S-1C-T from the test stand on Friday, July 29, 1966," grumbled Heimburg.[129] "The S-1C-T stage," wrote Heimburg on 1 August 1966, "was removed from the Saturn Static Test Facility on Friday and returned to ME Laboratory."[130] Instead, the S-1C-T would be moved to the Mississippi Test Facility for "checkout" of its newly constructed S-1C test stand.

The S-1C-3 launch stage—the first production launch stage assembled at the Michoud Assembly Facility—was installed on the S-1C Test Stand at Marshall on 3 October 1966.[131] The acceptance test of the S-1C-3 was completed at 3:38 p.m on 15 November 1966, with a mainstage duration of 121.7 seconds.[132] The stage was loaded onto a barge on 22 November 1966 to Michoud "for refurbishment and post-static checkout prior to shipment to KSC," reported Heimburg on 28 November 1966.[133]

Jackson L. Balch, Director of the Mississippi Test Facility, reported on 9 January 1967 that the first static testing of the S-1C-T on the S-1C test Stand at the Mississippi Test Facility was held up by "late deliveries of GSE [Ground Support Equipment] mod kits and parts and delay of stage checkout pending availability of hydraulics-pneumatics."[134] Expecting the first static test-fire of the S-1C-T launch stage on 9 February 1967, problems with these GSE systems caused some delay.[135] MTF undertook two "propellant load tests" of the S-1C-T, one on 14 February 1967 and another on 24 and 25 February 1967, further delaying the inaugural static test-fire of the S-1C test stand.[136] The first test fire of the S-1C-T ("T-Bird") launch stage at Mississippi Test Facility happened on Friday afternoon, 2 March 1967, with another firing on 17 March 1967.[137] Now, the test stand at MTF stood ready for acceptance testing of the second production launch stage built by the Michoud Assembly Facility, and the fourth overall production launch stage, S-1C-4. The "handoff" had been made from Marshall's engineers to those of Boeing.

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[128] Heimburg, "Weekly Notes," 7 June 1966 and 16 June 1966.
[129] Heimburg, "Weekly Notes," 25 July 1966.
[130] Heimburg, "Weekly Notes," 1 August 1966.
[131] Heimburg, "Weekly Notes, 10 October 1966.
[132] Heimburg, "Weekly Notes, 21 November 1966.
[133] Heimburg, "Weekly Notes, 28 November 1966.
[134] Jackson L. Balch, "Weekly Notes to Wernher von Braun," 9 January 1967.
[135] Balch, "Weekly Notes," 23 January 1967.
[136] Balch, "Weekly Notes," 20 February 1967, 27 February 1967.
[137] Heimburg, "Weekly Notes," 6 March 1967; Balch, "Weekly Notes," 20 March 1967.

But testing and assembly of production units would be put on hold as Apollo planned its first flights of the Saturn V rocket and its S-1C launch stage.

"All-Up" Testing, "Pogo" Vibration Problems, and The S-1C Launch Stage

Qualification tests, rework, and general engineering development of the components, engines, and stages of the Saturn V rocket finally led to actual flight tests. In 1967 and in 1968, NASA undertook flight tests of the Saturn V that approached the rocket's planned configuration. These flights were unmanned, and relied on the S-1C-1 and S-1C-2 launch stages, both produced at Marshall's own manufacturing facilities; the third Saturn V flight was manned, and employed a launch stage produced at Boeing's production facilities at the Michoud Assembly Facilty, the S-1C-3.

The approach of the first two test flights departed from the conservative approach of Marshall's engineers, who preferred testing one stage at a time, and thus building up the Saturn V rocket through individual flight tests. This was called an "incremental" approach, and it minimized the number of variables to consider and test for each flight. Engineers employed countless sensors that produced and organized data into the "extraordinarily detailed experience reports" that engineers needed to understand the vehicle's operation, and to understand the relationship among its many systems in practice. The first two flights, however, employed a strategy called "all-up" testing, the strategy of testing a complete rocket stage, which was championed by George E. Mueller, NASA's Director of the Office of Manned Space Flight. If the Apollo program was to land an astronaut on the moon in the decade of the sixties, it appeared that NASA needed to accept the greater risk associated with "all-up" testing.[138]

NASA engineers held their collective breath during the first "all-up" test flight of 9 November 1967, a flight that relied on a Saturn V rocket assembly designated AS-501, the mission called *Apollo 4*. If the mission failed—and especially if the S-1C launch stage failed—it would have sent NASA's engineers "back to the drawing board" and guaranteed that Americans would not achieve their goal of landing an astronaut to the moon and returning him safely by the end of the decade.

That first flight required a tremendously complex choreography among flight controllers at the Manned Space Center in Houston, the engineers at Marshall, and the controllers at the Kennedy Space Center at Cape Canaveral, who together worked to coordinate many systems for the first time—but complex choreographies are usually practiced before a performance, this needed to be done right the first time. When AS-501 finally did fly, the gamble paid off: *Apollo 4* proved unequivocally successful. George Mueller's advocacy of "all-up" testing was made to appear as if "common sense," and proved to be, from the standpoint of schedule, the most important milestone of the Saturn V.[139] Not even

[138] Bilstein, 347-350.
[139] Ibid., 351-355, quote drawn from p. 352.

Wernher von Braun believed that a flawless three-stage launch was possible in a first attempt.

The second flight test of the Saturn V, AS-502, *Apollo 6*, proved sobering for the engineers at Marshall, and was what Von Braun might have expected.[140] In the second flight, two of the five J-2 engines of S-II stage, the Saturn V's second stage, shut down inadvertently. Luckily, the third stage was able to propel the rocket "into an Earth parking orbit," under the power of its lone J-2 engine. However, when NASA's controllers transmitted the command to re-ignite the third stage and return to earth, it did not restart. To maneuver and propel the third stage for atmospheric re-entry, NASA's engineers relied on the stage's service module engine. Wernher von Braun lamented afterward that, "With three engines out, we just cannot go to the Moon."[141] The results of *Apollo 6* made it clear to Marshall's engineers that there was still much to do.

But the J-2 engine problems of the rocket's second stage, and its third stage, were not even the most important problem made apparent after *Apollo 6*. Despite the extensive test stand work in both the F-1 engine and the S-1C launch stage to find just such vibration resonances, it took AS-502 and the *Apollo 6* mission to reveal a dangerous vibration resonance along its cylindrical axis, the dreaded "Pogo instability." The surprise revealed, at once, just how difficult it is predict the performance of a rocket. It revealed the importance of testing, and it revealed that testing individual components and stages was rarely enough to understand the operation of a fully assembled rocket.

"Pogo" becomes dangerous when the natural frequency of the rocket's structure couples with the propulsion system's natural frequency; the coupling amplifies the rocket's axial expansion and contraction, leading to violent shaking for the Astronauts riding at the rocket's top, where displacements are most pronounced. Left unchecked, such a resonance can shake a rocket to pieces.

"Pogo instability" is commonly caused by variations of flow in a rocket's propellant feed system. Often, a mechanical resonance of the feed system cyclically varies the rate of fuel or oxidant entering the engine's thrust chamber (where the two are combined and ignited). When either the fuel or oxidant flow rate (or both) varies cyclically, the engine's thrust level correspondingly varies at the same cyclical rate—and the cyclically varying thrust pushes on the rocket, vibrating the entire structure.[142]

All mechanical structures have a natural frequency, which can often be heard by sharply striking the structure with a hard object and listening to resonating sound. The fifth string on a guitar—a very simple mechanical structure—resonates at 110 Hz, an "A" note (when in tune). When the natural frequency of a rocket (viewed as a mechanical structure) is the same or near to the rate of cyclically varying thrust, it tends to amplify the vibration,

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[140] Ibid., 357.
[141] Ibid., 360-363, quote drawn from p. 361.
[142] Sutton, *Rocket Propulsion Elements*, 269-271.

which may tear apart the engine or rocket—just as a glass window may shatter when a person sings and maintains a musical note that matches the window pane's natural frequency, because the glass flexes especially when excited at its natural frequency—and, after all, sound is cyclically varying movements of air that push on the glass, exciting the glass (and which our ear "drums" and brains interpret as particular pitches of sound).

At 125 seconds after lift-off, *Apollo 6*'s AS-502 (the particular Saturn V assembly) exhibited a natural frequency of approximately 5.25 Hz axially.[143] The feed system also exhibited a cyclical variation of "approximately" 5 Hz.[144] Coupling between the frequency of the engine and its feed system, on the one hand, and the natural frequency of vehicle's structure, on the other hand, created a feedback loop, increasing the amount of stretching and contraction in the vehicle's length, threatening to shake apart the rocket.

To solve the problem, NASA created a Pogo task force, bringing together engineers from Marshall, from military and NASA contractors who built rockets, and from universities.[145] The experts chose to "detune" the natural frequency of the F-1 engine's propellant feed system from that of the vehicle.[146] Engineers modified the LOX prevalve assembly to dampen vibration in the propellant feed system, adding a helium-filled reservoir to the feed line before the LOX entered the prevalve, thereby changing the natural frequency of the assembly. The LOX line prevalve determined the rate at which LOX (liquid oxygen) flowed into the turbopump and into the gas generator.[147]

Curiously, this was not a problem that engineers associated with the design of the launch stage—it was a problem they associated with the design of the F-1 Engine—which meant that solutions to the problem were tested on the F-1 Engine Test Stand. When testing the attempted solution, engineers reported that "the natural frequency of the LOX suction line was reduced to approximately 2.8 CPS [cycles per second]."[148] More tests on the F-1 Engine Test Stand confirmed that the resonant frequency of the propellant feed system decreased from 5 to "approximately 2.5 cps."[149]

In learning about, and verifying, that the pogo problem could be solved on the F-1 Engine Test Stand, engineers and Marshall Space Flight Center ran out of reasons to continue developing the S-1C Rocket Stage on their own Test Stand at Marshall Space Flight Center—this marked an informal "handoff" to Boeing for the production of the S-1C launch stage, and also figuratively gave Boeing the keys to the S-1C test stand at the Mississippi Test Facility. Henceforth, testing would be conducted only on production S-

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[143] Bilstein, 363. The natural frequency of the structure changed as the fuel and oxidizer tanks emptied.
[144] Richard Brown, "Weekly Notes to Wernher von Braun," 8 July 1968. NASA History Office, George C. Marshall Space Flight Center, Huntsville, Alabama.
[145] Bilstein, 362.
[146] Ibid., 363.
[147] Ibid., 363.
[148] Heimburg, "Weekly Notes," 3 June 1968.
[149] Brown, "Weekly Notes," 8 July 1968.

1C Launch Stages, and they would be produced henceforth at Boeing's manufacturing plant at the Michoud Assembly Facility. From then on, the S-1C Test Stand used to conduct acceptance tests would be the one located at the Mississippi Test Facility.

The understanding that a solution of to the Pogo problem could be solved with more development work on the F-1 Engine Test Stand seemed, in practice, to sever the developmental relationship that Marshall's engineers maintained with the S-1C Launch Stage. As for the Apollo Program, the rest was history: Future Apollo flights practiced the maneuvers that finally led to Apollo 11 landing on the surface of the moon on 20 July 1969, and to Neil Armstrong's "small step for man" onto the moon's dusty surface. NASA then turned its thinking to the question of what to do next—and the organization would land upon the Space Transportation System (STS) as its next program.

The Space Transportation System (the Space Shuttle) and the S-1C Test Stand

The story of the S-1C Test Stand continued when the test stand became an important instrument in the development of NASA's new vehicle system, called the Space Transportation System (STS), or the "Space Shuttle." Marshall's engineers, again taking a leadership role in the design of the vehicle and its propulsion systems, transformed the S-1C Test Stand at Marshall Space Flight Center into something suitable for structural load and pressure tests of the Space Shuttle's "External Tank" (ET). The ET shared much in common with the S-1C Launch Stage in that it also housed both a fuel tank and a tank to hold the oxidizant. The Test Stand was again modified for the Space Transportation System, this time to test the Space Shuttle Main Engine (SSME). Three of these engines were joined together as a cluster on the Space Shuttle's "Orbiter"—the spacecraft that glided back to Earth after completing its missions in low earth orbit.

After the initial development of the SSME, the S-1C Test Stand again underwent modifications in the mid 1980s which converted it to the SSME Technology Test Bed to support an ongoing program to develop technology and knowledge to enhance the performance and increase the useable minutes and starts of high-pressure liquid oxygen and liquid hydrogen propulsion systems based on the SSME.

The S-1C Test Stand continued to be modified and was renamed the Advanced Engine Test Facility. It was then used to evaluate the propulsion system of the Atlas III launch vehicle in the late 1990s, which included a Russian built RD-180 engine.

Conclusion

Tests undertaken on the S-1C Test Stand made it possible to safely and confidently launch human and non-human payloads into space during the Apollo and Space Shuttle programs. The story of the S-1C Test Stand is inextricably bound to the development of the S-1C launch stage, still the most powerful launch stage ever created. The S-1C Test

Stand became an instrument for NASA's engineers at the Marshall Space Flight Center to gather information that was important for engineers. Systems engineers used this information to combine the various stages of the Saturn V rocket, mechanical engineers used information gathered on this launch stage to improve the design of the Apollo program's launch pad, and to test the structural integrity of the Space Shuttle's earliest External Tank (ET) design, and rocket engineers used this test stand to develop the Space Shuttle Main Engine (SSME).

Engineers at the Marshall Space Flight Center used the S-1C Test Stand to analyze and qualify the successive designs of the S-1C Launch Stage. But the use of the launch stage also expressed a relationship between Marshall's engineers and those of Boeing's. In the time of Apollo, the Marshall Space Flight Center established a reputation for the expertise of its engineers in rocket design and for its advocacy of the "Arsenal System," in which they took a "hands-on" approach in designing, testing, and manufacturing the developmental and first articles of their rocket systems. Marshall's engineers created a division of labor: MSFC engineers would take responsibility for the overall development of the rocket design and even the design of manufacturing processes (in broad outline), leaving the detailed engineering of manufacturing processes to the Boeing Corporation. The use of the S-1C Test Stand reflected this division of labor, and Marshall used the test stand until they gained enough confidence, both in the design of the S-1C launch stage and in the design of the launch stage's manufacturing processes, to turn over the manufacture of the S-1C launch stage to Boeing's capable engineers. The approach proved tremendously successful for the Apollo program and for the nation.

Appendix

Test-Firings at the S-1C Test Stand[150]

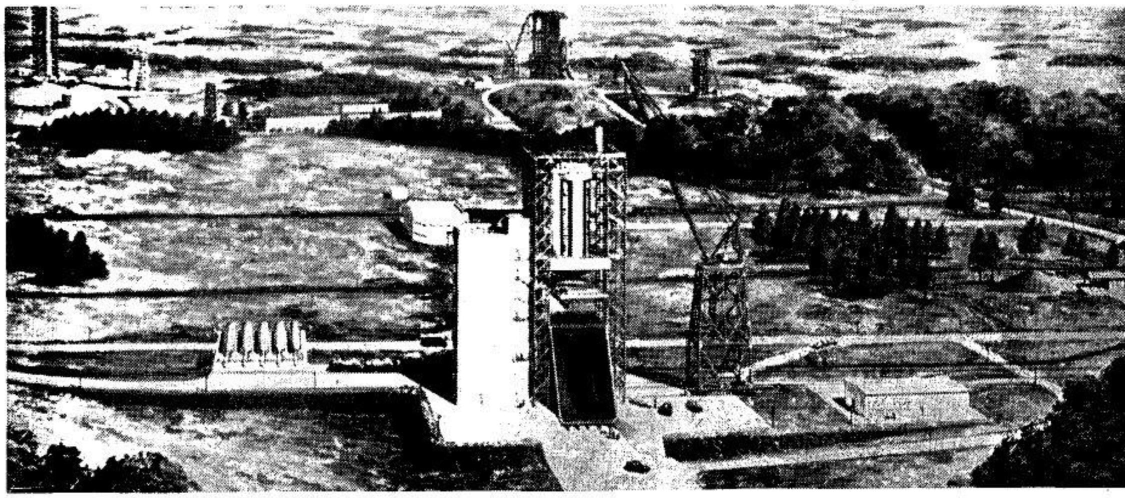
George C. Marshall Space Flight Center (MSFC)/Huntsville, Alabama

Test No.	Date	Time	Test Duration	Stage No.
S-1C-01	9 April 1965	4:21 P.M.	3 sec.	S-1C-T
S-1C-02	9 April 1965	6:42 P.M.	6 sec.	S-1C-T
S-1C-03	10 April 1965	5:12 P.M.	20 sec.	S-1C-T
S-1C-04	16 April 1965	2:57 P.M.	11 sec.	S-1C-T
S-1C-05	6 May 1965	3:10 P.M.	20 sec.	S-1C-T
S-1C-06	20 May 1965	2:58 P.M.	45 sec.	S-1C-T
S-1C-07	8 June 1965	4:08 P.M.	46 sec.	S-1C-T

[150] Table based on data drawn from Test-Fire Logs, *History of Static Firings Conducted at Saturn Static Test Facility, 1960-1970: S-1C-T, S-1C-1, S-1C-2, S-1C-3* (4572-SA-T STATIC TEST.pdf). NASA History Office, Marshall Space Flight Center, Huntsville, Alabama.

S-1C-08	11 June 1965	2:59 P.M.	91 sec.	S-1C-T
S-1C-09	29 July 1965	5:55 P.M.	18 sec.	S-1C-T
S-1C-10	5 Aug 1965	4:02 P.M.	143 sec.	S-1C-T
S-1C-11	8 Oct 1965	4:40 P.M.	42 sec.	S-1C-T
S-1C-12	3 Nov 1965	4:38 P.M.	91 sec.	S-1C-T
S-1C-13	24 Nov 1965	1:06 P.M.	159 sec.	S-1C-T
S-1C-14	9 Dec 1965	4:07 P.M.	158 sec.	S-1C-T
S-1C-15	16 Dec 1965	2:58 P.M.	46 sec.	S-1C-T
S-1C-20	1 Aug 1965	3:00 P.M.	10 sec.	S-1C-T
S-1C-21	3 Aug 1967	3:00 P.M.	11 sec.	S-1C-T
S-1C-22	3 Aug 1967	7:23 P.M.	49 sec.	S-1C-T
S-1C-16	17 Feb 1966	3:18 P.M.	41 sec.	S-1C-1

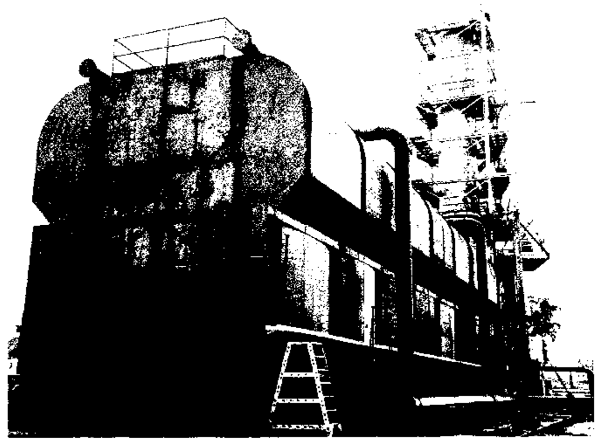
S-1C-17	25 Feb 1966	2:58 P.M.	83 sec.	S-1C-1
S-1C-18	7 June 1966	6:42 P.M.	126 sec.	S-1C-2
S-1C-19	15 Nov 1966	3:38 P.M.	127 sec.	S-1C-3



NEW STATIC TEST FACILITY—Artist's concept of the new $10,800,000 static test facility that will be constructed at the Marshall Center for static testing of Saturn. The test facility currently in use for static testing is shown directly behind the new facility. Plans for the new test facility were revealed by David Newby, director of the Office of Technical Services at Marshall, during the industry conference held here last week. (See Story Inside).

Figure 1: Artist's Conception of the S-1C Static Test Stand and Caption. *Source*: *Marshall Star*, 5 October 1960, p. 1.

Figure 2: Loading the S-1C-T Launch Stage into the S-1C Test Stand. *Source*: Image Reference Number MSFC-75-SA-4105-2C, Visual Media. History Office, George C. Marshall Space Flight Center. Huntsville, Alabama.



SOUND SUPPRESSOR

MSFC erected at its Interim Test Stand during this report period this sound suppressing structure. Initially tested with H-1 engines, the facility is designed to soften the sound of the Saturn V's F-1 engines.

Figure 3: Sound Suppressor. *Source*: David S. Akens, *History of the George C. Marshall Flight Center, From January 1 Through June 30, 1963*. MSFC Historical Monograph No. 7 (Huntsville, Alabama: MSFC Historical Office, November 1963), 138.

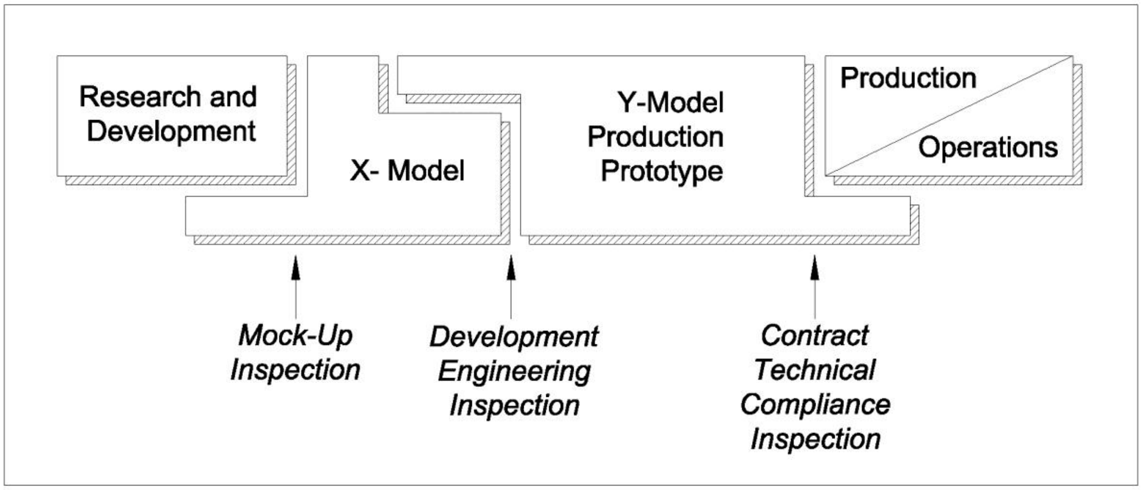


Figure 4: Fly-Before-You-Buy Sequential Development Program. *Source*: Adapted from Stephen B. Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore: Johns Hopkins University Press, 2002), 22, and Benjamin Bellis, L/Col USAF Office DCS/Systems, "The Requirements for Configuration Management During Concurrency," AFSC Management Conference, May 1962, Air Force Systems Command, Andrews Air Force Base, Washington, D.C., 5-24-2.

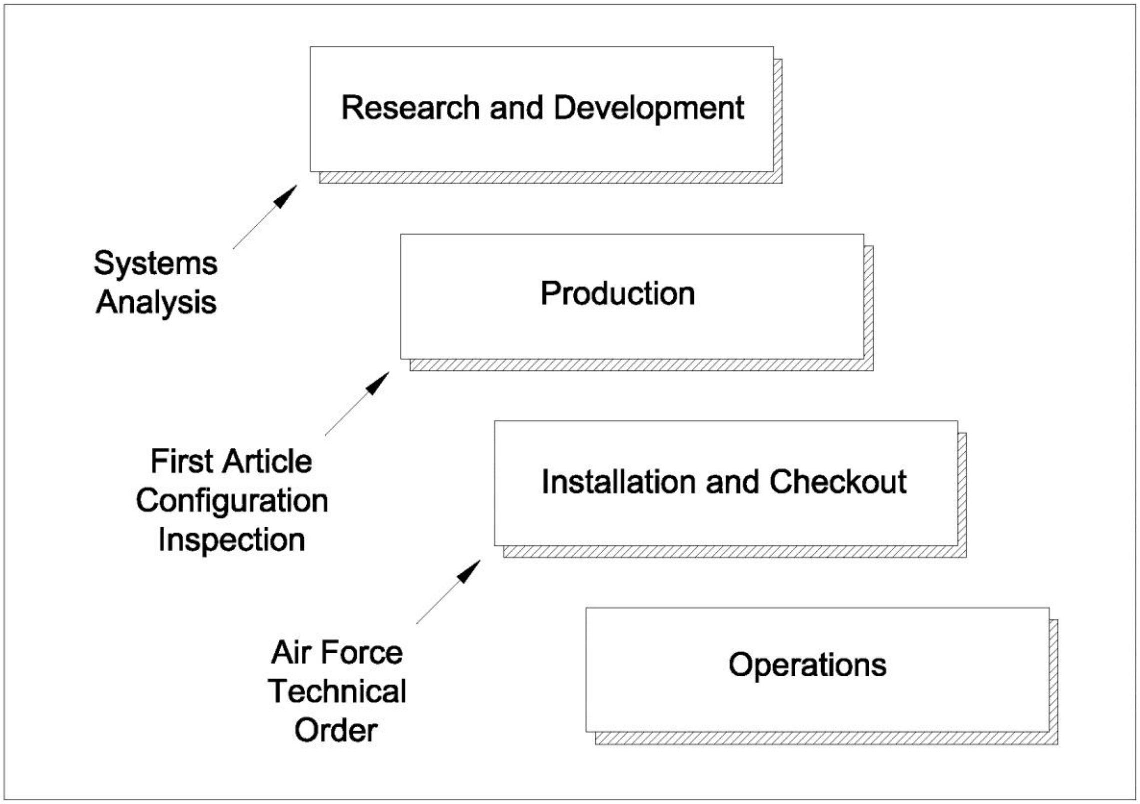


Figure 5: Concurrency. *Source*: Adapted from Stephen B. Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore: Johns Hopkins University Press, 2002), 42, and Benjamin Bellis, L/Col USAF Office DCS/Systems, "The Requirements for Configuration Management During Concurrency," AFSC Management Conference, May 1962, Air Force Systems Command, Andrews Air Force Base, Washington, D.C., 5-24-3.

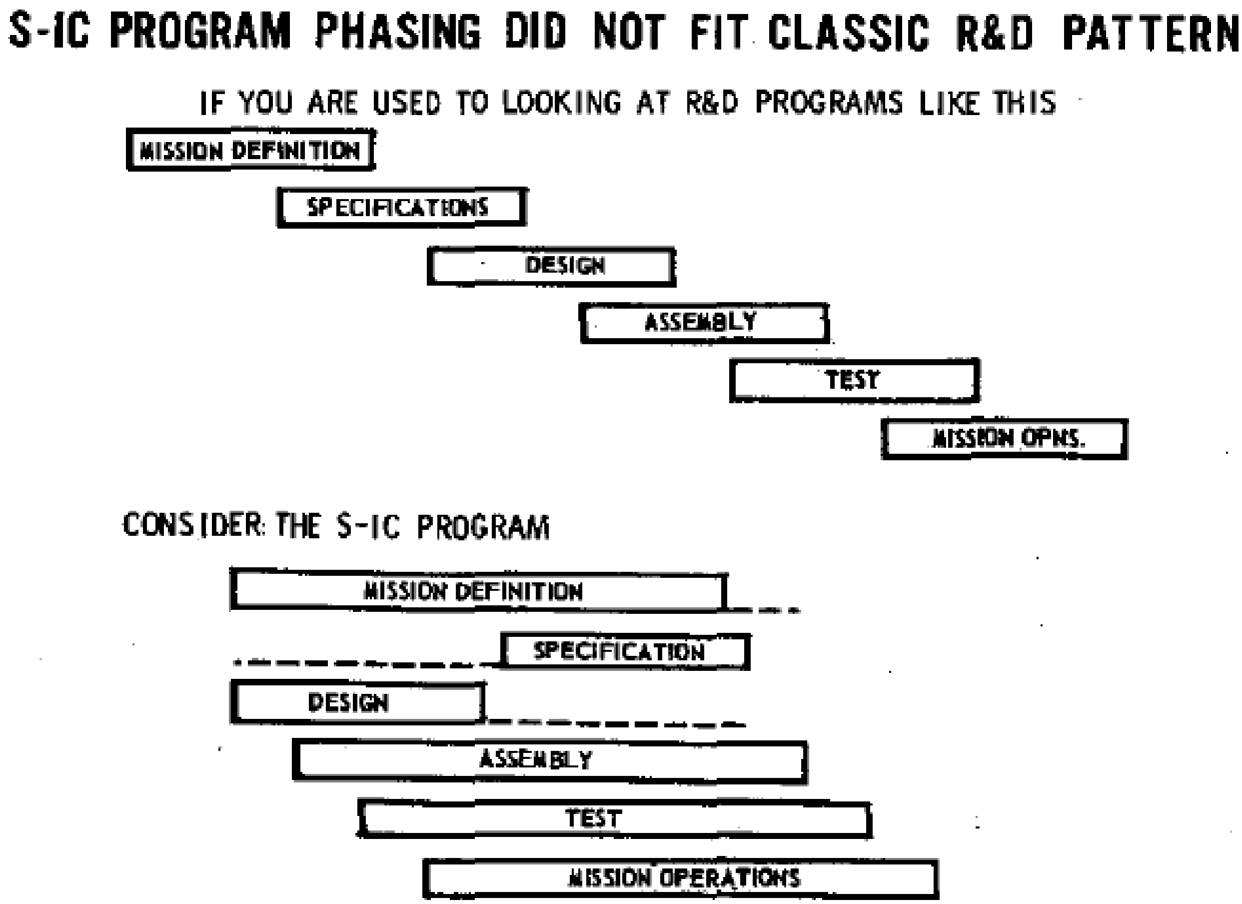


Figure 6: Concurrent Program of Development for the S-1C Launch Stage. *Source*: Figure 5, U.S. House of Representatives, Ninety-First Congress, First Session, *Apollo Program Management: Staff Study for the Subcommittee on NASA Oversight of the Committee on Science and Astronautics*. Washington, D.C.: U.S. Government Printing Office, 1969, 20.

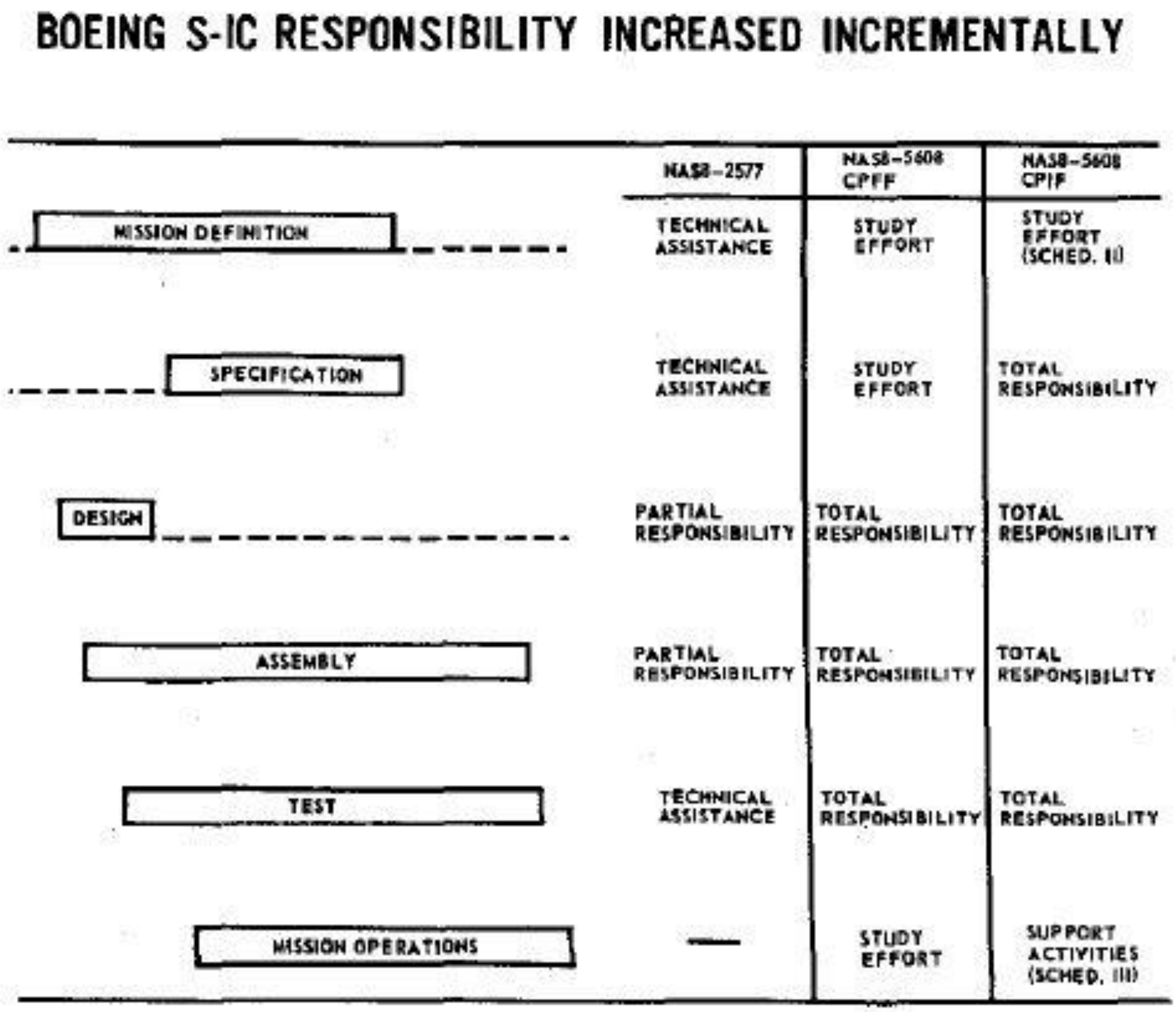


Figure 7: Boeing Responsibility for Development and Production of the S-1C Launch Stage. “Figure 6,” U.S. House of Representatives, Ninety-First Congress, First Session, *Apollo Program Management: Staff Study for the Subcommittee on NASA Oversight of the Committee on Science and Astronautics*. Washington, D.C.: U.S. Government Printing Office, 1969, 20.

Bibliography

Primary Sources

Interviews:

Tepool, Ronald. Interviewed by Douglas Jerolimov, 11 March 2013. Recording. NASA History Office, Marshall Space Flight Center, Huntsville, Alabama.

Tiesenhausen, Georg von. Interview by A. Dunar and S. Waring, 29 November 1988. MSFC History Project, transcript. NASA History Office, Marshall Space Flight Center, Huntsville, Alabama.

Urlaub, Matthew. Interviewed by Roger E. Bilstein. 29 July 1975. Transcript. NASA History Office, Marshall Space Flight Center, Huntsville, Alabama.

Speeches:

Kennedy, President John F., "We Choose to Go to the Moon..," Speech Given at Rice University, Houston, Texas, 12 September 1962.

Kenney, President John F., "Urgent National Needs," Speech Given to Joint Session of Congress, Washington, DC, 25 May 1961. Available at http://www.jfklibrary.org/Asset-Viewer/xzw1gaeeTES6khED14P1Iw.aspx.

Newspapers:

Marshall Star (Huntsville, Alabama)

Memoranda:

Heimburg, Karl L., Office of Director, Test Division, to David S. Akens [M-MS-H], Memorandum, "Test Division's Historical Report, July 1, 1962 – December 31, 1962," 19 March 1963, MSFC Annual Chronologies (1960-1990), Series 102 Chronologies, History Office, George C. Marshall Space Flight Center, Huntsville, Alabama.

Technical Manuals:

National Aeronautics and Space Administration, *Skylab Saturn IB Flight Manual*, Document NASA-TM-x-70137. Huntsville, Alabama: George C. Marshall Space Flight Center, 30 September 1972.

News Releases:

National Aeronautics and Space Administration, News Release, "The National Aeronautics and Space Administration will negotiate with the Boeing Co., Seattle, Wash.," December 15, 1961, History Office, Marshall Space Flight Center, Huntsville, Alabama.

Public Information Office, George C. Marshall Space Flight Center, "NASA … placed in force a $15,954,096 supplemental agreement to the contract with the Boeing Company, Seattle, for preparatory work leading to the design, development, fabrication and test of the first stage (S-1C) for the Saturn C5 vehicle," August 2, 1962, History Office, Marshall Space Flight Center, Huntsville, Alabama.

Test-Fire Logs:

Test-Fire Logs, *History of Static Firings Conducted at Saturn Static Test Facility, 1960-1970: S-1C-T, S-1C-1, S-1C-2, S-1C-3* (4572-SA-T STATIC TEST.pdf). NASA History Office, Marshall Space Flight Center, Huntsville, Alabama.

Management Sources:

Balch, Jackson L. "Weekly Notes to Wernher von Braun," NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.

Brown, Richard. "Weekly Notes to Wernher von Braun," NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.

Heimburg, Karl. "Weekly Notes to Wernher von Braun," NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.

Koelle, Heinz-Hermann. "Weekly Notes to Wernher von Braun," NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.

Kuers, William. "Weekly Notes to Wernher von Braun," NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.

Lange, Oswald H. "Weekly Notes to Wernher von Braun," NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.

Maus, Hans. "Weekly Notes to Wernher von Braun," NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.

Rudolph, Arthur. "Weekly Notes to Wernher von Braun," NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.

Smith, R.G. “Weekly Notes to Wernher von Braun,” NASA History Office, Marshall Space Flight Center. Huntsville, Alabama.

Reports

Test Laboratory, Technical Support Division, NASA. *Test Laboratory Facilities and Capabilities*. NASA History Office, Marshall Space Flight Center, Huntsville, Alabama, January 1, 1966.

U.S. House of Representatives, Ninety-First Congress, First Session. *Apollo Program Management: Staff Study for the Subcommittee on NASA Oversight of the Committee on Science and Astronautics*. Washington, D.C.: U.S. Government Printing Office, 1969.

Drawings

Hunt, Fred. “Building 4670, Replacement – Condensate System Plans – Details,” Drawing No. FAC-D-4670-M15. 15 July 1976, Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama.

Hunt, Fred. “Building 4670, Replacement – Condensate System Plans – Details,” Drawing No. FAC-D-4670-M16. 15 July 1976, Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama.

Lovin, R. P. [Designer]. “Saturn Static Test Facility,” Drawing No. 60-09-08, Sheet 3 of 33. April 1965. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama.

Whiteing, R. A. “LH2 External Tank Strength Test Facility. S-1C Test Stand Modification. Vestibule Bldg Details & Tower Alterations. Drawing No. FAC-B-4670-A1. 1 July 1974, Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama.

Other Primary Sources

“Loading an S-1C Launch Stage into the S-1C Test Stand.” Image 4355.jpg, n.d., ca. Apollo Program. 300 Series—Visual Media. History Office, George C. Marshall Space Flight Center. Huntsville, Alabama.

Saturn V News Reference, NASA History Office, George C. Marshall Space Flight Center, Huntsville, Alabama.

Secondary Literature

Akens, David S., Paul H. Satterfield, Helen T. Wells, and A. R. Jarrells, *History of the George C. Marshall Space Flight Center, From July 1 to December 31, 1961.* MSFC Historical Monograph No. 4. Huntsville, Alabama: MSFC Historical Office, March 1962. NASA History Office, Marshall Space Flight Center, Huntsville, Alabama.

Akens, David S. *History of the George C. Marshall Space Flight Center from January 1 Through June 30, 1963*. MSFC Historical Monograph No. 7. Huntsville, Alabama: MSFC Historical Office, George C. Marshall Space Flight Center, NASA, November 1963. NASA History Office, Marshall Space Flight Center, Huntsville, Alabama.

Bellis, Benjamin, L/Col USAF Office DCS/Systems, "The Requirements for Configuration Management During Concurrency," AFSC Management Conference, May 1962, Air Force Systems Command, Andrews Air Force Base, Washington, D.C. 5.24.1 – 5.24.14.

Bilstein, Roger E. *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles*. Washington, D.C.: NASA History Office, 1980.

Bromberg, Joan Lisa. *NASA and the Space Industry*. Baltimore: Johns Hopkins University Press, 1999.

Brooks, Courtney G., James M. Grimwood and Lloyd S. Swenson, Jr. *Chariots for Apollo: A History of Manned Lunar Spacecraft*. Washington, D.C.: National Aeronautics and Space Administration, 1979.

Cortright, Edgar M., Ed. *Apollo Expeditions to the Moon*. Washington, D.C.: U.S. Government Printing Office, 1975.

Ertel, Ivan D., Roland W. Newkirk and Courtney G. Brooks, *The Apollo Spacecraft: A Chronology*. Washington, D.C.: Scientific and Technical Information Division, Office of Technology Utilization, National Aeronautics and Space Administration, 1969-1978.

Dunar, Andrew J., and Stephen P. Waring, *Power to Explore: A History of Marshall Space Flight Center, 1960-1990.* Washington, D.C.: National Aeronautics and Space Administration, 1999.

Holley, Irving Brinton, Jr. *Buying Aircraft: Materiel Procurement for the Army Air Forces*, Volume 7 of Stetson Conn, ed., *United States Army in World War II*. Washington, D.C.: Dept. of the Army, 1964.

Johnson, Stephen B. *The Secret of Apollo: Systems Management in American and European Space Programs*. Baltimore: Johns Hopkins University Press, 2002.

_________. The United States Air Force and the Culture of Innovation, 1945-1965. Washington, D.C.: Air Force History and Museums Program, 2002.

_________. "From Concurrency to Phased Planning: An Episode in the History of Systems Management," pp. 93-112. In Agatha C. Hughes and Thomas P. Hughes, eds., *The Systems Approach in Management and Engineering, World War II and After*. Cambridge, Massachusetts: MIT Press, 2000.

McCurdy, Howard E. *Inside NASA: High Technology and Organizational Change in the U.S. Space Program*. Baltimore: Johns Hopkins University Press, 1993.

Lambright, W. Henry. *Powering Apollo: James E. Webb of NASA*. Baltimore: Johns Hopkins University Press, 1993.

Logsdon, John M., "Selecting the Way to the Moon: The Choice of the Lunar Orbital Rendezvous Mode," *Aerospace Historian 18*, June 1971, 63-70.

Sutton, George P. *Rocket Propulsion Elements: An Introduction to the Engineering of Rockets*. Sixth Edition. New York: John Wiley & Sons, 1992.

_________. *History of Liquid Propellant Rocket Engines*. Reston, Virginia: American Institute of Aeronautics and Astronautics, 2006.

Smith, Merritt Roe. *Harpers Ferry Armory and the New Technology: The Challenger of Change*. Ithaca, New York: Cornell University Press, 1977.

Smith, Merritt Roe. "The Harper Ferry Armory and the 'New Technology' in America, 1794-1854." Ph.D. Dissertation: Pennsylvania State University, 1971.

Tompkins, Phillip K. *Organizational Communication Imperatives: Lessons of the Space Program*. Los Angeles: Roxbury, 1992.

Von Braun, Wernher. "Saturn the Giant," pp. 41-58, In Edgar M. Cortright, ed. Apollo Expeditions to the Moon. Washington, D.C.: U.S. Government Printing Office, 1975.

Weitze, Karen J. *National Assessment of Marshall Space Flight Center, National Aeronautics and Space Administration*. Huntsville, Alabama: National Aeronautics and Space Administration, February 2007.

Lambright, W. Henry. *Powering Apollo: James E. Webb of NASA*. Baltimore: Johns Hopkins University Press, 1995.