

NASA JOHNSON SPACE CENTER, BUILDING NO. 32, SPACE
ENVIRONMENT SIMULATION LABORATORY, CHAMBERS A & B
2101 NASA Parkway
Houston
Harris County
Texas

HAER TX-109-B
HAER TX-109-B

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

REDUCED COPIES OF MEASURED DRAWINGS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
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HISTORIC AMERICAN ENGINEERING RECORD

NASA JOHNSON SPACE CENTER, BUILDING No. 32, SPACE ENVIRONMENT SIMULATION LABORATORY, CHAMBERS A & B

HAER No. TX-109-B

- Location:** 2101 NASA Parkway, Houston, Harris County, Texas
Latitude: 29.560767°, longitude: -95.088167°. The coordinate represents the approximate mid-point between Chambers A and B in the high-bay section of NASA, Johnson Space Flight Center's building 32. This coordinate was obtained on January 3, 2013 by plotting the point using TerraGo Technologies' tools applied to a digital copy of the 1:24000 League City, Texas USGS Topographic Quadrangle map. The accuracy of the coordinate is ± 12 meters. The coordinate's datum is North American Datum 1983.
- Present Owner:** National Aeronautics and Space Administration (NASA)
- Present Use:** Chambers A and B were reactivated in 1988. Chamber A is currently being modified to support the testing of the James Webb Telescope.
- Significance:** Chambers A and B of the Space Environment Simulation Laboratory were critical to the success of Project Apollo and to the manned spacecraft program. Chamber A could achieve conditions similar to those at 87 miles above the earth's surface and was used in testing of the Apollo vehicle. When completed, it was the largest man-rated vacuum chamber built. Chamber B was used for testing the Apollo command module, as well as providing a simulated space environment for training astronauts.
- Historian:** Adapted with permission from the report "To Create Space on Earth: The Space Environment Simulation Laboratory and Project Apollo" (NASA/CR—2003-208933) written by Lori C. Walters, Ph.D., University of Central Florida, February 2003. Walters' report is available in hard copy form from NASA Center for AeroSpace Information, 7121 Standard, Hanover, Maryland, 20716-1320. Additionally, it can be obtained electronically at http://ston.jsc.nasa.gov/collections/TRS/_techrep/CR-2003-208933.pdf.
- Project Information:** This recording project is part of the Historic American Engineering Record (HAER), a long-range program to document historically significant engineering, industrial and maritime works in the United States. The HAER program is administered by the National Park Service, U.S. Department of the Interior. The Space Environment Simulation

Laboratory recording project was cosponsored by the Planning and Integration Office of the Johnson Space Center (JSC) with guidance and assistance by Perri Fox, Sandra Tetley, and Mary Halligan. The field work and measured and interpretive drawings were prepared under the general direction of Richard O'Connor, Chief, Heritage Documentation Programs, National Park Service. The project was managed by Thomas Behrens, HAER Architect and Project Leader. The measured and interpretive drawings were produced by John Wachtel. The large-format photographs were produced by the Imaging Lab at Johnson Space Center. The written historical and descriptive data were adapted from a manuscript written by Dr. Lori C. Walters, University of Central Florida.

PART I. HISTORICAL INFORMATION

A. Physical History:

1. Dates of Construction: Chamber A was built from spring 1963 to May 1964. Additional modifications were undertaken in 1965 and 1966 after testing revealed some design problems. Chamber B was under construction and testing from spring 1963 to June 1964.¹

2. Architect/Engineer: Bechtel Corporation served as the architect-engineer for the Space Environment Simulation Facilities.²

3. Builder/Contractor/Supplier: Chicago and Bridge Iron was awarded the contract for Chambers A and B. Ets-Hokin and Galvan, Inc., won the contract for the facility foundation and high-bay superstructure. Industrial, Fisher, and Diversified was responsible for the cryogenic, mechanical, and electrical systems. The contract for the large lunar plane designed to rotate the Apollo vehicle was awarded to Paul Hardeman, Inc. Radio Corporation of America won the contract for the design, fabrication, and installation of a carbon-arc based solar simulation system.³

Brown & Root/Northrup (BRN) were responsible for the operation and support of SESL.

4. Original Plans: The initial design configuration developed by the “Working Group on Requirements for Space Environment Simulation Facilities” in February 1962 consisted of four chambers: Chamber A, human-rated space and lunar surface environment simulation; Chamber B, astronaut training and environmental control system studies; Chamber C, spacecraft module evaluation tests; and Chamber D, systems tests under extreme vacuum. In March 1962, the group submitted its initial draft design for use by the selected architect-engineer.⁴

Once Bechtel Corporation was selected as the architect-engineer, they developed the basic requirements of the working group into an engineering cost study. Early during the design phase, Bechtel and Manned Space Craft (MSC) representatives

¹ See “Apollo Chamber Tests to Start this Summer,” *Space News Roundup*, 5, no. 18 (June 24, 1966), 2, for additional information.

² Brown and Root Construction Company was the architect-engineer for the overall site.

³ J.P. Vincent, A.W. Johnson, and W.E. Freeborne, “Solar Simulation Systems of the Space Environment Simulation Laboratory at the Manned Spacecraft Center,” 4, Johnson Space Center’s History Collection at the University of Clear Lake, Houston, Texas (hereafter cited as JSC-SESL Archives).

⁴ Memo, Arthur H. Hinnens to Distribution, “Responsibilities of Working Committee for Establishment of Requirements for Space Environment Simulation Chambers for MSC, Houston, Texas,” February 16, 1962; Memo, Arthur Hinnens to Aleck Bond, “Proposed Schedule Space Environment Simulation Chambers, Manned Spacecraft Center, Houston, Texas,” no date provided, both in JSC-SESL Archives.

determined that NASA budgetary constraints would not allow the construction of Chamber C.⁵ A primary question to be resolved was the vacuum vessel's shape and material composition. For Chamber A, the designers evaluated both cylindrical with hemispherical heads and multispherical vessels with consideration to cost, reliability, and future adaptability. Construction materials considered included carbon steel, austenitic stainless steel, stainless steel, clad carbon steel, and aluminum-magnesium alloys with analyses of thermal expansion, the costs of material, and its fabrication. The study concluded that Chamber A should be a vertical cylindrical shell 75' in diameter with 97' straight sides, a hemispherical top head, ellipsoidal bottom head, and a 45'-diameter side opening door constructed of stainless steel clad carbon steel with carbon steel stiffeners. Chamber B should be a vertical cylindrical shell with an overall height of 60', 35' in diameter with a removable D/3 ellipsoidal top head and matching non-removable bottom head constructed of stainless steel with carbon steel stiffeners.⁶ The two chambers would be housed together in a multistory high-bay structure with an adjacent administrative building. Chamber D, the smaller ultra-high-vacuum chamber, would not be housed in the proposed SESL facility.

5. Alterations and Additions: Chamber A is currently being altered to accommodate testing of the James Webb Space Telescope. The modifications to allow testing of this instrument were slated to begin in summer 2008 and include:

1. Radiant Intensity Measurement System (RIMS) removal
2. Top Sun/Side Sun Shroud removal
3. Selected Door Entry Shroud removal
4. Air Flow Port Shroud modification
5. Lunar Plane Drive Shaft removal, and
6. Diffusion Pump demolition.⁷

B. Historical Context:

Introduction

Few undertakings in the history of humanity can compare to the great technological achievement known as Project Apollo. It is estimated that 500 million persons sat transfixed in front of television sets as Neil Armstrong ventured onto the lunar surface in July 1969.⁸ Apollo 11 achieved President John F. Kennedy's May 1961 pledge of

⁵ Aleck Bond, interview by Robert Merrifield, written transcript, October 10, 1967, 5; Joseph N. Kotanchik, interview by Robert Merrifield, written transcript, April 3, 1968, 2, JSC-SESL Archives.

⁶ "Progress Meeting Notes," April 13, 1962, JSC-SESL Archives.

⁷ "Consultation for Original Hardware Modification and/or Removal from the Space Environment Simulation Laboratory, Chamber A."

⁸ "Thirtieth Anniversary of Apollo 11: 1969-1999," available from http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_11_30th.html; Alan Shepard and Deke Slayton, *Moonshot* (Atlanta: Turner Publishing Inc., 1994), 244. The U.S. Census Bureau International Data Base estimates the mid-year 1969 world population at 3.6 billion, suggesting 14 percent of the world's population witnessed the event live.

landing men on the Moon by the close of the decade. Among those who witnessed Armstrong's flickering television image were thousands of people who had directly contributed to this historic moment. Amongst those in this vast anonymous cadre were the personnel of the Space Environment Simulation Laboratory (SESL) at the Manned Spacecraft Center (MSC) in Houston, Texas.⁹ At a time when NASA engineers had a limited understanding of the effects of extremes of space on hardware and crews, SESL was designed to literally create the conditions of space on Earth.

Sputnik and the Origins of NASA

A thin plume of orange rising into the Soviet sky on 4 October 1957 carried aloft humankind's first artificial satellite. The twenty-two-inch sphere called "Sputnik," in its purest form, was an incredible technological achievement that all of humanity should have taken pride in. Instead, it marked the beginning of a new phase in the Soviet-American Cold War power struggle—national prestige now included the heavens. The faint, constant beeps of Sputnik I bewildered an American public who had firmly believed their technological superiority could never be surpassed. Public bewilderment gave way to instances of panic in the wake of Sputnik II, launched one month later on November 3. With Sputnik II, not only had the Soviets successfully placed a living creature into Earth orbit, the payload weight of 1,121 pounds was staggering. Public concerns regarding the threat of atomic annihilation had existed since Soviet detonation of an atomic bomb in 1949. However, U.S. defense officials assured civilians that the threat from Soviet bombs was survivable, given the time frame from bomber detection to payload delivery. The payload capacity of the Sputnik II booster intensified public fears of Soviet warhead delivery from within hours to within minutes.

In Washington, D.C., critics charged that the U.S. educational system failed to stress the same fundamentals in science and mathematics as the Soviet system. Without a solid core of new scientists and engineers, the American way of life was in danger of being overrun by the ambitious "Reds." The National Defense Education Act of 1958 allocated nearly \$1 billion to increase emphasis on science, mathematics, and foreign language in elementary, secondary, and collegiate education. American school children needed to be as versed in algebraic formulas as they were in baseball batting averages, if the United States hoped to surpass Sputnik. For the nation's future space endeavors, the National Defense Education Act provisions would assist in the education of many who were involved in Project Apollo and subsequent programs.

Education in the sciences was only a portion of the federal response to the Soviet technological coup. President Dwight D. Eisenhower faced criticism that his policy of "fiscal responsibility" had hindered the military's ability to develop intercontinental ballistic missiles (ICBMs). Senate Majority Leader Lyndon Baines Johnson (D-Tex) opened a subcommittee of the Senate Armed Services Committee to review the nation's missile and space programs. Eisenhower partially succumbed to mounting political

⁹ SESL is pronounced "Cecil."

pressures by loosening budgetary purse strings to permit an increase in dollars allocated for missiles. However, Eisenhower was steadfast in his desire for the peaceful, non-military exploration of space. Under the guidance of the Eisenhower Administration and Congress, the National Aeronautics and Space Act of 1958 formally established the National Aeronautics and Space Administration (NASA), setting forth “the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind.”¹⁰ The President appointed Dr. T. Keith Glennan as the first Administrator of NASA. Through this infant civilian agency, the nation placed its hopes of regaining its tarnished technological leadership role and simultaneously limiting the expansion of blatant Cold War militarization into the new frontier of space.

The Road to Apollo

The creation of a civilian space agency did not instantly squash the U.S. military’s desire to control or, at the very least, directly participate in crewed spaceflight. The United States Air Force (USAF) coveted the Man in Space Program, as it believed the program to be a natural extension of its mission. The USAF had been working toward placing a human in space with its X-series of winged rocket planes. Thus, when it became apparent the fastest way to surpass the Soviets and put a human in space was through the placement of a human payload on a ballistic missile, the USAF lobbied for this assignment as well. President Eisenhower, the former military hero of World War II, now had to decide whether human space travel should continue as a natural extension of the USAF, become a prime directive of the newly created NASA, or be shared. From a propaganda standpoint, as the leader of the Free World, United States entry into crewed spaceflight would have to be a civilian effort. While the new astronaut corps comprised military test pilots, the overall program would be under the control of NASA.¹¹

The human spaceflight effort had been set forth and created as an entity within NASA. Under the direction of Dr. Robert R. Gilruth, the newly formed Space Task Group (STG) was charged with placing humans into orbit. STG set the parameters and goals for America’s first civilian-crewed foray into space with Project Mercury. The creation of STG had implications far beyond its autonomy within the NASA contingent at Langley Research Center. Those activities that comprised the group’s organizational nucleus at Langley essentially became the MSC in Houston, Texas—with Robert R. Gilruth serving at its first director.¹²

While STG designed the human payload capsule of Project Mercury, the development of new and wholly civilian boosters was an impossible task, as NASA sought the most expedient route in placing an American into space. It was necessary for this civilian

¹⁰ National Aeronautics and Space Act of 1958, Public Law No. 85-568, as Amended, Section 102 (a), available at <http://www.hq.nasa.gov/ogc/spaceact.html#POLICY>.

¹¹ Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (Baltimore: Johns Hopkins University Press, 1985), 200.

¹² Henry C. Dethloff, *Suddenly Tomorrow Came...A History of the Johnson Space Center*, SP-4307 (Houston: NASA Johnson Space Center, 1993), 19; Robert B. Merrifield, *Men and Spacecraft: A History of Manned Spacecraft Center, 1958-1969*, 2-2.

agency to rely on the military, specifically the Redstone surface-to-surface intermediate range ballistic missile technology under the control of the Army Ballistic Missile Agency and the still yet-to-be perfected USAF Atlas ICBM. Together, Redstone and Atlas served as the launch vehicles for all six crewed Mercury missions. The Air Force Missile Test Center at Cape Canaveral, Florida, supported all crewed launches.¹³

By 1959, when NASA/STG established a liaison office at Cape Canaveral, the Cape served as the nation's premier launch test facility. Subsequently, support and administrative space at the Cape became scarce and use of actual launch facilities highly competitive among the various military branches and NASA. The USAF assigned Hangar S for STG Mercury preflight use and complexes 5/6 and 14 for Mercury Redstone and Mercury Atlas launches, respectively. Cape Canaveral also served as the Mission Control Center for all crewed missions before Gemini 4.

Despite the political pressures, President Eisenhower steadfastly refused to engage in an outright "race" with the Soviet Union in both the development and stockpiling of ICBMs or in human spaceflight. Although NASA announced the selection of the seven Mercury astronauts on 9 April 1959 with tremendous media fanfare, the Eisenhower Administration did not harbor serious designs to implement a long-range crewed lunar landing program once Project Mercury ended.¹⁴ The presidential election of 1960 marked the ascendance of the Democratic Party to the presidency and, with this shift, a heightened drive toward ICBM development and the propaganda value of space. Throughout the 1960 campaign, candidate John Kennedy propagated a belief that the United States lagged behind the Soviets in the development and deployment of ICBMs. A belligerent tone toward the Communist nations continued to resonate in Kennedy's voice during his Inaugural Address—"We dare not tempt them [the Soviets] with weakness. For only when our arms are sufficient beyond doubt can we be certain beyond doubt that they will never be employed."¹⁵

His initial dealings with the Communist world presented Kennedy with a faltering political image at home and abroad. Within four months of his inauguration, the new President encountered a dogmatic Soviet Premier Nikita Khrushchev at their first meeting in Vienna, became embroiled in the ill-advised Cuban Bay of Pigs invasion, and faced a growing Communist threat in Laos. When the Soviet news agency TASS announced the Earth orbital flight of Yuri Gagarin on 12 April 1961, the Soviets technologically upstaged the United States just as they had done in 1957 with Sputnik. For STG and the Mercury Astronauts, Gagarin's flight brought disappointment and the realization that their reply to the Soviet orbital feat would be nothing more than a 300-mile suborbital

¹³ For documentation of the Redstone Arsenal, see Historic American Engineering Record (HAER), National Park Service, U.S. Department of the Interior, "Redstone Arsenal," HAER No. AL-9.

¹⁴ Robert A. Devine, *Sputnik Challenge: Eisenhower's Response to the Soviet Satellite* (New York: Oxford University Press, 1993), 107.

¹⁵ John F. Kennedy, *"Let the Word go Forth": The Speeches, Statements and Writings of John F. Kennedy, 1947-1963* (New York: Delacorte Press, 1988), 13.

hop from the Cape. Lt. Cmdr. Alan B. Shepard ascended for a fifteen-minute thirty-two-second glimpse into the heavens on 5 May 1961. Although the U.S. had not achieved Earth orbit, an American could now claim space travel. In return, the American public, who had been enamored with the Mercury Seven since their introduction some two years earlier, transformed the brash Shepard into a national hero akin to the days of Charles Lindbergh.

The Kennedy Administration now sensed the opportunity to transform human spaceflight into the ultimate in Cold War braggadocio. During a special address to Congress on 25 May 1961, President Kennedy publicly acknowledged a space “race” with the Soviets. He went on to assure the American people that space was an arena the Free World could not permit Soviet domination of and set forth his pledge for an American lunar landing by decade’s end.¹⁶ Project Apollo had been unveiled to the world. A bitterly disappointed Eisenhower declared Kennedy’s lunar race was an unfortunate “stunt.” As President, Eisenhower had gone to great pains to reduce the Cold War politicization of space and now he believed Kennedy was attempting to shift public attention from his recent Cold War setbacks to the playing field of space.¹⁷ Although Eisenhower’s observations regarding Kennedy’s motivations may have been highly accurate, the positive ramifications for human spaceflight were immediate.

Creation of the Manned Spacecraft Center

Since its inception, STG was an organization in search of an operational center because STG members were stationed at a variety of NASA centers and facilities. If human spaceflights were to become a long-range component of the nation’s space plan, logic dictated the creation of a central hub for crewed affairs. In 1961, Congress provided \$60 million for the establishment of a human spaceflight laboratory in the 1962 NASA appropriations bill. The primary question in 1961 was where to locate this new NASA facility. Official criteria for site selection included: temperate climate, accessibility to barge traffic, reasonable proximity to a metropolitan area for labor and cultural support, nearby academic institution(s), a minimum 1,000-acre plot of land, and the existence of basic supporting infrastructure. With the resignation of Glennan in January 1961, the new NASA Administrator James E. Webb established a four-member committee to visit twenty-three candidate sites during late summer 1961.

The Houston, Texas, area fulfilled the requirements; in addition, land acquisition costs could be defrayed as Rice University offered use of 1,000 acres of pastureland near Clear Lake for the facility.¹⁸ Public announcement of the Houston site selection was made 19

¹⁶ Kennedy, *“Let the Word go Forth”*, 173-174.

¹⁷ Michael R. Beschloss, *The Crisis Years: Kennedy and Khrushchev, 1960-1963* (New York: Edward Burlingame Books, 1991), 166.

¹⁸ In addition to fulfilling the technical criteria, Houston possessed political advantages for NASA. Congressman Albert Thomas (D-Tex) was Chairman of the House Appropriations Subcommittee responsible for NASA funding. As early as October 1958, Thomas supported the placement of a NASA facility in his home district of Houston; Vice-President Johnson hailed from Texas and was head of the Space Council; Speaker of the House Sam Rayburn

September 1961 with the understanding the facility would be “the command center for the manned lunar landing mission and all follow-on manned spaceflight missions.”¹⁹ Interim offices were set up throughout southeast Houston on a lease basis. Plans called to open the permanent facility by the close of 1963.

The task of transforming the cattle-trodden land near Clear Lake into the new training center for America’s astronauts must have seemed almost as daunting as sending men to the Moon by 1969. It would fall upon the shoulders of the U.S. Army Corps of Engineers to orchestrate the metamorphosis. NASA Administrator Webb officially informed the Chief of Engineers, Lt. Gen. W.K. Wilson, Jr., via a letter dated 22 September 1961.²⁰ It should be noted a 1960 cooperative agreement between NASA and the Corps established that it was “the policy of the Chief of Engineers to make available the services of his construction forces to perform design or construction services at such places as desired by NASA.”²¹ Webb elected to use the Corps primarily due to its prior experience in projects of this nature—in both a political and physical sense. A young agency such as NASA simply did not possess the necessary internal construction organization to accomplish a project as wide in scope as MSC, nor the political experience to weather any potential storms stemming from the award of large construction contracts. During its tenure overseeing the development of MSC, the Corps had to draw upon every ounce of knowledge gained from constructing USAF missile sites and Army Ballistic Missile Agency facilities. The Corps was responsible for design administration, construction contracting, and inspection of facilities to ensure compliance with design specifications; NASA retained direct control of payments.

Chief Engineer Wilson tasked the MSC project to the Fort Worth Division, under the direction of District Engineer Col. R. Paul West and Deputy District Engineer Lt. Col. Wayne A. Blair. NASA representatives I. Edward Campagna, James M. Bayne, and Martin A. Byrnes promptly informed West of NASA’s two-year MSC construction plan— six months of planning and eighteen months of construction. Even without a detailed understanding as to the scope of cutting-edge facilities under consideration for MSC, the Corps considered completion within the NASA timetable a challenging prospect.²² All parties understood each advancement toward the completion of MSC directly impacted the viability of reaching the Moon by 1970.

As the center for human spaceflight, MSC would contain facilities to both assist in astronaut training and conduct shake-down testing on Apollo hardware. But exactly what

(D-Tex) was also from Texas. The placement of a NASA facility in the home state of these influential political figures was politically savvy for NASA.

¹⁹ Dethloff, *Suddenly Tomorrow Came*, 40.

²⁰ D. Clayton Brown, *Rivers, Rockets and Readiness: Army Engineers in the Sunbelt* (Washington, D.C.: U.S. GPO, 1979), 56.

²¹ “Cooperative Agreement Between the National Aeronautics and Space Administration and the Corps of Engineers Department of the Army on Construction,” EM 1-1-7, December 7, 1960, 1.

²² Dethloff, *Suddenly Tomorrow Came*, 46.

facilities should MSC house? The new Center Director, Robert Gilruth, was determined that there would be no “white elephants” at MSC, there had to be an immediate need, with long-term usefulness, before approval of any facility.²³ A primary concern was to prevent the unnecessary duplication of facilities in existence or under construction at other NASA facilities. Thought was also given to having some test facilities at MSC rather than erecting costly facilities at the prime contractor plants.²⁴ Among the list of candidate facilities were the Flight Acceleration Facility, conceived as the world’s largest human-rated centrifuge to support NASA’s astronaut corps. To simulate the rigors of liftoff and space travel on the Apollo spacecraft, a vibration and acoustic laboratory was desired. The most ambitious of all undertakings would be the facility to recreate the vacuum and temperature extremes of space here on Earth—the SESL. A major challenge to the Corps was the cutting-edge technology implicit in such facilities. Because these facilities had never been designed on such a scale—NASA made numerous design modifications before erection of these state-of-the-art facilities—it was necessary to select an architecture-engineering firm to oversee the MC master plan and participate in the design of the facilities. The Brown and Root Construction Company, in association with Charles Luckman and Associates of Los Angeles, were awarded the \$1.5 million contract.²⁵

Vacuum Chambers before SESL

From the 1962 aerospace engineering perspective, creating SESL was essential to the success of Project Apollo. When facility planning began, humankind had but a handful of actual hours in space. Engineers and scientists could only theorize as to how Apollo hardware would react in the vacuum and thermal extremes of a lunar voyage. SESL offered realistic training in the relative safety of a controlled environment. Without the benefit of years of actual spaceflight data and engineering experience, this facility would be crucial to safeguarding the operational integrity of the Apollo spacecraft and, with it, the lives of its human cargo.

Project Mercury made the value of a thermal-vacuum chamber in spacecraft development and checkout apparent. By the summer of 1960, many quality issues with the Mercury capsule during preflight checkout at the Cape had frustrated the McDonnell personnel responsible for the capsule’s development and checkout and their Program Manager, John F. Yardley. Such problems led McDonnell to establish a space environment laboratory at their manufacturing plant in St. Louis to do a more thorough screening before sending the Mercury capsules to the Cape for checkout before launch. This activity, known as “Project Orbit,” subjected the Mercury capsules to the extremities of space travel in relation to vacuum, heat, and cold.²⁶ While the 30’ diameter x 36’

²³ Merrifield, *Men and Spacecraft*, 4-29; Aleck C. Bond interview, August 25, 1998, 12-31, JSC Oral History Project, available at http://www.jsc.nasa.gov/history/oral_histories/oral_histories.htm.

²⁴ Aleck Bond, interview by Robert Merrifield, Written Transcript, October 10, 1967, 6.

²⁵ Aleck Bond, interview by Robert Merrifield, October 10, 1967, 4-16.

²⁶ Loyd S. Swenson, Jr., James M. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury* (Washington, D.C.: NASA, 1989), 269-270, see <http://history.nasa.gov/SP-4201/toc.htm>.

chamber was too small for Apollo testing, in December 1962 members of the Apollo Spacecraft Program Office observed the 100-hour project orbit test at McDonnell in order to make recommendations for the proposed SESL facility at MSC.²⁷

In 1962, it was becoming clear that thermal-vacuum facilities available or under construction were “inadequate to most of the needs of Apollo-class spacecraft, either from considerations of size; weight-handling capacity, the man-rating of equipment, or work loads.”²⁸ Those chambers in existence included those at:

Lockheed	18’ (diameter) x 20’
RCA	26’ (diameter) x 20’
Republic Aviation	14’ (diameter) x 30’
Jet Propulsion Laboratory	27’ (diameter) x 64’
NASA-Goddard	27’ (diameter)
Chance Vought, Dallas	12’ (diameter) x 16’

Of the chambers listed, only the Republic facility was human-rated. At its Valley Forge plant, General Electric was in the process of upgrading its large 54’ x 32’ chamber. As MSC representatives toured the facility in November 1962, General Electric officials urged NASA to consider using this chamber for Apollo spacecraft testing. While not human-rated, GE officials assured NASA the facility could achieve human-rated status in approximately five months. Even with the proposed human-rating upgrade, however, the General Electric chamber still lacked the dimensions necessary for the breadth of testing MSC envisioned.²⁹

There was only one vacuum chamber in the United States or in the countries of its allies that could possibly rival the planned SESL at MSC—the Mark 1 chamber planned for the USAF’s Arnold Engineering Development Center near Tullahoma, Tennessee. The USAF sought an environmental chamber to support the “timely development of reliable military weapon systems.”³⁰ The proposed 42’ (diameter) x 82’ chamber would simulate thermal-vacuum conditions to an altitude of 300 miles. Planning for the chamber began in June 1959, with Congress appropriating \$17.5 million for construction on 20 September 1961. The Army Corps of Engineers—Mobile, Alabama, District—was tasked with construction of the facility. Site clearance began 9 April 1962, with an anticipated completion of the facility 1 August 1963. Like SESL, the complex Mark 1

²⁷ Memo, W.C. Fischer, AST-Flight Projects to Distribution, “Memorandum for the Manager, ASPO,” January 16, 1963, internal memo, JSC-SESL Archives.

²⁸ *Manned Space Flight Laboratory Fiscal Year 1962 Estimates*, JSC-SESL Archives. This determination is also verified in Memo, Maxime A. Faget to A. Bond, Assistant Director for Administration, “Proposed acceleration of construction schedule for Space Environment Simulation Facility,” November 12, 1962, JSC-SESL Archives.

²⁹ Memo, Aleck C. Bond to H. Kurt Strass, “Memorandum for Files, Subject: Visit to General Electric and Goddard Regarding Environmental Test Facilities,” December 10, 1962, JSC-SESL Archives.

³⁰ Morton Alperin, *Large Space Environments Facility Study*, AEDC-TN-6021, January 1960, v.

chamber faced delays and the Air Force did not assume beneficial occupancy until 20 September 1965.³¹

In the spring of 1962, SESL planners believed that the pace of Mark I indicated that the USAF facility could prove useful for preliminary uncrewed Apollo hardware testing. Early SESL studies indicated “first environmental test configurations will probably be tested in the Mark I facility at Arnold Engineering Development Center in unmanned configurations.”³² MSC considered incorporating Apollo test capabilities to the Arnold Engineering Development Center chamber as late as October 1962. However, the plan was aborted when the Air Force indicated that needed modifications would take thirteen additional months at a cost of \$6 million.³³ The inability to use Mark I for early Apollo tests resulted in the decision to accelerate the SESL construction schedule.

Design and Construction

On 12 February 1962, a “Working Group on Requirements for Space Environment Simulation Facilities” became operational to develop a set of detailed technical requirements for SESL. The group comprised the following eight members:

A.H. Hinners	Chairman, Systems Evaluation and Development Division
R.W. Helsem	Facilities Design and Construction Division
E.L. Hays	Life Systems Division
J.E. Pavolosky	Spacecraft Research Division
J.L. James, Jr.	Technical Services Division
C. Klaybosh	Flight Operations Division
A.B. Olsen	Systems Evaluation and Development Division
R.H. Rollins	Apollo Spacecraft Project Office

The group’s duties included coordinating SESL’s technical requirements, documenting requirements for the facility, and coordinating with and reviewing detailed designs created by the architecture-engineer firm, when selected.³⁴ Richard Piotrowski of Systems Evaluation and Development Division joined the working group 27 February 1962.³⁵ Additionally, W. Kincaide eventually replaced Hayes as the Life Systems Division representative.

³¹ All dates concerning the Mark I facility provided by AEDC historian David M. Hiebert; H.D. Moore and R.B. Williams, “Initial Pumpdown and Leak Check of the Aerospace Environmental Chamber (Mark I),” AEDC-TR-66-142, August 1966, 1.

³² Working Group on Requirements for Space Environment Simulation Facilities, “Requirements for Space Environment Simulation Chambers for the Manned Spacecraft Center, Clear Lake, Harris County, Texas,” Revised March 30, 1962, JSC-SESL Archives.

³³ “Space Environmental Facility Study,” October 26, 1962, 2, JSC-SESL Archives.

³⁴ MSC Circular, Robert R. Gilruth to Distribution, “Working Group for Space Environmental Simulation Facilities,” February 9, 1962, JSC-SESL Archives.

³⁵ Memorandum for Record, Arthur H. Hinners, “Minutes of February 27, 1962, and March 1, 1962, Meeting of Working Committee for establishment of requirements for Space Environment Simulation Laboratories,” 2 March 1962, JSC-SESL Archives.

On 20 February 1962, while the rest of the nation focused on the shores of Cape Canaveral, the SESL working group met for the first time to discuss design specifications and Project Apollo requirements.³⁶ After coming up with the initial laboratory configuration of four chambers, work then began on assembling a formal facility requirements study with a target completion date of 15 March 1962.³⁷ Specifically, this report would provide basic information for the use by the selected architect-engineer firm to initiate that firm's own engineering study of the four chambers.

A draft of the design requirements was submitted 16 March 1962. As precise data concerning the Apollo vehicles and detailed project test objectives were not yet defined, the report contained very broad criteria in regard to chamber size and configuration. The committee made assumptions to provide a "reasonable starting basis for a design study." It included requirements for the areas of vacuum, cryogenics, solar thermal radiation, albedo, and human-rating, with a notation of the desirability for future vibration and shock capabilities. Meteorite impact simulation, nuclear radiation, lunar soil simulation, and—most notably—zero gravity were considered beyond the current technical capabilities.³⁸

Human-rating a thermal-vacuum chamber on the scale of the proposed Chamber A presented numerous challenges. A human-rated chamber is defined as one permitting a simultaneous testing of human and equipment in a controlled, simulated space environment without exposing the test subject to unnecessary risks.³⁹ To protect the human occupant, man-locks to serve as holding areas for rescue personnel, emergency repressurization systems, and bio-monitoring and surveillance systems needed to be incorporated into the design of the chambers. The incorporation of these safeguards added to the overall complexity and cost of the facility design.

While Brown & Root served as the architect-engineer for the overall site development, the Bechtel Corporation of San Francisco, California, and MSC negotiated an architect-engineer contract between 20-24 March 1962. Bechtel was well-known for its ability to coordinate large projects—most notably their Six Companies' joint venture, the Hoover Dam. As the architect-engineer, Bechtel was required to perform a sixty day engineering/cost study for SESL based on the guidelines established by the Hinners working group. MSC contract NAS 9-419 provided for a \$281,335 fee with report

³⁶ A.H. Hinners, "Activity Report, Test Facilities Branch, Space Environment Facilities Branch," 2 March 1962, JSC-SESL Archives.

³⁷ Memo, Arthur H. Hinners to Distribution, "Responsibilities of Working Committee for Establishment of Requirements for Space Environment Simulation Chambers for MSC, Houston, Texas," February 16, 1962; Memo, Arthur Hinners to Aleck Bond, "Proposed Schedule Space Environment Simulation Chambers, Manned Spacecraft Center, Houston, Texas," no date provided, both in JSC-SESL Archives.

³⁸ "Requirements for Space Environment Simulation Chambers for the Manned Spacecraft Center, Clear Lake, Harris County, Texas," JSC-SESL Archives.

³⁹ James W. Anderson and Oliver L. Pearson, "Concepts for the Man-Rating of a Space Environment Simulation Chamber," 1963, 2, JSC-SESL Archives.

delivery no later than 1 June 1962.⁴⁰ Bechtel Corporation employed various sub-contractors. These included: Chicago Bridge and Iron for the chamber vessel; Air Products and Chemicals for cryogenics; Bausch and Lomb for radiation simulation; General Electric for data and human-rating; Rucker Company for lunar plan drive; and National Research for vacuum.⁴¹ Bechtel chose to use these supporting contractors based on their previous experience with environment vacuum chambers. Throughout the report preparation period, there was an intense and concentrated coordination between the architect-engineer and the Hinners group. Again, the importance of SESL to Apollo and the necessity of completing the facility as soon as possible resulted in members of the Hinners group being freed of all other tasks during the design study.⁴²

Together, the architect-engineer and MSC representatives transformed the basic requirements of the space environment simulation complex into a conceptual engineering project. They resolved the issue of the shape of the vacuum vessels and the materials to be used. The following tables reflect the architect-engineer estimated costs of Chambers A and B overall costs, including the high-bay structure and administrative wing.

Cost Estimates for Space Environment Simulation Complex⁴³

Land Acquisition	None
Site Development and Utilities	\$800,000
Facilities (“Brick & Mortar”)	\$3,000,000
Equipment, Instrumentation, and Support Systems	\$14,500,000
Abnormal Design Costs	\$1,250,000
TOTAL	\$19,300,000

⁴⁰ W. Kenneth Davis, Bechtel, VP, to E.A. Gilliam, NASA/MSC, June 7, 1962, JSC-SESL Archives; E.A. Gilliam to USAF Auditors General Branch Office, Oakland, CA, April 18, 1962, JSC-SESL Archives.

⁴¹ W. Kenneth Davis, Bechtel VP, to E.A. Gilliam, NASA/MSC, June 7, 1962, JSC-SESL Archives; Bechtel Corporation, “Progress Meeting Notes, MSC Chamber Studies, Contract NAS-9-419,” April 13, 1962, JSC-SESL Archives.

⁴² Memo, A.R. Hinners to Distribution, “Engineering Study of Space Environmental Simulation Chambers for Manned Spacecraft Center, Houston, Texas; Work Schedule,” March 30, 1962, JSC-SESL Archives.

⁴³ Source: Bechtel Cost Estimate, Space Environment Simulation Chambers, II-4.

Detailed Chamber A and B Cost Estimates for SESL Chambers⁴⁴

	Chamber A	Chamber B
Vacuum Vessel	\$3,123,000	\$950,000
Solar & Albedo Simulation	\$1,805,000	\$60,000
Cryogenic System & Lunar Plane	\$2,600,000	\$435,000
Instruments & Controls	\$1,207,000	\$586,000
Data Handling (does not include leased equipment)	\$317,000	\$270,000
Biomedical Facilities	\$60,000	\$35,000
Special Handling Systems	\$178,000	\$48,000
Pumping Systems-Vacuum, Water & Air	\$1,100,000	\$383,000
Chamber Repressurization (Normal & Emergency)	\$290,000	\$153,000
Electrical Power	\$190,000	\$60,000
Acceptance Tests	\$300,000	\$100,000
TOTAL	\$11,170,000	\$3,080,000

Based on the architect-engineer design study produced from the Bechtel contract, the NASA Headquarters Director of Manned Space Flight, D. Brainerd Holmes, directed that MSC proceed with the detailed design activity. Phase II called for awarding another architect-engineer contract to create the comprehensive design drawings, calculations, and specifications based on the Bechtel Study. Throughout this period, it was clear that that schedule was a critical element. Holmes said that the proposed facility was “a critical item required to support our program and should be designed and constructed as expeditiously as possible.”⁴⁵ Assuming the design and construction responsibilities, the Corps negotiated with Bechtel for SESL design Phase II as Bechtel’s previous design work provided the company with a decided time-saving advantage over other architect-engineer firms. “Conservative” NASA estimates believed negotiations with other firms would delay SESL “not less than two months” and that “serious consideration must be given to the impact of any delay in completion of the facility upon the Apollo testing and indoctrination program.”⁴⁶ Bechtel was awarded the sum of \$1,790,000 for the design of Chambers A and B to be completed in ten months.⁴⁷

As Bechtel commenced work on the detail designs, MSC made inquiries regarding possible acceleration of Chamber A from the mid-1965 target completion date to 15 December 1964.⁴⁸ Maxime Faget, Director for Engineering and Development, supported

⁴⁴ Source: Bechtel Cost Estimate, Space Environment Simulation Chambers, II-6.

⁴⁵ Letter, D. Brainerd Holmes to Robert R. Gilruth, June 26, 1962, JSC-SESL Archives.

⁴⁶ Letter, E.A. Gilliam to Col. R.P. West, August 30, 1962, Office of Aleck C. Bond, 1952-1971, Chemical and Mechanical Systems Division, Records of the Engineering and Development Directorate, General Records of Johnson Space Center, Record Group 225, National Archives Building, Ft. Worth, Texas. Note: the letter has no formal signature; “Gilliam?” is printed in the signature area.

⁴⁷ Letter, Col. R.P. West to Bechtel Corporation, September 10, 1962, JSC-SESL Archives.

⁴⁸ Telephone call memo, Col. West to Aleck Bond, October 19, 1962, JSC-SESL Archives.

the accelerated schedule. Without it, costly arrangements with other testing facilities would have to be made.⁴⁹ The Corps informed Wesley Hjernevik, Director of Administration, that any schedule acceleration of the larger Chamber A might significantly delay the completion of Chamber B. Additionally, to achieve an advancement of six months in schedule, a three-shift construction workday would be required at the cost of an additional \$3 million.⁵⁰ Since the MSC budget would not fund implementation of the 15 December 1964 completion date, the Corps provided MSC with alternative accelerated schedules and costs: January 15, 1965, \$1.3 million; February 15, 1965, \$640,000; April 15, 1965, \$525,000.⁵¹ Based upon compatibility with the Apollo test schedule, MSC accepted the 15 February 1965 alternative. This date would provide a four-month schedule acceleration.⁵² Formal MSC acceptance and notification was made on 30 November 1962 with increased costs not to exceed \$600,000.⁵³ The Chief of MSC Facilities, Design, Construction, and Operations Division, Leo T. Zbanek, advised the Corps that total funds for a complete “turnkey” facility could not exceed \$31,042,000 with specific notations that “additional funds above this amount will not be available.”⁵⁴

Based on the complex nature of the simulation chambers, the Corps of Engineers elected to award four separate contracts.⁵⁵ Chicago Bridge and Iron, who won the contract for Chambers A and B, was considered a leader in tank and vessel construction in the early 1960s due to its work on nuclear containment vessels for the Atomic Energy Commission and on the large chambers for both McDonnell and North American Aviation. Chicago Bridge and Iron began building the vacuum vessels on 7 May 1963. Ets-Hokin and Galvan, Inc., started work on the facility foundation and high-bay superstructure on 5 July 1963, while Industrial, Fisher, and Diversified began contract work on 25 September 1963. Off-site fabrication of the lunar plane commenced 18 September 1963.⁵⁶

One year after beginning chamber fabrication, the first trial pumpdown of Chamber A to inspect for vacuum leaks was under way on 20 May 1964. Unfortunately, during this routine pre-acceptance test, the structural integrity of the vessel was compromised. The resulting damage required that a major redesign of the larger chamber be made, which led to significant delays in testing the Apollo vehicles.⁵⁷ Industrial, Fischer and Diversified staff, under the direction of Chicago Bridge and Iron, and with NASA, Corps of Engineers, and Chicago Bridge and Iron personnel present, initiated the trial pumpdown

⁴⁹ Memo, Maxime A. Faget, MSC, to Wesley Hjernevik, November 12, 1962, JSC-SESL Archives.

⁵⁰ Letter, R.P. West to Wesley Hjernevik, October 26, 1962, JSC-SESL Archives.

⁵¹ Letter, Lt. Col. A.J. Hall, Fort Worth Division Deputy District Engineer, to Wesley Hjernevik, November 8, 1962, JSC-SESL Archives.

⁵² Memo, Faget to Hjernevik, November 12, 1962, JSC-SESL Archives.

⁵³ Letter, Leo T. Zbanek, Chief, Facilities Design, Construction and Operations Division, to Lt. Col. Wayne A. Blair, Fort Worth Division, November 30, 1962, JSC-SESL Archives.

⁵⁴ Letter, Leo T. Zbanek to Lt. Col. Wayne A. Blair, December 26, 1962, JSC-SESL Archives.

⁵⁵ Joe Pouzar, interview by Lori C. Walters, tape recording, Houston, Texas, July 19, 2001, JSC-SESL Archives.

⁵⁶ JSC Real Property Records, 1962-1978, Microfiche #27, not available; contact author for information.

⁵⁷ Joe Pouzar, “Test Report of the Structural Integrity and Vacuum Tests 1 Thru 5 on Chamber A, Bldg. 32,” 1, JSC-SESL Archives.

at 2:00 p.m. As the massive pumps began to evacuate the vessel, crackling noises were reported at approximately 3:45 p.m. and were interpreted as a seating of the 40' chamber door seal.⁵⁸ At 10:00 p.m., with the absolute gauge reading 30 mm HG, a 2½" misalignment at the bottom of the door flange was noted. Chicago Bridge and Iron representative Charles Stoffer contacted the Chicago office to report the misalignment findings, but no action was advised, and the pumpdown continued.⁵⁹

By midnight, the Corps representatives changed shifts as R. L. Wood replaced Roy Eklund; Wood was informed of "sharp popping noises" earlier during the pumpdown. At this time, Stoffer conferred with Wood and expressed concern about the degree of door skin deformity. As the misalignment of the door increased, Stoffer and Wood advised Industrial, Fisher, and Diversified at 12:35 a.m., 21 May, not to activate the additional blowers required to reduce the vacuum below the current absolute gauge reading of 10 mm HG.⁶⁰ In his report of events, Wood indicated he and Stoffer proceeded to inspect the door region and noted the door was "terrifically distorted," but the full extent of possible damage was undeterminable due to poor night lighting.⁶¹ Stoffer ordered a representative of the vessel to begin at 1 a.m., achieving atmospheric pressure at 6 a.m. The extent of damage became apparent by morning. Deformities were found in the door, doorframe, and actual vessel surfaces flanking and below the doorframe.⁶²

As the government agency responsible for the construction of SESL, the Corps initiated an investigation into the failure of Chamber A. Simultaneously, Joseph V. Pilund, Chief of the Office of Technical and Engineering Services, appointed by a parallel MSC structural investigation panel on 21 May 1964 to determine the scope of damage and cause of the failure. The three-member panel consisted of Arthur D. Crabtree, Facilities Division; Thomas C. Snedecor, Engineering Division; and George E. Griffith, Structures and Mechanics Division. Indicative of the importance of Chamber A to the Apollo Program, the investigation was to be conducted on an "emergency basis."⁶³

Both the Corps and MSC analyses revealed damage well beyond what was reported during the days immediately after the failure. During the pumpdown to 10 mm HG, the doorframe buckled inward and became permanently distorted out of round. Subsequently, this distortion led to local buckling of doorframe and vessel stiffeners,

⁵⁸ "Record of Pumpdown Chamber A," there is no date or author attributed to this document, which is located in the JSC-SESL Archives. The document lists engineers present during some portion of the May 20, 1964, pumpdown: NASA—Frank A. Knox and Wayne Potter; Corps of Engineers—Bill Metcalfe, [Roy] Eklund and [R.L.] Wood; Chicago Bridge and Iron—[Charles] Stoffer and Triplet. Note the document did not include the full names of all involved.

⁵⁹ U.S. Army Corps of Engineers, Spacecraft Center Area Office, "History of Events for Vacuum Test on 20 and 21 May 1964 of Chamber 'A', Space Environment Simulation Chambers," 3-5.

⁶⁰ U.S. Army Corps of Engineers, "History of Events," 3-5.

⁶¹ Memorandum for Files, R.L. Wood, "Vacuum Testing of Chamber A," May 22, 1964, JSC-SESL Archives.

⁶² U.S. Army Corps of Engineers, "History of Events," 5-6.

⁶³ Memo, Joseph V. Piland to Distribution, "Appointment of a structural investigation panel, Chamber 'A,' Space Environment Laboratory," May 22, 1964, JSC-SESL archives.

vessel panels and the o-ring. This movement brought damage to three of the chamber's supporting columns. The Corps report concluded that the failure occurred due to the inability of the octagonal frame structure surrounding the doorframe to provide adequate support during the stress of vacuum pumpdown.⁶⁴

With the probable cause of the deformation determined, attention now turned toward redesigning and repairing the vessel with minimal delay to the Apollo Program. Bechtel Headquarters in San Francisco dispatched a proposal to the Corps outlining two general approaches for repairs. The first called for replacing the distorted materials while the second method proposed minimal replacement of damaged materials, opting for straightening of the distorted regions when possible. Bechtel recommended the latter proposal, as it required the least amount of time "in view of the critical schedule" of the facility.⁶⁵ Corps and NASA officials, considering both options, proceeded to create a board of independent consultants to analyze the proposed repair methods.⁶⁶

While discussions continued to determine the most viable course of action to repair Chamber A, Chamber B was in the midst of a series of acceptance pumpdown tests. On 1 April 1964, Industrial, Fisher, and Diversified initiated the initial vacuum test for Chamber B, which proceeded without incident. Between 2 April and 9 June 1964, Chamber B successfully completed ten pumpdown tests. A week after the Chamber A failure, the Corps suggested that Bechtel develop a deflection measuring program for Chamber B. Bechtel felt, however, that since there was an absence of problems with test series to date, it preferred to focus all of the firm's efforts on the Chamber A redesign. The Corps accepted Chamber B on 10 June 1964.⁶⁷

On 24 June 1964, the Corps/MSL contingent—now under the direction of District Engineer Colonel F.P. Koisch—implemented the repair scheme as recommended by the independent consultants: alternative number two with minimal removal of materials and straighten damaged areas and reinforce where needed. As an insurance against possible failure of this option, the Corps also ordered material for a major restoration. Bechtel was instructed to finalize repair and restructure plans.⁶⁸ Documents suggest a lack of confidence in Bechtel/ Chicago Bridge and Iron during the redesign process by MSL

⁶⁴ Robert H. Hectman, "First Progress Report on Study of Chamber A Deformation," June 10, 1964, 1-2, JSC-SESL Archives.

⁶⁵ Telegram, D. Furlong, Bechtel SESL Project Manager to Lt. Col. Wayne A. Blair, Deputy District Engineer Spacecraft Area Office, Corps of Engineers, June 4, 1964, JSC-SESL Archives.

⁶⁶ Letter, E.E. Wilmoyt, Acting Director of Military Construction to Southwestern Corps of Engineers Division Engineer, "Board of Consultants for Review Chamber A Repair Design," June 17, 1964, JSC-SESL Archives. The Board of Consultants consisted of E.P. Zackrison, Chief of the Engineering Division; Dr. Howard Simpson, who supervised the digital computer analysis of the Vehicle Assembly Building's structural frame; Dr. M. Henteyl of Stanford University; and Dr. Charles Norris, University of Washington.

⁶⁷ Bechtel Corporation, "Preliminary Engineering Analysis for Space Environment Simulation Chamber 'B' Redesign," November 20, 1964, 1-7, JSC-SESL Archives.

⁶⁸ Report, A.D. Crabtree to Distribution, "Reports on Matters Related to Chamber A," June 25, 1964, JSC-SESL Archives.

and Corps officials.⁶⁹

Although originally considered, a structural model program was not used to verify Bechtel's original design of Chamber A. Aleck Bond and other MSC officials had urged the Corps to construct scale models to assist in the design. Viewing models as an unnecessary and costly delay, the Corps had failed to provide a process that might have detected the inadequate door support before construction.⁷⁰ MSC officials ordered the construction of two 1/20-scale structural models of the chamber to simulate the structural properties of the vessel as originally designed in an attempt to duplicate the failure. The second model incorporated the approved modifications. The latter model successfully confirmed Bechtel's redesign.⁷¹ To further investigate and verify Chamber A's remedial design, MSC acquired the engineering consulting firm of Simpson, Gumpertz, and Heger.⁷² The firm's computer analyses of the chamber, as redesigned by Bechtel, revealed no large deflections. While the Simpson data concluded Bechtel's modifications were adequate, the firm recommended several minor additional strengthening measures—including stiffeners around viewports and beneath the lunar plane.⁷³

The solar simulation capabilities of chambers A and B proved equally challenging during this chamber redesign period. Previous attempts to recreate the full spectral capacity of the Sun in large vacuum facilities had been unsuccessful. Bausch and Lomb was the Bechtel subcontractor to provide a preliminary solar simulation design. The system needed to fulfill several criteria, including uniformity of intensity of the irradiant beam, decollimation angle, close solar spectral match, number of chamber penetrations, and guarantee of performance.⁷⁴ MSC officials interpreted the reluctance of Bausch and Lomb to both guarantee the performance of their design and submit a fixed price quotation as a "lack of confidence in the ability of their design" to meet budgetary limitations.⁷⁵ A request for proposals based on the Bausch and Lomb design was let on 20 October 1962. The respondents indicated they had "grave doubts" as to the merits of the Bausch and Lomb design and reserved the right to significantly modify or develop

⁶⁹ Comments such as "the contractor's proposed redesign...does not greatly improve on what we feel are the major shortcomings in the present design," Memo H.G. McComb and M.M. Mikulus, "Reinforcement of Vehicle Access Door on Space Environment Simulation Chamber A," June 12, 1962; "The report lacks details and depth regarding design concepts," Crabtree, June 25, 1964, JSC-SESL Archives.

⁷⁰ Aleck C. Bond, interview by Summer Chick Bergen, written transcript, Houston, Texas, September 3, 1998, 13-5, JSC-SESL Archives.

⁷¹ P.C. Glynn and J.T. Milton, "A Report of Chamber A Structural Integrity Test," April 1965, 1, JSC-SESL Archives.

⁷² Memo, Philip Glynn to Aleck Bond, "Report on trip to firm of Simpson, Gumpertz, and Heger," December 1, 1964, JSC-SESL Archives.

⁷³ Simpson, Gumpertz, and Heger, Inc., "Verification of Remedial Design for Chamber A," March 25, 1965, 62, JSC-SESL Archives.

⁷⁴ Vincent, Johnson, and Freeborne, "Solar Simulation Systems," 3. While no exact date is provided, the document notes tests no later than 1966.

⁷⁵ Memo, Aleck C. Bond to Ernie Gilliam, "Procurement of Solar Simulator Models for Manned Spacecraft Center Space Environment Facility," October 16, 1962, JSC-SESL Archives.

alternate approaches for the simulation system.⁷⁶ A six-member committee from the Systems Evaluation and Development Division was selected to technically evaluate proposals received from Minneapolis-Honeywell, Radio Corporation of America (RCA), and Space Technology Laboratories.⁷⁷

In December 1962, MSC awarded a contract to RCA for design, fabrication, and installation of a carbon-arc based solar simulation system.⁷⁸ As envisioned, the system called for modular units set in an aligned pattern to provide total coverage of the Apollo command and service module (CSM) during testing. Although markedly cleaner than carbon arc units, early 1960s xenon bulb technology was inferior in its ability to match the full spectrum of the Sun and was deemed unsuitable for Apollo testing.⁷⁹ The nature of carbon arc simulation provided for a difficult working environment for SESL solar technicians. Often the Gatling gun-like carbon rod feeding mechanism into the unit's electric arc failed, creating a blackout of the unit, resulting in an uneven solar grid during testing. Like firefighters combating a blaze, carbon dust-covered solar technicians scurried up and down the side solar grid elevator in a vain attempt to maintain an acceptable grid level throughout the solar portion of a test.

In the midst of the Chamber A failure, other problems arose with the solar simulator bank as a result of the redesigned chamber. Strengthening modifications to the chamber created interference with the side solar bank chamber penetration nozzles.⁸⁰ Acting as the conduit to permit solar unit access to the vessel's interior, the redesigned chamber forced the repositioning and strengthening of several of the nozzles. The top sun and side sun units were installed in March and June of 1966, respectively.⁸¹ Portions of the RCA system would continue to be problematic during the trial vacuum runs of the side sun. Two sections comprised the solar simulation unit, the carbon arc unit that remains outside the thermal-vacuum chamber and an electroformed mirror unit within the vessel. The mirror unit, manufactured by Electro-Optical systems of Pasadena, California, had a reflective nickel coating applied to an aluminum casting. During vacuum testing, the water circulation system required to dissipate the intense heat generated by the carbon arc units experienced blockage problems. The impediment resulted in the deformation of approximately half of the mirrored reflectors.⁸²

Design modifications to the Chamber B top sun bank required strengthening the vessel. The requirement for additional solar units, resulting in a 90,000-lb load increase, reached Bechtel 7 July 1964. Recognizing that installing the modified top sun bank might induce

⁷⁶ Memo, Bond to Gilliam, "Procurement."

⁷⁷ Memo, Aleck C. Bond to K.H. Espy, "Technical evaluation of proposals for a Solar Simulation System, NASA, Manned Spacecraft Center FRP 328P, dated October 20, 1962," November 13, 1962, JSC-SESL Archives. The six-member panel included H. Kurt Strass, A.H. Hinners, J.A. Muller, R.J. Piotrowski, L.D. Allen, and J.P. Vincent.

⁷⁸ Vincent, Johnson, and Freeborne, "Solar Simulation Systems," 4.

⁷⁹ Aleck C. Bond, interview by Summer Chick Bergen, 13-4.

⁸⁰ Kurt Strass, Unpublished SESL Repair Diary, October 22, 1964, JSC-SESL Archives.

⁸¹ Vincent, Johnson, and Freeborne, "Solar Simulation Systems," 8-10.

⁸² Merrifield, 6-9.

a structural failure in the Chamber B top head, the Corps directed Bechtel to reinforce the vessel. Mathematical models and other analysis revealed that the top head required stiffening at each solar module intrusion point and additional stiffening to the basic structure of the top head.⁸³ With the first human flights of Project Gemini less than a year away, use of Chamber B for crew preparation was now in jeopardy. Corps and MSC officials instructed Bechtel to expedite their redesign and repairs of Chamber B to accommodate scheduled Gemini testing.⁸⁴

Eleven months after the initial pumpdown failure, the heavily reinforced Chamber A stood ready for its qualifying structural integrity test. Supervised by the Corps, a series of five tests (performed from 13 April to 2 May 1965) were designed to ascertain the chamber's ability to withstand a vacuum pumpdown.⁸⁵ While the first test revealed numerous leaks, primarily from Industrial, Fisher, and Diversified failing to have flange covers on instrumentation ports, MSC officials noted the "structural integrity appears good."⁸⁶ The chamber successfully passed the structural integrity and vacuum shakedown with vacuum and leakage rates within accepted specifications.⁸⁷

The successful 1965 test of the modified Chamber A did not bring complete closure to the failure. The redesign presented a sizable increase in the overall cost of project construction. The Corps and MSC subsequently brought suit against Bechtel and Chicago Bridge and Iron to recover these additional costs. The Bechtel defense argued the facility represented the "state of the art" and, as such, they could not be held responsible for design shortcomings. Without previous work on this scale, there was no guiding model available. Eventually an out-of-court settlement was reached.⁸⁸

Test operation and support services for SESL were the responsibility of Brown & Root/Northrup (BRN) as a component of an overall contract awarded to BRN in September 1964 for the operation and support of various MSC test facilities/laboratories. These included SESL, vibration and acoustic facility, flight acceleration facility, crew systems lab, and the thermochemical test area.⁸⁹ BRN was an entrepreneurial joint venture between the Houston-based Brown & Root engineering company (MSC master plan designers) and Northrup Aerospace of California.⁹⁰ During the height of Apollo testing, over 200 Northrup technicians and engineers—under the direction of C.E. 'Pete'

⁸³ Strass Diary, September 14, 1964.

⁸⁴ "Preliminary Engineering Analysis for Space Environment Simulation Laboratory Chamber B Redesign," Bechtel Corporation, November 20, 1964.

⁸⁵ Pouzar, "Test Report on the Structural Integrity," 1.

⁸⁶ Strass Diary, April 13, 1965.

⁸⁷ Strass Diary, May 3, 1965; Pouzar, "Test Report," 3.

⁸⁸ McLane interview, July 18, 2001.

⁸⁹ MSC Press Release, September 17, 1964.

⁹⁰ Although test operation was outside the specialization of Brown and Root, the company possessed superior political connections, and being a local firm was equally beneficial. Northrup brought its extensive aerospace knowledge to the partnership.

Gist—staffed the giant thermal-vacuum facility.⁹¹

Chamber B—Gemini Testing Begins

While SESL testing of the Gemini spacecraft was never intended, the Gemini Project Office anticipated using Chamber B for Gemini spacesuit and Extravehicular Mobility Unit (EMU) evaluation and training. The failure of Chamber A, with the subsequent modifications to both Chamber A and Chamber B, led to an abbreviated use of the facility for Project Gemini. By the time uncrewed shakedown tests to qualify Chamber B for operation began on 14 September 1965, three crewed Gemini missions had already been completed. Therefore, only five uncrewed qualification tests took place in Chamber B between 14 September and 20 October 1965.⁹² Crewed altitude tests began on 10 December 1965 when BRN employee Robert Piljay became the first human to enter Chamber B under high-altitude conditions of 300,000'. Piljay, who had previous experience in high-altitude chambers, remained in the chamber for eleven minutes. The test verified both the altitude and solar capabilities of Chamber B.⁹³

Gemini hardware testing in Chamber B officially began in January 1966. MSC and the USAF began testing the Modular Mobility Unit (MMU) in support of the forthcoming Gemini 9 and 12 missions.⁹⁴ The USAF was particularly interested in the MMU for the development of the propulsion and communication unit for its own human-in-space effort. In 1963, when given the opportunity to include an experiment during a Gemini flight, the USAF selected the MMU backpack device.⁹⁵ Gemini 9 pilot Charles A. Bassett became the first astronaut to undergo thermal-vacuum testing in February. Astronauts Bassett, Eugene Cernan and Edward Givens also participated in similar MMU tests in January and February 1966.⁹⁶ The USAF announced that all of the MMU test objectives had been met during the SESL vacuum tests.⁹⁷

In June 1966, the Crew Systems Division requested use of Chamber B in support of Gemini 10 and 11. These tests were intended to demonstrate the flight readiness of Gemini 10 and 11 Extra Vehicular Activity (EVA) hardware, and to subject the crews to

⁹¹ "The BRN Story," Houston, Texas, 9, JSC-SESL Archives. No date is attributed to this BRN brochure.

⁹² "Final Test Report for Chamber B Shakedown," Manned Spacecraft Center, October 25, 1966, 2-1, JSC-SESL Archives.

⁹³ "Manned Tests of Chamber B Includes Temperature Extremes," *Space News Roundup* 5, no. 5 (December 23, 1965): 3, *Space News Roundup* issues are available at the JSC History Collection at University of Houston, Clear Lake, or online at <http://www.jsc.nasa.gov/history/roundups/roundups.htm>; C.E. Gist interview by Lori C. Walters, tape recording, Seabrook, Texas, July 11, 2001, JSC-SESL Archives

⁹⁴ In regard to using Modular Mobility Unit (MMU), both MMU and Astronaut Mobility Unit (AMU) terms were found in research. In this report, MMU will be used exclusively.

⁹⁵ Barton C. Hacker and James M. Grimwood, *On the Shoulders of Titans: A History of Project Gemini*, SP-4203 (Washington, D.C.: NASA, 1977), 326.

⁹⁶ Givens was appointed to the astronaut corps in April 1966. During these tests, he was assigned as Project Officer with the USAF at MSC. Consequently, although Givens predates Bassett in Chamber B testing, Bassett is actually the first astronaut to test in Chamber B.

⁹⁷ "Major Test Accomplishments of the Engineering and Development Directorate, 1966," (Houston: Manned Spacecraft Center, 1967), 7-13, JSC-SESL Archives.

the scheduled spaceflight workloads. The Crew Systems Division also wished to determine if there would be visor fogging or icing stemming from the emergency life support system inlet. Cernan had experienced this during his EVA on Gemini 9 earlier in June. Astronauts C.C. Williams, Michael Collins, and Dick Gordon observed that the Chamber B experience had provided them with confidence in the equipment used and was “the best simulated utilization of the flight equipment experienced to date.”⁹⁸ With the final Gemini mission scheduled for November 1966, Gemini testing in Chamber B drew to a close.

The SESL technicians began converting Chamber B in preparation for Apollo suit evaluations. Tests were designed to assess lunar space suit mobility and the portable life support system in a simulated one-sixth gravity thermal-vacuum environment.⁹⁹ Metabolic profiles of test participants were of equal significance, as they provided valuable information for calculating life support requirements on the lunar surface. Although hardware qualification tests began on 12 September 1966, facility and Apollo hardware failures led to the premature termination of the first five test runs. While the test subject during the sixth test remained in the chamber for 180 minutes, the participant completed only twenty-five minutes of scheduled exercise. The subject indicated the suit was “painful” and experienced visor fogging. The unforeseen testing delays led to scheduling conflicts in Chamber B and to the transfer of these activities to Chamber A in January 1967.¹⁰⁰

Chamber A – Apollo Block I – S/C 008 Testing

With the successful pumpdown of Chamber A, attention could now be turned toward compatibility tests of the Apollo CSM. Initially, small-scale models provided BRN workers with an overview of the task, who then used a CSM boilerplate for insertion procedure familiarization. As the entire CSM could not be inserted into the chamber in one piece, workers had to transfer each module into the chamber and stack the vehicle on a test stand. To accomplish this, the modules were hoisted onto a small trolley platform, the “Hooterville Trolley,” and rolled into the chamber, where another hoist would stack the module onto the test stand, which rested on the lunar plane.¹⁰¹

Early Apollo spacecraft design and testing plans called for the thermal-vacuum testing of each flight-ready spacecraft in SESL before delivery to the Florida launch site. This rather costly and cumbersome plan was quickly deemed impractical. Program managers devised an alternative approach using an altitude chamber at the launch facility that would subject every CSM to a flight-readiness vacuum. The more rigorous thermal-

⁹⁸ “Major Test Accomplishments,” 7-16.

⁹⁹ The one-sixth simulated gravity was achieved through using an overhead trolley with a constant force spring to relieve the test participant of the portable life support system weight.

¹⁰⁰ “1966 Accomplishments,” 7-16.

¹⁰¹ Michael Clark, interview by Lori C. Walters, tape recording, Houston, Texas, August 1, 2001, JSC-SESL Archives. The name “Hooterville” trolley was obtained from the popular 1960s television program *Petticoat Junction*.

vacuum tests would be conducted on a single test configuration. With this resolved, discussion moved toward the selection of the test hardware. Initially, the team considered using a production spacecraft. Under this approach, after completion of thermal-vacuum testing, the vehicle would be refurbished and flown on a later Apollo mission. This was abandoned as being too costly.¹⁰² A second approach called for constructing a simplified test vehicle, but this was considered unrealistic, as one of the primary purposes of SESL was to provide astronauts with near identical spaceflight experiences. The accepted approach was the construction of a production command module (CM) dedicated to thermal-vacuum testing in Chamber A. Any subsequent hardware modifications to flight hardware would also be reflected in the test configuration for additional testing. This testing philosophy was also used for the lunar module hardware.

Apollo CM number FRM-008 was assigned as the vehicle for Apollo Block I thermal-vacuum testing at SESL and was routinely referred to as S/C 008.¹⁰³ (The initial S/C 008 tests at SESL were in support of the planned launch of the AS-204 mission, in which three astronauts perished during an unrelated ground test.) The testing of S/C 008 temporarily stopped after the AS-204 fire with three full thermal-vacuum testing blocks completed.

S/C 008 arrived at MSC between 5 May and 9 May 1966.¹⁰⁴ Like the boilerplate tests that predated it, S/C 008 was stacked by the Westheimer Riggers and inserted into Chamber A on 17 May 1966.¹⁰⁵ The elaborate test stand and utility pole obscured much of the service module portion of the vehicle. To provide crew access, a circular walkway from the 31' level man-lock surrounded the CM. Once crew ingress occurred, the walkway split and the sections retracted against the chamber wall during testing.

Testing began on 26 July 1966 with a planned duration of ninety-four hours to demonstrate the capability of the CSM and its compatibility with the ground support equipment. The ground support equipment for the test was virtually identical to that at Kennedy Space Center—the only differences being the additional equipment necessary for SESL testing. The July test results revealed several anomalies with S/C 008. The CM hatch failed to seal properly, but the problem was resolved by slightly pressurizing the cabin before chamber pumpdown. Other issues included excessive cabin moisture, inadequate cabin odor removal, and ice buildup in the heat shield. The largest problem involved freezing of potable water transfer lines.¹⁰⁶

The prime and backup crews were engineers from the Flight Crew Support Division and

¹⁰² McLane, *Apollo Experience*, 4.

¹⁰³ S/C 008 refers to the mated command and service modules.

¹⁰⁴ Photo, *Space News Roundup* 5, no. 20 (July 22, 1966): 3.

¹⁰⁵ Robert C. Emeigh, interview by Lori C. Walters, tape recording, Houston, Texas, July 24, 2001, JSC-SESL Archives; insertion date attributed to "1966 Accomplishments," 7-19.

¹⁰⁶ "1966 Accomplishments," 7-20.

not astronauts. Donald R. Garrett, Joel M. Rosenweig, and Neil B. Anderson served as the prime crew, while Joseph A. Gagliano, William M. Anderson, and Michael K. Lake were the backup crew.¹⁰⁷ The volunteer test subjects entered S/C 008 on 1 August 1966 at 10:15 p.m. for their eight-day thermal-vacuum odyssey.¹⁰⁸ They encountered a range of problems from the outset. The scheduled nineteen-hour chamber pumpdown period was doubled due to difficulties with the emergency repressurization and the chromatograph cabin-atmosphere sampling systems. The temperamental solar simulators proved particularly troublesome, generating several holds in their inaugural test.¹⁰⁹ Problems began for the three-man crew when the urine dump line froze, forcing the collection and storage of urine within the crew cabin. While SESL replicates near space conditions, the one item it cannot simulate is weightlessness. Although the cabin sleeping quarters were slightly modified from the flight-configured spacecraft for crew comfort in a gravity environment, the crew discovered their near-perpetual state of being on their backs led to sinus and lung congestion.¹¹⁰ As the 175-hour test progressed, frustration with the S/C 008 performance became apparent; as the crew monitor log noted, “the crew is losing confidence with the environment.”¹¹¹

Even with these difficulties, the facility performed its designated task, which was uncovering potential problems with the Apollo vehicle under controlled Earth-bound conditions. Of primary concern was the fogging of spacecraft windows. The crew noted all windows fogged up “badly” and condensation appeared in the dead air space between the panes of both the center hatch and left-hand docking windows. Anderson reported the instrument panel was “dripping water” with condensation covering the walls and floor. The test also revealed another potential mission problem: the crew was forced to remove their underwear, as the fabric outgassed poisonous lithium fluoride gas.¹¹² Based on this test experience, several recommendations were made to alter S/C 012, including insulating the water glycol lines to prevent cabin condensation, adding charcoal in the lithium hydroxide cartridges to reduce cabin odor, and adding heaters on the hydrogen vent line.¹¹³

In continued support of S/C 012 and portions of the S/C 014 flight, a second crewed test of S/C 008 was conducted between 26 October and 1 November 1966. Astronauts Joseph P. Kerwin and Edward G. Givens and MSC engineer Joseph A. Gagliano served

¹⁰⁷ “Historical Record of Spacecraft 008 Thermovacuum Test,” (Houston: Manned Spacecraft Center, 1966), 4-37; *Space News Round Up*, August 5, 1966, 8; Memo, Donald K. Slayton, Astronaut Office to Joseph F. Shea, Apollo Spacecraft Program Office Manager, “Management improvement of follow-on-thermal-vacuum testing,” August 31, 1966, JSC-SESL Archives.

¹⁰⁸ “Pilots’ Report, Apollo Spacecraft 008, Manned Thermal Vacuum Test,” Folder September 26, 1966, Box: 067-34/35, Apollo Program Chronological Files, Apollo Collection, Johnson Space Center.

¹⁰⁹ McLane, *Apollo Experience*, 43.

¹¹⁰ “Historical Record S/C 008,” 5-11.

¹¹¹ “Historical Record S/C 008,” 5-14.

¹¹² “Historical Record S/C 008,” 5-19 to 5-20.

¹¹³ “Quick Look Summary Report of CSM 008 SESL Test Results,” August 12, 1966, 2, JSC-SESL Archives.

as crew.¹¹⁴ As with the August trials, the spacecraft experienced urine dump line problems. While this naturally proved uncomfortable for the crew, a fuel cell failure generated the greatest concerns. During test-readiness procedures, two fuel cells failed, but the test continued. The remaining third fuel cell and ground power were used to support the testing. The problem was eventually traced to a procedural sequence error. The Kennedy Space Center launch team was notified to include proper caution notes to prevent a recurrence.¹¹⁵ Overall, the combined S/C 008 human testing resulted in fourteen design and an additional fourteen procedural changes to the Block I spacecraft.¹¹⁶

Apollo 204

By January 1967, S/C 008 had been removed from Chamber A so that thermal qualification tests on the Apollo EMU could be conducted. They were designed to simulate the effects of maximum Sun elevation anticipated during a lunar stay. The tests, from 23 January to 25 January, revealed several shortcomings in the Apollo EMU. Test subject, Ed Kuykendall, reported deficiencies in the EVA gloves' cooling capabilities. On 27 January, Richard Hermling began the first of what was to be a series of cold soak operation tests to simulate deep shadow and night Earth orbit. The test subject reported that, when touching the test equipment, his fingers were "noticeably" cold.¹¹⁷ EMU testing at SESL ended abruptly on the evening of January 27 when news of the tragic Apollo 204 fire reached the facility.¹¹⁸

While SESL did not play a direct role in the 204 fire investigation, the latter led to numerous changes to facility operations. MSC promptly began a major review of its crewed ground test facilities.¹¹⁹ A fire in another oxygen-rich environment in a vacuum chamber at the USAF School of Aviation Medicine in San Antonio, Texas, in 1967 initiated additional concerns for SESL above the general MSC crewed test facility review. Before 1967, no universally accepted criteria governing human-rated vacuum chambers existed. Without appropriate procedures and standards, many safety decisions during tests were based on the judgment and experience of the test conductors.¹²⁰ A special task force was formed to develop minimum safety standards and these were

¹¹⁴ "Apollo Ends Six-Day Chamber Test," *Space News Roundup* 5, no. 1 (November 11, 1966): 8.

¹¹⁵ Memo, Joseph F. Shea to Major General S.C. Phillips, October 26, 1966, JSC-SESL Archives.

¹¹⁶ James C. McLane, Jr., "Apollo Testing in the Space Environment Simulation Laboratory," presented to the 1969 International Vacuum Metallurgy Conference, Pittsburgh, PA, June 16-19, 1969, 12.

¹¹⁷ Memo, Richard S. Johnston to distribution, 16 March 1967, with attached "Quick Look Test Report."

¹¹⁸ Robert C. Emeigh, interview by Lori C. Walters, Tape Recording, Houston, Texas, July 24, 2001, JSC-SESL Archives; "Quick Look Test Report, March 16, 1967," Manned Spacecraft General File, 1 January 1967-30 September 1967, Record of the Office of the Director, General Records of Johnson Space Center, Record Group 225, National Archives and Records Administration-Fort Worth, Texas (hereafter cited as RG 225, NARA-Fort Worth).

¹¹⁹ Memo, John W. Conlon, Chairman Safety Procedures Review Group, to Deputy Director, March 18, 1967, Manned Spacecraft General File, 1 January 1967-30 September 1967, Record of the Office of the Director, General Records of Johnson Space Center, RG 225, NARA-Fort Worth; "Major Test Accomplishments of the Engineering and Development Directorate, 1968," 8-5.

¹²⁰ McLane, *Apollo Experience*, 32.

subsequently issued as requirements in a special section of the MSC safety manual.¹²¹

The Apollo 204 fire investigation generated several significant physical alterations to the SESL facility. As the vacuum environment during testing was itself a fire suppressant, attention was focused on the pre-test checkout phase prior to vacuum pumpdown and repressurization. The team developed a high-volume water deluge system. While a vital component in crew survivability, damage to the chamber cryopanel and solar simulators by an accidental release of water was a primary concern. As a result, an automatic trigger device was not installed. Rather, a member of the test crew had to initiate it.¹²² A subsequent problem of a water-based suppression system developed during subfreezing chamber temperatures. Tests revealed that the resulting “cold fog” hampered rescue operations, as rescuers literally would not be able to see ‘victims’ in the chamber.¹²³

Also in the wake of the Apollo 204 investigation, limited access to the CM hatch during chamber testing emerged as a point of concern for MSC officials. As originally configured, Chamber A possessed a single man-lock at the 31’ level where crew ingress/egress into the CM occurred. To provide permanent medical personnel presence during testing, MSC safety studies recommended expansion to a double man-lock at this access level. Budgetary constraints for 1967 delayed man-lock modifications until April 1968 with the awarding of a contract to Kaiser Engineering.¹²⁴

Chamber A – Apollo Block II – 2TV-1 Testing

The Apollo 204 fire contributed to marked delays in Apollo Block II testing originally scheduled to begin June 1967.¹²⁵ As 1968 unfolded, the newly modified SESL was readied to continue its integral contribution to fulfilling the lunar landing goal by decade’s end. The Apollo 2TV-1 (Apollo Block II thermal-vacuum) test articles arrived at MSC in April and personnel finished stacking the modules in Chamber A on 23 April.¹²⁶ Initial testing of the 2TV-1 vehicle simulated the SC-101 configuration for Apollo 7. The uncrewed testing, designed to verify the pressure integrity of the test vehicle, oxygen compatibility of the powered spacecraft, and an emergency dump of onboard cryogenic oxygen, was conducted from 8 June to 11 June 1968.

Overall, this test was satisfactory, paving the way for the reintroduction of human test subjects. One anomaly of interest centered on the emergency liquid oxygen dump. The detanking procedure resulted in a significant increase over the anticipated completion time of three minutes or less. During testing, tank one experienced a twenty-one-minute detank

¹²¹ McLane, *Apollo Experience*, 33.

¹²² McLane, *Apollo Experience*, 35.

¹²³ H.R. Hansen, “Chamber A Emergency Repressurization Upgrading Function Test, June 26-30, 1967,” Brown & Root-Northrup, Report Number 40-09-21, 49, JSC-SESL Archives.

¹²⁴ File Memo, D.J. Pearse, Kaiser Engineers Project Manager, April 15, 1968, JSC-SESL Archives.

¹²⁵ “A Description of the Space Environment Simulation Laboratory—January 16, 1967” (Houston: Manned Spacecraft Center, 1967), 35.

¹²⁶ “Major Test Accomplishments of the Engineering and Development Directorate, 1968,” 8-11.

time and tank two required eleven minutes. This did not generate immediate concern.¹²⁷ However, interest in this anomaly returned with the Apollo 13 flight incident. The Apollo 13 service module had experienced a slow liquid oxygen detank at Kennedy Space Center, similar to that of 2TV-1. The Apollo 13 post flight investigation revealed problems with the fill-line standpipe delaying the discharge of the liquid oxygen and it was postulated that this contributed to the failure of the Apollo 13 tank. This conclusion would lead to an emphasis within the SESL test organization to “completely explain all anomalies that occur during the test and that even remotely involve the spacecraft.”¹²⁸

With Apollo uncrewed testing complete, preparation began on a rapid chamber turnaround for the first crewed vehicle test since S/C 008. Work was on a twenty-four-hour-a-day basis, until the chamber and spacecraft configuration were completed at 0300, 15 June 1968.¹²⁹ SESL had become a hive of activity, as its vacuum chambers were considered vital in training astronauts and for performing hardware evaluations. The SESL test team for 2TV-1 consisted of more than 400 people, including eighty-five facility and data system operations personnel, thirty-five in engineering data evaluation, twenty in support of medical, safety, and quality assurance, and sixty-five North American technical liaison representatives. Shifts averaged twelve hours except for the eight shifts for those in critical safety stations. Test conductors—monitoring the activities from within the chambers using television monitors and a myriad of system control panels—staffed the Chamber Control Room, located on the second floor of the administrative wing. Other duty stations were far less demanding. When George Low, the Apollo Program Manager, visited the facility, he noticed a technician perusing a copy of *Playboy* magazine. Low questioned the facility manager, who responded that the individual staffed a non-critical duty station and may need a stimulus to stay awake. An amused Low just smiled.¹³⁰

The primary objective of this test was to demonstrate the flight worthiness of the Apollo Block II spacecraft as configured for Apollo 7 mission. Unlike the Apollo Block I test of S/C 008, in which military and contractor personnel acted as the participants, astronauts Vance Brand, Joseph Engle, and Joseph Kerwin served as the crew. The crew entered the CM on 16 June 1968 to begin their 188-hour thirty-one-minute mission simulation.¹³¹

The comprehensive testing of the Block II spacecraft displayed the full range of SESL capabilities. An initial “hot soak” with the top sun modules began on 17 June with the heat focused on the top of the CM. SESL workers noted that the intensity of the solar simulation charred the once bright blue CM outer skin.¹³² To replicate

¹²⁷ “Major Test Accomplishments of the Engineering and Development Directorate, 1968,” 8-12.

¹²⁸ McLane, *Apollo Experience*, 53.

¹²⁹ “S/C 2TV-1 Test Project Engineering Report, Thermal Vacuum Test, June 24, 1968,” 3-1.

¹³⁰ James McLane, Jr., interview by Lori C. Walters, tape recording, Houston, Texas, July 18, 2001, JSC-SESL Archives.

¹³¹ “Test Accomplishments, 1968,” 8-13.

¹³² Clark interview, August 1, 2001.

the cold extremes of the Earth's shadow while in orbit, testing next included a cold soak on 18 June. The fifty-four side sun modules were fired up on 19 June to provide the entire CSM with a hot soak and simulate craft rotation in orbit with the lunar plane. On 20 June, a facility water line burst, shorting out a large section of the side sun, forcing a complete side sun shutdown.¹³³ The side sun failure led to a twenty-eight-hour loss of test time and the implementation of revised test procedures that included cabin depressurization and repressurization. Astronaut egress occurred on 24 June with no major spacecraft anomalies. Structures and Mechanics Division Chief Joseph Kotanchik declared, "the measure of this success is that no retest of 2TV-1 in support of the next manned Apollo mission is required, and therefore, there are no constraints on proceeding with that manned mission."¹³⁴ This Apollo 7 simulation resulted in twelve hardware design and thirteen crew procedure changes with the Apollo Block II spacecraft.¹³⁵

With the successful completion of these tests, Chamber A and the test spacecraft were modified to simulate a lunar flight configuration, including the first installation of the steerable high-gain antenna. An uncrewed thermal-vacuum test conducted between 24 August and 27 August 1968 verified the chamber's compatibility with the spacecraft. Of particular interest in this uncrewed test was a new lightweight side crew-access hatch.¹³⁶ Military personnel attached to the Flight Crew Support Division served as the prime crew for the second and final crewed evaluation of 2TV-1. Air Force Majors Alfred H. Davidson, Turnage R. Lindsey, and Lloyd Reeder entered the CM on 4 September 1968. The test called for a fifty-four-hour side sun hot soak, followed by fifteen hours of cold soak, and a final fifteen-hour top sun hot soak. The crew successfully performed a simulated EVA under vacuum conditions requiring depressurizing the compartment, opening the hatch, and subsequently repressurizing the cabin. With the flight of Apollo 7 scheduled for October, testing of the new crew access hatch was of paramount importance. Crew egress occurred on 9 September with the completion of 125 hours' simulated space conditions. Again, testing in SESL resulted in numerous changes to the CSM, including seven in hardware design and three in crew procedures.¹³⁷

Together, the 2TV-1 crew recommendations led to a redesign of biomedical cables, food stowage procedures, water chlorination, and refitting of the window shades. The crew also reported eye and skin irritation in the "constant wear" garment, leading to a change in material. As with S/C 008, window fogging occurred and was originally attributed to moisture condensation between the panes. Once removed, the 2TV-1 CM windows revealed that the condensation resulted from the silicone sealant outgassing. The value of the thermal-vacuum testing extremes in SESL far exceeded the thirty-three design and

¹³³ "S/C 2TV-1 Report, June 24, 1968," 3-3.

¹³⁴ "Successful Apollo 2TV-1 Test Called 'Significant Milestone'," *Space News Roundup* 7, no. 19 (July 5, 1968): 1.

¹³⁵ McLane, "Apollo Testing," 12.

¹³⁶ "Test Accomplishments, 1968," 8-14.

¹³⁷ McLane, "Apollo Testing," 12.

thirty procedural changes directly attributed to this testing. The combined tests of 2TV-1 demonstrated the integrity and safety of the redesigned post-Apollo 204 fire CSM.

Chamber B – Lunar Module LTA-8 Testing

Activity in SESL proceeded at a near-frenzied pace throughout 1968. With the successful completion of 2TV-1 testing, the large chamber was reconfigured for lunar surface simulations. Chamber B was in the midst of testing the lunar module, LTA-8. This was one of six test articles constructed by Grumman specifically for ground testing.

Initial test plans called for mating the lunar module (LM) to the CM in Chamber A. However, by January 1966, the Apollo Spacecraft Program Office had elected to conduct separate tests on the LM. Solar testing of a mated 2TV-1 and LTA-8 in Chamber A would have required an additional \$3 million in carbon arc lamps to bathe both vehicles to achieve the heat of a solar environment. Questions were also raised about the viability of inserting LTA-8 into the chamber for mating with the CM, and whether Grumman could deliver the test article in time. Finally, there were concerns about having the crew trying to access an inverted LM in a non-weightless environment.¹³⁸ These issues led to the final decision to use Chamber B for the LTA-8 testing.

Grumman delivered LTA-8 on 18 September 1967 in support of LM-2 and LM-3 Earth orbit configurations.¹³⁹ Whereas a massive door provides vehicle entry into Chamber A, test articles had to be lowered into Chamber B removing the top of the chamber head. SESL's 50-ton-capacity overhead crane would lower LTA-8 into the 35'-diameter chamber. Riggers questioned whether the unconventional-looking vehicle would even fit into the chamber.¹⁴⁰ The diameter restrictions of Chamber B would not permit full extension of the LM's spider-like legs and forced the use of a support stand for the test vehicle. Buildup and chamber/vehicle preparation occurred through the first three months of 1968.

Two late configuration changes to the LM had not been incorporated into LTA-8. However, these two changes—modified propellant fluid distribution fittings and electrical wire size increase from 22 to 18 gage—created problems during chamber/vehicle test preparations. Fitting leakage and wire breakage delayed the initiation of shakedown testing until 1 April 1968 with a duration of 193 hours and thirty-two minutes.¹⁴¹

With the shakedown test completed, attention turned to conducting a human-rated test, which began on 6 May 1968 with LTA-8 configured to simulate the LM-3 mission. Of

¹³⁸ Memo for records, C.H. Perrine, January 17, 1967, SESL Papers 1963-64, Box 7, Section 115, STI History Collection, JSC-SESL Archives.

¹³⁹ McLane, *Apollo Experience*, 53.

¹⁴⁰ Clark Interview, August 1, 2001.

¹⁴¹ McLane, *Apollo Experience*, 53.

the eighty-four-hour and twenty-five-minute test period, thirteen hours were crewed.¹⁴² Astronauts James Irwin and John Bull had been slated as the prime crew. With Bull's sudden resignation from the astronaut corps for medical reasons, Grumman test pilot Gerald P. Gibbons joined Irwin. Both men reported satisfaction with the vehicle and noted no major vehicle/crew interface issues. Upon leaving the vehicle, however, Irwin exhibited symptoms characteristic of hypoxia. The man-lock staff assisted Irwin out of Chamber B. A medical examination concluded Irwin had suffered no ill effects; it was subsequently determined that a "poorly fitting mask" led to Irwin's state of hypoxia.¹⁴³

With the successful conclusion of the facility/spacecraft integration tests, attention turned toward achieving a crewed rating of the LM for the scheduled December 1968 flight of James McDivitt, Russell Schweickart, and David Scott. Thermal-vacuum tests were performed from 24 May to 2 June 1968. Irwin and Gibbons, who again served as the crew, entered Chamber B on 27 May for the first in a series of two "cold soak" tests. LM cabin checkout and system operations were conducted in this ten-and-a-half-hour test. The crew returned on 29 May to complete twelve hours of cold soak testing. Irwin and Gibbons also simulated CSM/LM separation, LM maneuvering, and docking procedures.¹⁴⁴

Since neither the LM nor SESL experienced "disabling anomalies" during the cold soak phase, it was decided to abandon the scheduled eleven-day turnaround period between the cold and hot soak testing.¹⁴⁵ The chamber was maintained at a partial vacuum so "hot soak" testing could begin as soon as possible. On 31 May, Grumman test pilot Glennon Kingsley and USAF Maj. Joseph A. Gagliano began nine hours of hot soak testing. While leaving the LM, a shear pin on the LM's side hatch was damaged. On 1 June, Irwin and Gibbons began the fourth and final of the scheduled LM tests. During their fourteen hours in the LM, the crew repaired the shear pin damaged during the previous test. The repair demonstrated the viability of limited LM repairs in a hard vacuum should actual crews experience similar difficulties on the lunar surface.

Contemporary news coverage revealed a high public interest in the SESL testing. Moreover, the tests represented the first human "space" activity since the Apollo 204 fire. For their efforts in support of testing the LM, Irwin, Gagliano, Gibbons, and Kingsley received the first 'Silver Snoopy' awards at MSC.¹⁴⁶ With over forty-eight hours of crewed "flight" in SESL, these Earth orbit tests of LTA-8 cleared the way for McDivitt's Apollo 9 flight. Perhaps the words of Space Environment Test Division Chief, James McLane, best exemplified the euphoria surrounding the tests of LTA-8: "The craft passed its final preflight tests with flying colors. We have removed the last uncertainty.

¹⁴² "LTA-8 Test Report, Man-Rating" (Houston: MSC, 1968), 1, JSC-SESL Archives.

¹⁴³ "LTA-8 Test Report," 6.

¹⁴⁴ McLane, *Apollo Experience*, 54.

¹⁴⁵ "Testing Accomplishments, 1968," 8-9.

¹⁴⁶ *Houston Chronicle*, June 9, 1968.

We're home free!"¹⁴⁷

Lunar mission LM-5 configuration tests began in October 1968. Grumman test pilots Glennon Kingsley and Gerald Gibbons served as the crew for the initial crewed cold-soak testing commencing on 23 October.¹⁴⁸ Kingsley and Jim Irwin repeated a twelve-hour cold soak test on 25 October. These tests were designed to simulate descent from lunar orbit, lunar landing, and stay, and the launch and ascent back to lunar orbit. Evaluation of the LM under hot soak conditions began on 10 November with Gibbons and Kingsley, followed by similar hot soak testing with Gibbons and Kingsley on 12 November, and concluding on 14 November with Irwin and Gibbons. Major anomalies from fifty-nine hours of crewed testing included erroneous ranges in the rendezvous radar, failure of the S-band antenna, and "unanticipated master alarm" occurrences.¹⁴⁹

These constituted the final tests for LTA-8 in SESL. LTA-8 had played an important role in finding anomalies in the LM design. As the crew of Apollo 8 neared lunar orbit on Christmas Eve 1968, Donald K. Slayton wrote a memo on the future of LTA-8, indicating that "no additional test requirements are foreseen at this time."¹⁵⁰ In March 1971, the LTA-8 module—a veteran of nine simulated missions—was placed on public display and can be viewed at Space Center Houston.¹⁵¹

Lunar Support Testing

With the completion of CSM and LM vehicle crewed rating tests, SESL's test conductors' primary task now became to familiarize the astronauts with the hostile environment of space using their space suits. Typically, astronauts would arrive at the first floor of SESL's administrative wing for showering and a physical examination. After the medical exam, there would be three hours of denitrification with the crew breathing pure oxygen to prevent the "bends" during vacuum tests. Astronauts had biomedical instrumentation and sensors applied and then suited up. Astronauts were then escorted to the entrance of the man-lock, where communication umbilicals were attached and the portable life support system was donned. After final checks, the man-lock pumpdown proceeded to simulate 35,000 feet above the Earth's surface. The crew would then enter the man-lock to achieve the vacuum equalization existing in the test chamber. Five hours after their arrival at the SESL administrative wing, crewmen would enter the chamber for three to five hours. The chamber egress required thirty minutes.¹⁵²

For various reasons, including operational costs and longer pumpdown time, Chamber

¹⁴⁷ UPI Wire Service Press Release Sheet, June 3, 1968.

¹⁴⁸ "LTA-8/LM-5 Flight Crew Support Team Summary Report, December 10, 1968," 3, SESL-JSC Archives.

¹⁴⁹ "LTA-8/LM-5 Flight Crew Support Team Summary Report," 3-4.

¹⁵⁰ Memo, Donald K. Slayton to Manager Apollo Spacecraft Program, December 25, 1968, JSC-SESL Archives.

¹⁵¹ "SESL/STB/Heat-Pipe Undergo Workout," *Space News Roundup* 9, no. 10 (March 13, 1970): 2.

¹⁵² Orvis E. Pigg, "Manned Testing of Extravehicular Activity Equipment in a Simulated Space Environment," in *ASTM, IES, AIAA Space Simulation Conference Proceedings*, held in Philadelphia, Pennsylvania, 11-13 September 1967, 198-199.

A did not support the majority of crew EVA training. However, with Chamber B being used for the LTA-8 testing through November 1968, it became necessary to use Chamber A for the Apollo 9 crew training. Apollo 9 prime crew members Russell Schweickart, David Scott, and Alan Bean experienced “space” in the confines of Chamber A for their series of tests between 16 December and 22 December 1968. Goals included pressurized EVA suit orientation in vacuum environment, validation of Apollo 9 EVA procedures, and an intravehicular suit test. Although the CM pilot did not participate in EVAs, familiarization with open-hatch procedures was desired.¹⁵³

With the completion of the Apollo 9 tests, Chamber A was readied for evaluation of the Apollo Mobile Quarantine Facility (MQF). The MQF was a modified Airstream travel trailer designed to transport and isolate lunar astronauts from the recovery site to the Lunar Receiving Laboratory in Houston. In response to scientific concerns about possible contamination while on the lunar surface, astronauts returning from the lunar surface were initially required to spend three weeks in isolation to protect Earth from possible lunar microbe contamination. Since a C-141 aircraft would transport the MQF isolation trailer to Houston, the MQF’s emergency oxygen system needed to operate at flight altitudes in excess of 35,000’. The large 65’ diameter of Chamber A could easily accommodate the MQF and determine the capabilities of its emergency oxygen system. On 6 February 1969, four crew support technicians and two members of the Landing Recovery Division entered the MQF to determine whether the emergency system could support six occupants for twenty minutes at an altitude of 35,000’.¹⁵⁴ The test was successful and the MQF achieved human-rating.

The February 1969 availability of Chamber B marked the resumption of crew testing in the smaller chamber. Apollo 13 LM pilot Kenneth Mattingly and Jack Mays, a Crew Systems Division test subject, participated in the Chamber B tests during 17-28 February and 6-7 March. The crew was subjected to a variety of anticipated lunar surface conditions.¹⁵⁵ A lunar surface thermal simulator simulated both temperature and the directional and spectral radiation deflection from the lunar surface.

Subsequent testing in Chamber B moved beyond the simple goal of providing the astronaut exposure to the “feel” of a vacuum environment. During lunar missions, astronauts would be expected to deploy scientific packages and interact with these experiments. Having enough chamber space for the necessary mobility to support familiarization with scientific equipment became a concern. Other types of lunar simulations to reflect the one-sixth gravity of the lunar surface had used a simple, single-track weight relief system. The one-dimensional aspect of this rigging greatly limited astronaut movement in the vacuum chamber. To enhance crew mobility, the

¹⁵³ “Testing Accomplishments, 1968,” 8-18; McLane, “Apollo Testing,” 16.

¹⁵⁴ “Mobile Quarantine Facility Altitude Test, February 6, 1969” (Houston: Brown and Root-Northrup, 1969), 6, JSC-SESL Archives.

¹⁵⁵ “Space Environment Simulation Laboratory Technical Report: EMU Lunar Surface Qualification Test, February 19, 1969, Report No. 122-10-22” (Houston: Brown and Root-Northrup, 1969), 1, JSC-SESL Archives.

NASA team developed a traversing beam supported on parallel rails, which permitted an astronaut to have an 8' by 9' simulated lunar surface.

With the scheduled July flight of Apollo 11 rapidly approaching, prime and backup crewmembers Neil Armstrong, Edwin Aldrin, James Lovell, and Fred Haise began lunar surface training in SESL. Between 5 May and 9 May 1969, the astronauts gained their first exposure using the Apollo EMU in the thermal-vacuum environment. Beyond simple physical movements, they practiced deploying several scheduled lunar experiments—the Early Apollo Scientific Experiment Package, Apollo Lunar Surface Experiment Package, and the Modularized Stowage Assembly.¹⁵⁶ During testing, the crew reported numerous failures in the test packages and with the Hasselblad camera, but it was noted many components were used in training exercises outside of SESL and these failures were attributed to excessive use.¹⁵⁷ Apollo 12 crewmembers Pete Conrad and Alan Bean participated in similar tests from 25 May to 26 May. The astronauts deployed the Apollo Lunar Surface Experiment Package, collected geologic specimens from the lunar plane, and successfully used the Hasselblad camera under thermal-vacuum conditions.¹⁵⁸

Training for the Apollo 13 crew represented the first lunar surface simulation tests in Chamber B since the success of Apollo 11 mission. As there were no significant changes in SESL test procedures between Apollo 11 and 13, this should be interpreted as an indication of the quality of SESL training. Apollo 13 crewmembers Fred Haise and James Lovell participated in SESL testing on 5 October and 6 October 1969, respectively—with backup crew Charles Duke and John Young on 10 December and 11 December 1969. The astronauts reported only minor problems with the scientific test packages. The crews observed that they considered the SESL training “very valuable,” and recommended that it continue for future Apollo missions.¹⁵⁹

Apollo 14 astronauts Edgar Mitchell and Alan Shepard, along with the backup crew of Eugene Cernan and Joseph Engle, participated in the thermal-vacuum testing in Chamber B on 13 January, 14 January, 16 January, and 19 January 1970, respectively. As with previous simulated lunar surface testing, they reported no major anomalies. One incident worthy of note stems from Engle experiencing a “mild” case of the bends during a preliminary altitude run in Chamber B on 22 December 1969.¹⁶⁰ Such altitude tests were conducted before all thermal-vacuum testing to provide participants a

¹⁵⁶ “Space Environment Simulation Laboratory Technical Report: EMU LM-5 Crew Training Test. May 5-9, 1969, Report No. 134-10-22” (Houston: Brown and Root-Northrup, 1969), 1, JSC-SESL Archives.

¹⁵⁷ “Test Report, Mission G (LM-5), Crew Thermal Vacuum Training Tests” (Houston: Manned Spacecraft Center, 1970), 29, JSC-SESL Archives.

¹⁵⁸ “Space Environment Simulation Laboratory Technical Report: EMU LM-6 (Prime Crew) Mission H Training, May 27, 1969, Report No. 141-10-22” (Houston: Brown and Root-Northrup, 1969), 3, JSC-SESL Archives.

¹⁵⁹ “Test Report Apollo 13 (LM-7) Crew, Altitude and Thermal Vacuum Training Tests” (Houston: Manned Spacecraft Center, 1970), 17-19, JSC-SESL Archives.

¹⁶⁰ “Test Report Apollo 14 (LM-8) Crew, Altitude and Thermal Vacuum Training Tests” (Houston: Manned Spacecraft Center, 1970), 1, JSC-SESL Archives.

familiarization with the facility. Center Director Gilruth appointed a five-member safety investigation committee—James H. Chappee, Safety Office; Dr. Charles LaPinta, Medical Operations Division; William Bush, Crew Systems Division; Richard Piotrowski, Space Environment Test Division; and James Ellis, Flight Crew Support Division—to review the incident.¹⁶¹ The committee concluded that neither improper test procedures nor equipment caused the incident.¹⁶² The committee findings did result in new guidelines for astronaut pre-breathing and flying aircraft before and after altitude chamber testing. It was believed that the Engle incident was a result of being on an aircraft shortly before his participation in the Chamber B altitude test run.¹⁶³

The three remaining lunar missions, Apollo 15, 16, and 17, called for extended lunar stays and increased scientific exploration. A redesigned EMU, to accommodate longer-duration lunar EVAs, began Chamber B qualification testing in March 1971. Incorporating previous mission experience into testing protocols, the EMU suits were covered with paint designed to simulate lunar dust. Mission data suggested that lunar dust increased the space suit's absorbency of solar energy, thereby decreasing the thermal insulation properties of the EMU. The redesigned suit performed except during the hot and cold soaks, when the test subject noted an uncomfortable thermal sensation in the fingertips.¹⁶⁴ A second series of tests from 2 June to 4 June 1971 explored the potential of fatigue and dehydration that the crews could experience with their seven-hour EVA schedule. Test results indicated that the planned seven-hour lunar surface activity period should not overly fatigue or dehydrate crews and were feasible as planned.¹⁶⁵

In 1969, SESL test conductors evaluated the use of Chamber A for testing the lunar roving vehicle (LRV). The proposed testing would have verified the hardware, provided the Apollo 15 crew with an opportunity to operate the LRV under simulated lunar conditions, and created baseline data for comparison during actual mission use. However, limitations on the availability for contractor support staffing in 1970 led to a suspension of planning for testing of the LRV in SESL.¹⁶⁶ During a LRV review meeting at Kennedy Space Center in March 1971, questions arose regarding crew ability to use the LRV on the lunar surface. Specifically, concerns were expressed about the LRV fenders' performance during their lunar surface deployment. As a result, Chamber B was

¹⁶¹ Memo, Robert Gilruth to list, "Investigating Committee—Termination of Altitude Test with Astronaut Joe Engle on December 22, 1969," December 23, 1969, JSC-SESL Archives.

¹⁶² Memo, Robert Gilruth to list, 12.

¹⁶³ Memo, Christopher Kraft to list, "Review of Apollo 14 Crew Familiarization Test Incident," January 20, 1969, Folder: January 25-26, 1970, Box 72-23/24, Apollo Program Chronological Files, Apollo Collection, JSC-SESL Archives.

¹⁶⁴ Identity of test participants is believed to be the Apollo 15 prime crew. This cannot be confirmed from test technical reports.

¹⁶⁵ "Major Test Accomplishments of the Engineering and Development Directorate, 1970-1971" (Houston: Manned Spacecraft Center, 1972), 4-21, JSC-SESL Archives.

¹⁶⁶ "LRV," 1969, 16, JSC-SESL Archives. No author is attributed to this document that details a potential testing of the LRV in Chamber A.

readied to validate the mechanics of the fenders during deployment with a series of hot and cold case tests on the LRV fender units. Conducted between 25-31 March 1971, the cold case test revealed that the fender slide mechanism was inoperable in cold extremes and that the LRV should be placed in full sun on the lunar surface to keep the slide mechanism from freezing.¹⁶⁷

Skylab Support

After completing most of its Apollo Program support, SESL continued to play an important role in human spaceflight for the Skylab Program. To conserve costs, the 2TV-1 vehicle (CSM 098) was configured and designated as 2TV-2. Five uncrewed tests were conducted between 10 February and 22 March 1971 on the 2TV-2 in Chamber A.¹⁶⁸

For the final Apollo missions, a new scientific instrument module designed to conduct scientific experiments while in lunar orbit occupied two service bays of the service module. While in lunar orbit, the panel covering bay I would eject, exposing the scientific instrument module. The thermal-vacuum tests in SESL revealed the CSM could make the return portion of the flight without experiencing thermal problems due to the added exposure from the ejected bay I covering.¹⁶⁹ Four remaining 2TV-2 service module bays were configured for Skylab operations. The value of SESL testing was again confirmed with the discovery of five major anomalies in the Skylab thermal/control systems.¹⁷⁰ Most significantly, these problems were discovered two years before the first Skylab CSM launch, resulting in minimal delay to the Skylab Program. Moreover, program officials indicated that, without these thermal-vacuum tests, the first Skylab mission would have probably necessarily been “prematurely terminated.”¹⁷¹

The Apollo telescope mount (ATM) to be used on Skylab represented a significant percentage of SESL operational usage from 1970 to 1972. SESL officials had actively sought out the testing for this Marshall Space Flight Center project. As the ATM testing involved the actual flight hardware rather than non-flight test articles, Marshall officials required a contaminant-free chamber environment. A contamination cleaning and control program was initiated to create class 10,000-cfm white room conditions in Chamber A.¹⁷² Using oil diffusion pumps in the operation of Chamber A created a special challenge in obtaining the necessary clean room standard. Ultimately, Marshall achieved the contaminant-free environment through the installation of air flow traps and filters and

¹⁶⁷ “Test Accomplishments, 1970-1971,” 4-18.

¹⁶⁸ “Test Report Command Service Module 2TV-2 Thermal-Vacuum Tests” (Houston: Manned Spacecraft Center, 1972), 1.

¹⁶⁹ “Test Accomplishments, 1970-1971,” 4-9.

¹⁷⁰ “Test Accomplishments, 1970-1971,” 4-8.

¹⁷¹ “SESL Completes 2TV-2 Testing,” *Space News Roundup* 10, no. 11 (April 9, 1971): 1, 4.

¹⁷² McLane Interview, July 18, 2001.

new ventilation measures.¹⁷³ Tests designed to certify the cleanliness of the chamber were conducted in May 1970.¹⁷⁴

Three components comprised the ATM testing activity: the ATM thermal subsystems unit, the ATM prototype unit, and the actual ATM flight hardware. The thermal subsystems unit was a full-scale test article designed to verify the thermal control components of the ATM. The thermal subsystems unit, used to develop the shipping, handling, and testing procedures for the ATM, was successfully subjected to hot and cold thermal-vacuum tests on 22-26 July 1970 and 3-16 August 1970.¹⁷⁵ Testing revealed no major design problems.¹⁷⁶

As 2TV-2 occupied Chamber A between the thermal systems unit (TSU) and ATM prototype tests, chamber contamination cleaning and certification were again required. The ATM prototype arrived at MSC in early September 1971. During preparation for the scheduled October thermal-vacuum test, a crewed subsystem evaluation was conducted. Test crews were located in the A-4 man-lock with the ATM control and display panel under simulated orbital pressure. The crews performed three separate successful operations of the ATM panel. Thermal-vacuum testing of the prototype unit in October and November revealed no major unit anomalies. Testing of the ATM flight hardware in July and August 1972 was less eventful than the arrival of the unit at MSC. Procedure called for MSC's rigging contractor, Westheimer Riggers, to install the unit in Chamber A. However, as the transfer got under way, Marshall Space Flight Center representatives felt that sufficient care for handling the hardware was not being taken and halted the operation. Union representatives for the riggers protested the MSFC actions. After some additional negotiations, the riggers finished inserting the hardware into Chamber A.¹⁷⁷ Thermal-vacuum testing confirmed the flight-readiness of the ATM hardware.

Naturally, the Earth-orbiting operating environment of Skylab required an alteration of the Apollo lunar suits. The redesigned Skylab EMU underwent a series of crewed evaluation tests beginning on 3 April 1972.¹⁷⁸ John Samouce of the Crew Procedures Division and astronaut Story Musgrave participated in both hot and cold case tests over a four-day period in Chamber B. The test revealed the redesigned Skylab suit successfully protected crewmen under "worst case" hot and cold extremes.¹⁷⁹

Perhaps the most significant contribution of SESL to the Skylab Program came shortly after the launch of the laboratory in May 1973. Upon reaching Earth orbit, it became

¹⁷³ "SESL/STB, Heat-Pipe Undergo Workout," 2.

¹⁷⁴ "Test Accomplishments, 1970-1971," 4-10.

¹⁷⁵ "Skylab Program Payload Integration: Apollo Telescope Mount (ATM) Thermal Systems Unit (TSU) Test Thermal Evaluation," October 16, 1970, 6, JSC-SESL Archives.

¹⁷⁶ "Test Accomplishments, 1970-1971," 4-11.

¹⁷⁷ McLane Interview, July 18, 2001; Clark Interview, August 1, 2001.

¹⁷⁸ "Test Report Skylab EMU Low Temperature Evaluation Test" (Houston: Manned Spacecraft Center, 1972), 3.

¹⁷⁹ "Test Report Skylab EMU Low Temperature Evaluation Test," 38.

clear that the vehicle was in serious trouble as one of the main solar panels and a micrometeoroid/thermal shield were damaged during launch. Without the meteoroid shield/thermal shield, rising temperatures inside the laboratory would damage the delicate electronic equipment and make it uninhabitable. The fate of Skylab rested on the ability to repair the facility in an expeditious fashion. The solution was a lightweight parasol that was deployed to shade the surface of the vehicle. Before the first Skylab crew was launched on their repair mission, it was necessary to test the mechanics of the parasol deployment in a thermal-vacuum environment.¹⁸⁰ Testing of the parasol confirmed its integrity for use in space, and the Skylab 2 crew was able to save the ailing scientific space platform and permit the Skylab Program to complete all objectives.

Post-Apollo Problems

For the American public, the afterglow of Neil Armstrong's historic 'giant leap' dimmed with each successive lunar mission. The financial and psychological toll of the conflict in Vietnam combined with an increased desire to spend federal monies on numerous earthbound problems produced public apathy on the subject of space exploration. NASA had achieved Kennedy's goal and humanity had broken its earthly bonds and surveyed another celestial body on six voyages to the lunar surface. From the Congressional perspective, the Cold War-induced space race had been won—America had regained its technological leadership—the Soviet Union had been vanquished. In the wake of this changing climate of interest, budgetary constraints followed for NASA.

SESL had been constructed specifically to test the hardware of Apollo. What role would the massive chamber play after the Apollo Program? In 1973, as part of a cost-reduction effort, NASA Headquarters initiated a review of the Agency's large thermal-vacuum facilities. A delegation reviewed Chamber A and B at MSC (now the Lyndon B. Johnson Space Center), the 27' x 85' chamber at Jet Propulsion Laboratory, and the 33.5' x 60' chamber at Goddard Space Flight Center. The study revealed the operating costs of SESL to be "disproportionately larger than those of the other somewhat similar facilities."¹⁸¹ Task team recommendations included a need for an immediate reduction of operating costs at all locations with a guarantee of their continued use through 1974.¹⁸² With the increased pressure to reduce the cost of operations for SESL, Chief of the Space Environment Test Division James McLane set forth an internal study to "identify radical changes in our approach to laboratory operations which will result in significant cost savings." McLane noted that "the importance of this activity [the operating study] to the future of this laboratory can not be overstressed" as the task team would reconvene in late 1974 to again review potential facility closures.¹⁸³

¹⁸⁰ McLane Interview, July 18, 2001; Emeigh Interview, July 24, 2001.

¹⁸¹ Memo, James C. McLane to Chief Engineering Operations Branch, "Operations Study," September 21, 1973, JSC-SESL Archives.

¹⁸² Memo, Milton W. Rosen, "Review of Large Thermal Vacuum Facilities in NASA," October 17, 1973, JSC-SESL Archives.

¹⁸³ McLane Memo, September 21, 1973.

Chamber B would accommodate the tests for the Apollo Soyuz Test Program. Manufactured by Rockwell International, the Program's docking module and docking system underwent a series of thermal-vacuum tests from 23 June to 2 August 1974.¹⁸⁴ The backup flight docking module was used in combination with Apollo command module and Soyuz thermal simulators to obtain docking module operational data under near-space conditions. Crewed testing confirmed the validity of the unit's ability to protect crews from extreme heat and cold during crew transfers. The conclusion of the Apollo-Soyuz tests brought the official end of the requirements for which SESL had been originally designed.¹⁸⁵

The prospect of continued large-scale testing in Chamber A looked bleak. Although preparations for the Space Shuttle Orbiter were under way within NASA, the configuration of the Shuttle permitted limited testing in SESL. Designed to accommodate the cylindrical Apollo CSM, a full-scale winged Shuttle could not be tested in Chamber A. As a human-rated facility, Chamber A costs were significantly higher than traditional non-human-rated thermal-vacuum chambers.¹⁸⁶ Unless there was a unique Chamber A size requirement, Shuttle components would be tested in the most cost-competitive facility, often not SESL. The Orbiter heat rejection system was the largest Shuttle testing program conducted in Chamber A. Prototype testing of the heat rejection system began in 1974 with full-scale testing of the system mounted on cargo bay doors continuing through 1978.

Fiscal years 1974 and 1975 marked the beginning of significantly decreased test loads for SESL.¹⁸⁷ SESL officials aggressively pursued outside reimbursable test projects. If current NASA programs failed to fill SESL's operating schedule, perhaps universities or non-aerospace corporations could use the chambers. A few years earlier, James McLane and Aleck Bond had initiated a campaign to attract aerospace contractors, other federal agencies, the Department of Defense, and academic institutions. McLane and staff members again toured the country attempting to sell the unique capabilities of SESL. As attempts to secure outside testing grew, the early brochures evolved into slick publications more reminiscent of those used in automotive sales. With the deactivation of NASA's Plum Brook Station vacuum chamber in 1975, the academic community turned to SESL to continue studies of the ionospheric plasma environment.¹⁸⁸ Unfortunately, the nature of thermal-vacuum testing poses a time problem for attracting users.

¹⁸⁴ "Test Report Apollo Soyuz Test Program Docking Module/Docking System Thermal Vacuum Test in Chamber B" (Houston: Lyndon B. Johnson Space Center, 1975), 3.

¹⁸⁵ Memo, Maxime A. Faget to Assistant Director for Administration, "Proposed acceleration of construction schedule for Space Environment Simulation Facility," November 12, 1962.

¹⁸⁶ Memo, Maxime A. Faget to Assistant Director for Administration.

¹⁸⁷ Bernard J. McGee, *FY 74 Cost and Operations Study: Facilities of the Space Environment Test Division* (Houston: Lyndon B. Johnson Space Center, 1974), 1, JSC-SESL Archives; Bernard J. McGee, *FY 75 Cost and Operations Study: Facilities of the Space Environment Test Division* (Houston: Lyndon B. Johnson Space Center, 1975), 1, JSC-SESL Archives.

¹⁸⁸ Bjorn Grandal, ed., *Artificial Particle Beams in Space Plasma Studies* (New York: Plenum Press, 1982), 331.

Preparations for and actual thermal-vacuum testing requires a significant investment of time and many organizations do not wish to leave their home areas for protracted periods. Instead, they tend to use smaller and closer chambers and adapt to their lesser capabilities.¹⁸⁹

Hollywood became one of the more unusual users of SESL during this period. Looking for a futuristic setting for their science fiction thriller *Futureworld*, American International Pictures negotiated with Johnson Space Center for an extensive thirty-day shoot. Throughout April 1976, the crew filmed scenes in the myriad of Johnson Space Center facilities, including a fifty-foot leap from Chamber A.¹⁹⁰ In 1977, Hollywood returned to SESL during the filming of *Red Alert*. Chamber A took center stage with daring stunts using the massive 40' vessel door as a backdrop.¹⁹¹

Located on a low-lying coastal plain, the Houston area is susceptible to periodic flooding during tropical storms. In June 1976, such floodwaters damaged Texas Medical Center records and a variety of materials from the Contemporary Art Museum. SESL officials were contacted to use Chamber B for removing moisture from the materials and records. All materials were placed on 120°F heated shelves within the chamber. While many of the materials retained the fine silt left by the floodwaters, the seventy-two-hour pumpdown period in SESL assisted in drying the records.¹⁹² Chamber B would be pressed into document-drying service again in 1987 with assistance to the University of Houston library. Most recently, in the summer of 2002, after Tropical Storm Allison flooded area hospital storage facilities, this process was employed again to save many research and medical records.

Within the federal arena, the Defense Nuclear Agency (DNA) sought to secure the use of a large thermal-vacuum chamber to conduct tests on Department of Defense satellites in 1979. The tests were designed to investigate the resistance of satellites to X-radiation from exoatmospheric nuclear blasts and were intended to be long duration.¹⁹³ A DNA site selection committee narrowed the choices to Chamber A and the USAF Mark I facility at Tullahoma. While the DNA testing opportunity would have provided SESL with a steady client, significant structural modifications and integration of additional equipment would have been required. This would have greatly restricted chamber use by any future NASA projects during the DNA occupancy period of October 1980 – October 1984. Without a major test program for SESL, JSC Director Christopher Kraft and NASA Deputy Administrator Alan Lovelace initially supported the DNA proposal, as it

¹⁸⁹ McLane Interview, July 18, 2001.

¹⁹⁰ Charles Redmond, "O.K. Quiet Please, This is Picture," *Space News Roundup* 15, no. 7 (April 9, 1976): 4.

¹⁹¹ Photo, *Space News Roundup* 16, no. 5 (March 4, 1977): 1.

¹⁹² "SETD Saves Valuable Flood-damaged Records," *Space News Roundup* 15, no. 13 (July 2, 1976): 1, 4; Press Release, Johnson Space Center, Release Number 76-42, 18 June 1976.

¹⁹³ Letter, Christopher C. Kraft to Alan M. Lovelace, May 15, 1980, JSC-SESL Archives.

would defray NASA's operating costs for the nearly idle facility.¹⁹⁴ However, the \$80 million in DNA modifications to SESL would significantly alter the solar simulation capabilities of chamber A, and NASA withdrew support for this reconfiguration.¹⁹⁵

Faced with "a lack of funds" for SESL test operation, JSC officials elected to temporarily deactivate the facility.¹⁹⁶ Richard Piotrowski served as the SESL Phasedown Manager for deactivation slated to begin August 1981. During the deactivation period, a Northrup caretaker crew conducted periodic safety inspections and maintained the basic support systems. Although reactivation was scheduled for 1 October 1982, budget restrictions and a lack of scheduled tests led to more permanent deactivation of SESL.¹⁹⁷ Unlike the deactivation of 1981-1982, the new plan discontinued the maintenance activity and the formal closure of SESL commenced 30 November 1982.¹⁹⁸

Epilogue

In 1985, three years after closure, SESL was added to the National Register of Historic Places. The facility was deemed a National Historic Landmark for its significant contribution to the success of crewed and uncrewed spaceflight. Such recognition would have been a fitting concluding chapter in the facility's history that had been "designed for a useful life of twenty years."¹⁹⁹ The opportunity for SESL to once again contribute to the U.S. space program came with its reactivation in 1988. The Space Shuttle's return to flight after the STS-51L explosion made reactivation an important prospect. An updated Chamber B could once again provide astronauts their first exposure to the rigors of the space environment. However, although a human-rating for Chamber A would not be pursued due to the costs involved, it is still an active contributor in testing large pieces of hardware such as the International Space Station TransHab component in December 1998.

What, then, is the legacy of the giant thermal-vacuum chambers in SESL? Perhaps the recollections of Richard Hermling, a former Apollo-era SESL engineer, best expresses the spirit of the facility's cadre about its greatest endeavor: "We did it first—before the flight—and it was risky, even though we were all on the ground."²⁰⁰ SESL had accomplished what it had been designed to do—create some of the rigors of space on Earth. In doing this, SESL launched humankind's first mission to the Moon from the coastal plains of Texas.

¹⁹⁴ Letter, Christopher C. Kraft to Alan Lovelace, July 18, 1980, JSC-SESL Archives; Letter, Alan Lovelace to Christopher Kraft, September 5, 1980, JSC-SESL Archives.

¹⁹⁵ Record, James C. McLane, "DNA Proposal to Modify SESL, Briefing for the NASA Deputy Administrator," October 7, 1980, JSC-SESL Archives.

¹⁹⁶ Memo, James C. McLane, "SESL Phasedown," March 5, 1981, JSC-SESL Archives; Harry W. Hart, "Deactivation Plan Space Environment Simulation Laboratory Building 32," July 1981, JSC-SESL Archives.

¹⁹⁷ Memo, James Moore to Distribution, "SESL Closing Plans," September 21, 1982, JSC-SESL Archives.

¹⁹⁸ Memo, Alan L. Branscombe, Jr. to Distribution, "Implementing TPS's for SESL Deactivation," October 13, 1982, JSC-SESL Archives.

¹⁹⁹ "Design Criteria: Chamber A and B Complex," 3, JSC-SESL Archives.

²⁰⁰ James Hartsfield, "Reunion Honors Unique Work," *Space News Roundup* 33, no. 38 (October 7, 1994): 4.

PART II. STRUCTURAL/DESIGN INFORMATION

A. General Description:²⁰¹ The Space Environment Simulation Laboratory (Building 32) houses two large thermal-vacuum chambers (A and B) with solar simulation capabilities on the main floor. The building is 123'-2" x 264'-6". Chamber A has exterior dimensions of 120' tall x 65' diameter while the interior is 90' tall x 55' diameter. The external structure of this chamber is a sheathing of stainless steel, encasing cryo panels and liquid nitrogen shrouds. Chamber A sits in a sump pit. On the south elevation at 0' and 31' are dual man-locks. These man-locks were a way for the crew to move into and out of the thermal-vacuum environment inside the chamber. The massive 40' chamber door, which opens at a 120° angle, is located on the east elevation. The side solar simulators are located on the north elevation, while the diffusion pumps can be found on the west elevation. Hoist portals for the 25-ton hoists are located at the 91'-8" elevation, and solar simulators are located on the 101'-5" elevation. Stairs and observation catwalks provide access. The chamber floor (the lunar plane) can be rotated approximately 180° "about its vertical axis at continuously variable angular velocities up to a maximum of 0.8 rpm."²⁰² The chamber has a vacuum pumping capacity of 1×10^{-6} torr (unit of measure of the pressure of gases) allowing it to simulate an altitude greater than 130 miles above the Earth. To reproduce the temperature extremes of space, interior chamber walls cool to -280°F as two banks of carbon arc modules simulate the unfiltered solar light/heat of the Sun.

Chamber B has the same configuration as Chamber A but on a smaller scale and with a non-rotating lunar plane. This chamber has an exterior diameter of 35' and stands 43' tall. The interior dimensions are 25' diameter x 26' tall. It also sits in a sump pit and has a double man-lock on the south elevation. Diffusion pumps ring the remainder of the chamber. A removable head base is located at the 19'-10" elevation, with top solar simulators at the 39' elevation. Chamber B is equipped with two rolling bridge cranes of 100,000 pound capacity.

B. Mechanicals/Operation: In order to simulate the conditions of space, the chambers are equipped with a vacuum system comprised of mechanical/diffusion pumps. To control the temperature, thermal shrouds were used. The repressurization systems were used for emergency and normal repressurization, chamber heating, and chamber ventilation. The emergency repressurization system required dry gas, made up of a mixture of 70 percent nitrogen and 30 oxygen that could repressurize the chamber within 90 seconds.²⁰³

²⁰¹ Lori C. Walters' report has been augmented in this section with information from James Hartsfield, "Reunion Honors Unique Work," *Space News Roundup* 33, no. 38 (October 7, 1994): 4; Harry Butowsky, "Space Environment Simulation Laboratory (SESL)," National Register of Historic Places Inventory-Nomination Form, May 15, 1984, Section 7; and fieldwork completed by the HAER team.

²⁰² Harry Butowsky, "Space Environment Simulation Laboratory (SESL)," National Register of Historic Places Inventory-Nomination Form, May 15, 1984, Section 7.

²⁰³ "Apollo 009 Undergoes Manned Chamber Test," *Space News Roundup* 5, no. 1 (August 5, 1966): 9.

An article in *Space News Roundup* from June 1966 described the operation of Chamber A.

A set of vacuum pumps can suck out almost all of the air molecules out of the chamber and maintain a vacuum environment which is normally found 87 miles above the earth.

It can also produce the thermal environment. The heat of the sun comes from banks of carbon arc lamps in the back and top of the chamber. Heat loss in space can be simulated by panels in the chamber walls which are supercooled by liquid nitrogen.²⁰⁴

The solar simulation system was installed by RCA and consisted of “electric carbon arc lamps projecting through a system of self-contained mirrors and lenses along the top and side” of the chambers.²⁰⁵

Early Chamber B tests included the Gemini modular maneuvering unit (MMU), Apollo extravehicular activity (EVA) mobility unit (EMU), and the lunar module (LM). Since Gemini astronaut Charles Bassett first ventured into the chamber in 1966, Chamber B has assisted astronauts in testing hardware and preparing them for work in the harsh extremes of space.

D. Site Information: Chambers A and B are located in Building 32, the Space Environment Simulation Laboratory. This is part of NASA’s Johnson Space Center.

PART III. SOURCES OF INFORMATION

A. Primary Sources

Alperin, Morton. *Large Space Environments Facility Study*, AEDC-TN-6021. January 1960.

Bechtel Engineering Corporation. “Preliminary Engineering Analysis for Space Environment Simulation Laboratory Chamber B Redesign.” November 20, 1964.

Bond, Aleck C. Interview, August 25, 1998. Johnson Space Center Oral History Project, available at http://www.jsc.nasa.gov/history/oral_histories/oral_histories.htm.

Bond, Aleck. Interview by Robert Merrifield, written transcript. October 10, 1967.

²⁰⁴ “Apollo Chamber Tests to Start this Summer,” *Space News Roundup* 5, no. 18 (June 24, 1966): 2.

²⁰⁵ “RCA to Build Solar Simulation System for New Space Chamber,” *Space News Roundup* 2, no. 6 (January 9, 1963): 1.

Chemical and Mechanical Systems Division, Records of the Engineering and Development Directorate, General Records of Johnson Space Center, Record Group 225, National Archives and Records Administration-Fort Worth, Texas.

“Cooperative Agreement Between the National Aeronautics and Space Administration and the Corps of Engineers Department of the Army on Construction,” EM 1-1-7. December 7, 1960.

“A Description of the Space Environment Simulation Laboratory—January 16, 1967.” Houston: Manned Spacecraft Center, 1967.

Hiebert, David M., H.D. Moore, and R.B. Williams. “Initial Pumpdown and Leak Check of the Aerospace Environmental Chamber (Mark I),” AEDC-TR-66-142. August 1966.

“Historical Record of Spacecraft 008 Thermovacuum Test.” Houston: Manned Spacecraft Center, 1966.

Johnson Space Center, History Collection. Located at the University of Houston Clear Lake, Houston Texas. This collection contains a variety of material relating to this structure, including memos, letters, studies, progress reports, editions of *Space News Roundup*, and interviews. Individual documents are cited in the footnotes of this report.

Manned Spacecraft General File, 1 January 1967-30 September 1967, Record of the Office of the Director, General Records of Johnson Space Center, Record Group 225, National Archives and Records Administration-Fort Worth, Texas.

McLane, James C. “Apollo Testing in the Space Environment Simulation Laboratory.” Presented to the 1969 International Vacuum Metallurgy Conference, Pittsburgh, PA, June 16-19, 1969.

National Aeronautics and Space Act of 1958, Public Law No. 85-568, as Amended. Available at <http://www.hq.nasa.gov/ogc/spaceact.html#POLICY>.

Pigg, Orvis E. “Manned Testing of Extravehicular Activity Equipment in a Simulated Space Environment.” In *ASTM, IES, AIAA Space Simulation Conference Proceedings*, in Philadelphia, Pennsylvania, 11-13 September 1967.

“Pilots’ Report, Apollo Spacecraft 008, Manned Thermal Vacuum Test.” Folder, September 26, 1966, Box 067-34/35, Apollo Program Chronological Files, Apollo Collection, Johnson Space Center.

Johnson Space Center Roundup, available online at:
<http://www.jsc.nasa.gov/history/roundups/roundups.htm>

“RCA to Build Solar Simulation System for New Space Chamber.” *Space News Roundup 2*, no. 6 (January 9, 1963): 1-2.

“Manned Tests of Chamber B Includes Temperature Extremes.” *Space News Roundup 5*, no. 5 (December 23, 1965): 3.

“Apollo Chamber Tests to Start this Summer.” *Space News Roundup 5*, no. 18 (June 24, 1966): 2.

Photo. *Space News Roundup 5*, no. 20 (July 22, 1966): 3.

“Apollo 008 Undergoes Manned Chamber Test.” *Space News Roundup 5*, no. 1 (August 5, 1966): 8.

“Apollo Ends Six-Day Chamber Test.” *Space News Roundup 6*, no. 2 (November 11, 1966): 8.

“Successful Apollo 2TV-1 Test Called ‘Significant Milestone’.” *Space News Roundup 7*, no. 19 (July 5, 1968): 1.

“SESL/STB/Heat-Pipe Undergo Workout.” *Space News Roundup 9*, no. 10 (March 13, 1970): 2.

“SESL Completes 2TV-2 Testing.” *Space News Roundup 10*, no. 11 (April 9, 1971): 1, 4.

Redmond, Charles. “O.K. Quiet Please, This is Picture.” *Space News Roundup 15*, no. 7 (April 9, 1976): 4.

Photo. *Space News Roundup 16*, no. 5 (March 4, 1977): 1.

“SETD Saves Valuable Flood-damaged Records.” *Space News Roundup 15*, no. 13 (July 2, 1976): 1, 4.

Hartsfield, James. “Reunion Honors Unique Work.” *Space News Roundup 33*, no. 38 (October 7, 1994): 4.

“Test Report Command Service Module 2TV-2 Thermal-Vacuum Tests.” Houston: Manned Spacecraft Center, 1972.

“Test Report Skylab EMU Low Temperature Evaluation Test.” Houston: Manned Spacecraft Center, 1972.

“Test Report Apollo Soyuz Test Program Docking Module/Docking System Thermal Vacuum Test in Chamber B.” Houston: Lyndon B. Johnson Space Center, 1975.

B. Secondary Sources

Beschloss, Michael R. *The Crisis Years: Kennedy and Khrushchev, 1960-1963*. New York: Edward Burlingame Books, 1991.

Bond, Aleck C. *Lecture on Space Environment Simulation*. University of Tennessee Space Institute, November 10, 1970.

Brown, Dr. Clayton. *Rivers, Rockets and Readiness: Army Engineers in the Sunbelt*. Washington, D.C.: U.S. GPO, 1979.

Dethloff, Henry C. *Suddenly Tomorrow Came...A History of the Johnson Space Center*, SP-4307. Houston: NASA Johnson Space Center, 1993.

Devine, Robert A. *Sputnik Challenge: Eisenhower's Response to the Soviet Satellite*. New York: Oxford University Press, 1993.

Hacker, Barton C. and James M. Grimwood. *On the Shoulders of Titans: A History of Project Gemini*, SP-4203. Washington, D.C.: NASA, 1977.

Kennedy, John F. *“Let the Word go Forth”: The Speeches, Statements and Writings of John F. Kennedy, 1947-1963*. New York: Delacorte Press, 1988.

McDougall, Walter A. *The Heavens and the Earth: A Political History of the Space Age*. Baltimore: Johns Hopkins University Press, 1985.

McLane, James C. *Apollo Experience Report: Manned Thermal-Vacuum Testing of Spacecraft*. NASA Johnson Space Center, March 1974, NASA Technical Note, NASA TN D-7610, March 1974.

National Aeronautics and Space Act of 1958, Public Law No. 85-568, as Amended. Available at <http://www.hq.nasa.gov/ogc/spaceact.html#POLICY>.

Swenson, Loyd S. Jr., James M. Grimwood, and Charles C. Alexander. *This New Ocean: A History of Project Mercury*. Washington, D.C.: NASA, 1989. Available at <http://history.nasa.gov/SP-4201/toc.htm>.

“Thermal Vacuum Laboratories: User Guide.” NASA Johnson Space Center, March 23, 1981.

“Thirtieth Anniversary of Apollo 11: 1969-1999.” Available at http://nssdc.gsfc.nasa.gov/planetary//lunar/apollo_11_30th.html.