

HISTORIC AMERICAN ENGINEERING RECORD
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
RADAR BORESIGHT RANGE CONTROL BUILDING
(Building 18)

HAER No. TX-109-G

LOCATION:

The Radar Boresight Range Control Building (Building 18) is located on 2nd Street northeast from the controlled Antenna Test Range area, in Area 4 at the Johnson Space Center (JSC) in Houston, Harris County, Texas.

The building is located at latitude: 29.558052, longitude: -95.093154. This coordinate was obtained on November 5, 2021 using Google Earth. The coordinate's datum is World Geodetic System 1984. There is no restriction on its release to the public.

PRESENT OWNER:

National Aeronautics and Space Administration, Johnson Space Center, Houston, Texas

PRESENT USE:

Currently, the building is being prepped for demolition and all re-usable equipment is being repurposed in other buildings located within the JSC campus or placed in storage at JSC.

SIGNIFICANCE:

The Radar Boresight Range Control Building (Building 18) was originally designed to test the Apollo rendezvous radar and the Apollo landing radar subsystems, with the rendezvous radar first used in space during the Apollo 9 mission in March 1969 and the landing radar first used in space during the Apollo 11 lunar landing mission in July 1969. The Radar Boresight Range Control Building (Building 18) is significant as the full functionality of the intended antennae testing at JSC could not be realized without this facility.¹ The Radar Boresight Range Control Building had significant associations with not only the Apollo Program (1961 to 1972), but also Skylab (1965 to 1979), Apollo-Soyuz Test Project (1971 to 1975), Shuttle-Mir (1993 to 1998), Space Shuttle (1981 to 2011), and ISS (1993 to current). The Radar Boresight Range Control Building also conveys a visual sense of the overall historic environment, represents an interrelated arrangement of historically connected properties, and is united historically with numerous other buildings and events within the geography of the JSC campus.

Additionally, the Radar Boresight Range Control Building retains its original PEAFF panel walls that reflect the Modern design concept used by federal contractors in the 1960s and 1970s, designed in the style of Brutalism, which is a thick masonry variation of Modernist architecture. The PEAFF panel walls were an outstanding engineering achievement and pioneering design concept in the early 1960s and illustrate the implementation of President Kennedy's Federal Program Guiding Principles for Federal Architecture and the GSA's philosophies of engineering functionality and economical materials selection.

HISTORIAN:

¹ Letter, Justin Kockritz to Sandra J. Tetley, "Project Review under Section 110 of the National Historic Preservation Act, Final Historic and Architectural Survey and Evaluation of Facilities at the NASA's Lyndon B. Johnson Space Center, Houston, Harris County (NASA/110, THC #201701384)," December 19, 2016.

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PROJECT INFORMATION:

The Radar Boresight Range Control Building HAER recording project was completed with guidance and assistance by Sandra J. Tetley, Real Property Officer, Historic Preservation Officer, NASA JSC. The project was managed by Adam Graves, GRAVitate, HAER Project Leader. The measured drawings are copies produced by Marilyn Blevins, Facilities and Real Estate Division, NASA JSC. The large-format photographs were produced by the Imaging Lab at JSC. The written historical and descriptive data were adapted from a technical report written by Natalie J. Graves, GRAVitate.

NASA, like all federal agencies, is required to follow a federal mandate to reduce costs and square footage, reduce energy consumption, consolidate space, and divest surplus and inefficient properties. Over the years, Building 18 has deteriorated to the point that it is no longer cost effective to maintain and operate. Specific issues include: storm damaged roof; storm damaged and rusting exterior doors; the interior is in poor condition; the air handler needs to be replaced; and piping throughout the building is leaking. Therefore, NASA JSC believes Building 18 is at the end of its serviceable life for its type of construction and it has been designated for demolition.

LIST OF ACRONYMS

AFB	Air Force Base
ARPA	Advanced Research Projects
ASTP	Apollo-Soyuz Test Project
CM	Command Module
CRA	Crew Reception Area
CSM	Apollo Command and Service Module
DoD	Department of Defense
ESA	European Space Agency
FCR-1	Flight Control Room 1
GPO	Gemini Project Office
GSA	General Services Administration
HAER	Historic American Engineering Record
ISS	International Space Station
JSC	Johnson Space Center
KSC	John F. Kennedy Space Center
LEM	Apollo Lunar Excursion Module
LM	Lunar Module
MCC	Mission Control Center
MOCR	Mission Operation Control Center
MSC	Manned Space Center
MSFC	Marshall Space Flight Center
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NPS	National Park Service
NRHP	National Register of Historic Places
PEAF	pre-cast exposed aggregate facing
SRB	Solid Rocket Boosters
SHPO	State Historical Preservation Office
SSP	Space Shuttle Program
STG	Space Task Group
STS	Space Transportation System
U.S.	United States
USACE	U.S. Army Corps of Engineers

Part I. Historical Information

A. Physical History:

1. Date of construction: commenced on September 30, 1965, with the contract filed by NASA as complete on December 31, 1966.
2. Architect/Engineer: Unknown, not relayed on drawings or Master Data Sheet.
3. Builder: Scientific Atlanta Incorporated of Atlanta, Georgia.
4. Original plans and construction: The exterior of the Radar Boresight Range Control Building, at the time of documentation, resembles the original design. Original construction features included a concrete foundation, PEAFF panel walls, and vinyl asbestos tile floors.² When first constructed the building measured 28' in length and was 28' wide, covering 1,568 square feet.³ The interior has been modernized and modified several times since 1966, as needed, to accommodate the U.S. space program within the Federal Program Guiding Principles for Federal Architecture building design mandate.⁴
5. Alterations and additions: Improvements to the building, such as installing floodlights and safety rails, upgrading fire suppression systems, and modernizing electrical wiring and plumbing, have occurred since the building was originally constructed. Major alterations to the original facility layout occurred in 1997 when a 20' x 28' addition to the north was constructed to support two new control rooms which added 1,200 square feet (Enclosure 2). At the same time, outside stairs and anechoic shielding was installed on the north wall.⁵ The first floor is subdivided into a storage supply room (Room 100), two bathrooms, and one mechanical room (Room 104). The second floor is accessible via an exterior stairwell located on the northwest side of the building and consists of two sub-divided rooms (Rooms 200 and 202). During Project Morpheus, Morpheus Mission Control was located on the second floor in rooms 200 and 202 with additional test facilities on the roof. Building alterations were made to support Project Morpheus (circa 2012) which included the installation of new computers, command telemetry, cables, and fiber optics.⁶

B. Historical Context:

1. NASA Johnson Space Center, Houston, Texas

a. Setting the Stage for Man-in-Space

The specter of the Sputnik satellite as it launched into space from the Soviet Union on October 4, 1957, remains the pivotal event in the birth of the U.S. manned spaceflight program; an event, as Texas Senator Lyndon B. Johnson recalled, that ushered in "a new era of history."⁷ The Soviet Union's achievement in designing, building, and successfully launching an Earth-satellite created an immediate wave of response in the United States. Senator Johnson called for an inquiry by the Preparedness Investigating Subcommittee of the Senate Committee on Armed Services into the nature of U.S. satellite and missile programs. As future Director of the Manned Space Center, Dr. Robert R. Gilruth recalled, "it [Sputnik] put a new sense of value and urgency on the things we had

² Drawing No. FHP-18-1, scanned copy.

³ Master Data Sheet, NASA/1047/128 (n.d.)

⁴ Master Data Sheet, NASA/1047/128 (n.d.)

⁵ Master Data Sheet, NASA/1047/128 (n.d.)

⁶ Master Data Sheet, NASA/1047/128 (n.d.)

⁷ Henry C. Dethloff, *Suddenly, Tomorrow Came... A History of the Johnson Space Center The NASA History Series*, NASA SP-4307 (Washington, DC: U.S. Printing Office, 1993), 1.

been doing.”⁸ Sputnik I was quickly followed by a second pioneering Soviet space mission—the Earth-orbital launch of the dog Laika aboard Sputnik II on November 3, 1957.⁹ Gilruth continued, “When I saw the dog go up, I said, ‘My God, we better get going because it’s going to be a legitimate program to put a man in space.’”¹⁰

The U.S. space program predated Sputnik with the U.S. military conducting extensive research using captured German rocket technology during the Second World War.¹¹ Beginning in the 1940s, the U.S. military, primarily the Air Force, conducted a large number of aeronautics test and development projects with the National Advisory Committee for Aeronautics (NACA) at the Langley Aeronautical Laboratory (later renamed Langley Research Center) in Hampton, Virginia.¹² It was during this time that a number of government-university research centers worked in cooperation on space and aeronautics-related research, developing primarily military satellites and rockets, and beginning a close military-civilian relationship.¹³ Following the launch of Sputnik I and II, the Department of Defense (DoD) believed they should house the space program, as space-related research and development properly belonged in a military agency.¹⁴ However, the scientific community argued that purely scientific and nonmilitary aspects of space research should not be under the control of the military.¹⁵ President Dwight D. Eisenhower believed there was no need for creating a civilian space agency outside the DoD to avoid duplication of effort and because military space programs were of paramount importance.¹⁶ Vice President Richard Nixon believed advancing the U.S. position in the world was important and required the U.S. having a civilian space program that was separate from the military.¹⁷ The Preparedness Subcommittee conducted an exhaustive inquiry into national defenses, ultimately finding post-war Army and Navy rocketry development, as well as NACA space research programs, in good order for adaptation of an Air Force-run “man-in-space” program.¹⁸ Meanwhile, Senator Johnson and other aerospace proponents, organized under the Senate Special Committee on Space and Aeronautics, worked tirelessly to pass the legislation that would create a civilian space agency, arguing that it was the “best hope for peaceful development of outer space.”¹⁹ After hearing the initial findings of the Preparedness Subcommittee, President Eisenhower addressed the nation with a call for increased scientific education, basic research, community scholarship, and a centralized civilian program for satellite and missile development.²⁰

On July 29, 1958, Eisenhower signed the National Aeronautics and Space Act of 1958 into law, providing “for research into the problems of flight within and outside the Earth’s atmosphere” and establishing the National Aeronautics and Space Administration.²¹ The Space Act stipulated that NASA would, in fact, be a restructured NACA pending a ninety-day transition. NASA was officially formed on October 1, 1958. One week later, a joint NASA/ARPA (Advanced Research Projects Agency) committee unofficially created the Space Task Group (STG)—an initial working group of thirty-six engineers and other specialists assembled by Gilruth, then Assistant Director of the Langley Research Center, in order to begin work on a manned satellite program. Concurrently, five NACA facilities transitioned into the inaugural NASA program that would become Project Mercury.

⁸ Dethloff, *Suddenly Tomorrow Came*, 17.

⁹ Dethloff, *Suddenly Tomorrow Came*, 17.

¹⁰ Jennifer Ross-Nazzari, “The Right Place—Houston Makes History,” *Houston History Magazine Vol 6, Number 1* (2008), 6.

¹¹ Dwayne A. Day, “Invitation to Struggle: The History of Civilian-Military Relations in Space” in *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Vol II, External Relationships*, ed. John M. Logsdon (Washington, DC: U.S. Printing Office, 1995), 235.

¹² Day, *Invitation to Struggle*, 235.

¹³ Day, *Invitation to Struggle*, 235.

¹⁴ Day, *Invitation to Struggle*, 248.

¹⁵ Day, *Invitation to Struggle*, 248.

¹⁶ Day, *Invitation to Struggle*, 250.

¹⁷ Day, *Invitation to Struggle*, 250.

¹⁸ Day, *Invitation to Struggle*, 250.

¹⁹ Dethloff, *Suddenly Tomorrow Came*, 13.

²⁰ Dethloff, *Suddenly Tomorrow Came*, 4.

²¹ Dethloff, *Suddenly Tomorrow Came*, 14.

These included the Lewis Research Center in Ohio, the Langley Research Center and Wallops Rocket Test Range Station in Virginia, and the Ames Research Center and Muroc Aircraft Test Range (later renamed Edwards Air Force Base) in California.²² Gilruth officially opened Project Mercury on November 26, 1958, and continued to recruit additional engineers from AVRO Aircraft, Ltd. of Canada, which from 1958 to 1961 was based largely out of Langley and reported directly to NASA Headquarters in Washington, DC.²³

As the STG grew with the development of Project Mercury, organizational issues became apparent, and working relationships became strained between Gilruth and policy directors.²⁴ Additional personnel requirements had resulted in the creation of a sixth NASA facility, the Goddard Space Flight Center near Washington, DC, in Greenbelt, Maryland (then called Beltsville) by May 1959. At this time, administrative control was relocated to Harry Goett in Washington, under the policy direction and control of Dr. Abe Silverstein at Goddard, with technical direction by Gilruth still at Langley. This fragmented STG configuration plagued the early management of the project, and Gilruth and Silverstein's relationship suffered. After May 25, 1961, the scope of NASA's human spaceflight endeavors expanded to meet President John F. Kennedy's call to Congress and the nation "to commit itself to achieving the goal, before the decade is out, of landing a man on the Moon and returning him safely to Earth."²⁵ The size constraints of Goddard, the administrative issues that had forced STG management back to Langley in January 1961, and, with an accelerating man-in-space goal, the need for a new NASA lead center became clear to STG leadership.

b. Breaking Ground in Houston

On September 19, 1961, NASA Administrator James Webb announced the selection of Houston, Texas, as the location of NASA's Manned Space Center (MSC). (MSC was renamed Johnson Space Center, or JSC, after its dedication on February 19, 1973, in honor of the late U.S. President Lyndon B. Johnson.²⁶ Prior to this date, the site-selection team investigated twenty-three potential locations for the proposed MSC.²⁷ The federal government acquired title to the Clear Lake Site in 1961, through the combination of a 1,000-acre donation by Rice University and the purchase of an additional 600 acres adjacent to the Rice lands.²⁸ In 1961, Humble Oil and Refining donated land to Rice University with the proviso that Rice would offer some of that land to NASA for the MSC site.²⁹ Humble Oil and Refining specified that Rice had to give the federal government 1,000 acres but could sell 600 acres to the federal government, which they did for \$1.4 million.³⁰ The new boundaries of the Clear Lake Site encompassed a twenty-acre reserve drilling site. The Clear Lake Site, located approximately twenty-five miles southeast of downtown Houston, was selected based on a suite of attractive advantages, including the presence of nearby deep-water transportation facilities, educational institutions, an industrial plant, extant Air Force facilities at Ellington Field, formerly known as Ellington Air Force Base (AFB), and a skilled work force, as well as political and business relationships that connected Houston with aerospace proponents in Washington.³¹ In particular, Houston lay within the congressional district of House Appropriations Committee Chairman Albert Thomas, whose influence concerning the 1962 budget proved invaluable. Congress approved the appropriation of approximately \$60 million to NASA in Fiscal Year 1962 for

²² David S.F. Portree, "NASA's Origins and the Dawn of the Space Age" in *Monographs in Aerospace History, Number 10* (Washington, DC: U.S. Printing Office, 1998).

²³ NASA, "Johnson Space Center," from https://crgis.ndc.nasa.gov/historic/Johnson_Space_Center (2014).

²⁴ Dethloff, *Suddenly Tomorrow Came*, 26-27.

²⁵ John F. Kennedy's Special Message to Congress on Urgent National Needs, May 25, 1961, <https://archive.org/details/jfks19611025>.

²⁶ Dethloff, *Suddenly Tomorrow Came*, 33.

²⁷ Dethloff, *Suddenly Tomorrow Came*, 39.

²⁸ William D. Angel, "The Politics of Space: NASA's Decision to Locate the Manned Spacecraft Center in Houston," *The Houston Review* Volume VI (2), (1984), 63-81.

²⁹ Angel, *The Politics of Space*, 70.

³⁰ Angel, *The Politics of Space*, 70.

³¹ Angel, *The Politics of Space*, 70.

the purchase of land and the design and construction of the first four proposed MSC facilities that included Flight Project Facility, Equipment Evaluation Laboratory and Support Facility, Flight Operations Facility, and Environmental Testing Laboratory. An additional \$4.5 million was set aside for site development and utilities. NASA's overarching design for the Clear Lake Site consisted of a "command center for the manned lunar landing mission and all follow-on manned spaceflight missions."³²

By mid-1962, NASA had leased approximately 295,996 square feet of office and laboratory space in at least eleven separate locations within the same vicinity of Houston.³³ However, the bulk of interim personnel offices were located in greater proximity to the Clear Lake Site at Ellington Field. Approximately 1,500 MSC personnel worked from renovated World War II barrack structures at Ellington Field before the Clear Lake Site was developed.³⁴

President John F. Kennedy conducted a "whirlwind tour of the nation's space facilities" in September 1962.³⁵ The tour included NASA facilities in Huntsville, Alabama, and Cape Canaveral, Florida, as well as the McDonnell Aircraft Corporation plant—then responsible for spacecraft manufacturing—in St. Louis, Missouri. President Kennedy arrived in Houston the evening of Tuesday, September 11, and the following day the presidential motorcade brought President Kennedy to the MSC's temporary spacecraft research and development facility, where Gilruth and other NASA officials gave a one-hour briefing and tour of the Apollo lunar landing vehicle, or "Lunar Bug".³⁶

On September 12, 1962, President Kennedy delivered his historic speech at Rice University in which he celebrated the City of Houston as the new heart of the scientific community and declared:

*We choose to go to the Moon. We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard...many years ago the great British explorer George Mallory, who was to die on Mount Everest, was asked why did he want to climb it. He said, "Because it is there." Well, space is there, and we're going to climb it, and the Moon and planets are there, and new hopes for knowledge and peace are there.*³⁷

c. MSC Master Plan

Converting the Clear Lake Site into the new training center for U.S. astronauts fell upon the shoulders of the U.S. Army Corps of Engineers (USACE), as NASA and the USACE had recently entered into a cooperative agreement in 1960.³⁸ The agreement established that the USACE, Chief of Engineers, had to make available the services of his construction forces to perform design or construction services at such places as desired by NASA.³⁹ NASA Administrator Webb officially informed the then-Chief of Engineers, Lieutenant General W.K. Wilson, Jr., in September 1961, that, as a young agency, NASA did not possess the necessary internal construction organization to accomplish a project as wide in scope as MSC, nor the political experience to negotiate the award of large construction contract.⁴⁰ The USACE was made responsible for design administration, construction contracting, and inspection of facilities to ensure compliance with

³² Dethloff, *Suddenly Tomorrow Came*, 40.

³³ Burton Chapman, "The First Days in Houston," *Houston History Magazine* Volume VI (1) (2008), 29.

³⁴ Dethloff, *Suddenly Tomorrow Came*, 46.

³⁵ Dethloff, *Suddenly Tomorrow Came*, 51.

³⁶ Chapman, *The First Days*, 30.

³⁷ John F. Kennedy's Address at Rice University on the Nation's Space Effort, September 12, 1962, <http://er.jsc.nasa.gov/ricetalk.htm>.

³⁸ National Park Service (NPS), "NASA Johnson Space Center, Building No. 32, Space Environment Simulation Laboratory, Chambers A & B (HAER No. TX-109-B)," (Washington D.C, n.d.), 10.

³⁹ NPS, HAER No. TX-109-B, 10.

⁴⁰ NPS, HAER No. TX-109-B, 10.

design specifications, while NASA retained direct control of payments for all services.⁴¹ In order to meet the schedule of reaching the moon by 1970, NASA gave the USACE six months for planning and eighteen months for construction.⁴² Chief Engineer Wilson assigned the MSC project to the Fort Worth Division, to be supervised by District Engineer Colonel R. Paul West and Deputy District Engineer Lieutenant Colonel Wayne A. Blair. Lieutenant Colonel Blair, a civil engineer who had recently returned from Korea after serving a tour of duty as commander of the 11th Engineer Combat Battalion, was placed in charge of the project.⁴³ The USACE's expertise was in building dams and public works systems, not buildings; thus inexperience partnered with the mandatory tight deadline on completion was not without problems. According to Dethloff, unilateral decisions made by the USACE affected MSC operations, and since the MSC required sound engineering and rigid quality controls, NASA quickly created a Change Order Board to oversee and approve all design changes.⁴⁴

The MSC was to be the state-of-the-art lead center for all space missions involving astronauts; therefore, the MSC facilities had to house large scale, innovative, never built before, engineering feats. Numerous design modifications were made that required an established architecture-engineering firm to direct the MSC Master Plan and participate in the design of these new facilities, in cooperation with NASA and USACE engineers. The Brown and Root Construction Company, of Houston, Texas, in association with Charles Luckman and Associates of Los Angeles, California, was awarded the initial \$1.5 million contract to design the MSC Master Plan.⁴⁵ The MSC Master Plan defined the general site planning objective that established the need for orderly growth and development of the new Center. Specific requirements for organizations and major facility settings and considerations were also established based on the functional relationships between organizations and their operations, adjacent off-site land conditions, and environmental and community factors. The Master Plan land planning criteria comprised the site to contain five land use elements that included a 485-acre test area, a T-shaped antenna Test Range, an eighteen-acre Lunar Landing Area, a Barge Berthing Facility, and Building Facilities.⁴⁶ Building Facilities included Project Management, General Support, Central Data and Support, Technical Services, Spacecraft Research, Life Systems Facility, Astronaut Training Facility, Flight Operations, Space Physics, Development Test and Evaluation, Environmental Test Facility, Cafeterias, Maintenance Supply and Support, and Miscellaneous Support Buildings.⁴⁷

The MSC Master Plan divided the Center into four sectors (Areas 1–4) following the intersection of Second Street and Avenue B as it roughly bisected the Site.⁴⁸ This land use pattern formed the basis of the JSC Facility Numbering System. The southeast sector (Area 1) comprised the Main Facility Complex. The northeast sector (Area 2) consisted of semi-permanent structures supporting the Main Facility Complex, including the primary support facility 138 kilovolt (kV) Electrical Substation. The northwest sector (Area 3) was reserved for hazardous activities and industrial support for the Center, while the southwest sector (Area 4) was reserved for large land area requirements to support special systems testing and development, as well as warehousing, shipping and receiving, motor pool, logistical support, and other housekeeping operations. The MSC Master Plan also accounted for additional ground space, within major land use areas, divided into zones according to restricted, semi-restricted, and general use classification. NASA Road 1

⁴¹ NPS, HAER No. TX-109-B, 10.

⁴² NPS, HAER No. TX-109-B, 10.

⁴³ "Corps of Engineers Supervise Construction at Clear Lake Site," *Space News Roundup* (March 4, 1964), 2.

⁴⁴ Dethloff, *Suddenly Tomorrow Came*, 48.

⁴⁵ NPS, HAER No. TX-109-B, 11.

⁴⁶ Brown & Root, Inc., Charles Luckman Associates, Brooks & Barr, Harvin C. Moore, Mac Kie & Kamrath, and Wirtz, Calhoun, Tungate & Jackson, "Master Plan and Architectural Concept: Manned Spacecraft Center, National Aeronautics and Space Administration, Clear Lake, Harris County, Texas." *Corps of Engineers Contract No. DA-41-443-CIVENG-62-702*, prepared for U.S. Army Engineering District, Fort Worth, Texas, 1962, 5-6.

⁴⁷ Brown and Root, et al, Master Plan, 7.

⁴⁸ GRAVitate, "JSC Survey," 22.

was created from a portion of Farm-to-Market Road 528, after the Texas Legislature introduced a bill defining a new and “unprecedented” highway category for NASA—the first and only of its kind.⁴⁹ The initial architect-engineer MSC Master Plan included principal planning for the installation and design of the flight project facility, the engineering evaluation laboratory, flight operations facility, and their utilities.⁵⁰ By January 1962, designs for the new Center were in process that divided the work into three phases. The first of three primary construction phases began in March of the same year with the Phase I contract, in the amount of \$3,673,000, awarded to the lowest bidder, Morrison-Knudsen Construction Company of Boise, Idaho, and Paul Hardeman, Inc. of Stanton, California.⁵¹ Major Phase I work consisted of site development and basic utility installation, including overall site grading and drainage, an electrical power system, complete water supply and distribution systems, the utility tunnel, canal relocation, bridges, basic roads, security fence, and street lighting, with actual construction beginning on April 2, 1962.⁵² In October of the same year, the Phase II contract was awarded in the amount of \$4,145,045 to W.S. Bellows Construction Corporation and Peter Kiewit & Sons Corporation, both of Houston, Texas.⁵³ Phase II included the construction of thirteen buildings meant to house the majority of the MSC’s employees and technicians.⁵⁴ Phase II work provisioned the Center with permanent service structures, including the Central Data Office Building, water treatment plant and building, sewage treatment plant, central heating and cooling plant, and a fire station.⁵⁵ Phase III commenced in December 1962 with a \$19-million contract awarded to C.H. Leavell and Company of El Paso, Texas, the Morrison-Knudsen Construction Company, and Paul Hardeman, Inc., for the major portion of the building construction that included 11 office and laboratory buildings and temperature and control machinery for the site.⁵⁶ Phase III buildings included the auditorium, project management building, cafeteria, flight operations and astronaut training building, life systems laboratory, technical services office building, technical services shop building, systems evaluation laboratory, systems evaluation and development division laboratory and office building, a spacecraft research lab and office building, and the data acquisition building.⁵⁷

d. U.S. Army Corps of Engineers

The Fort Worth USACE was given the responsibility of managing the design and construction of the MSC. The Fort Worth USACE District Office assembled a supervisory group of engineers (civil, mechanical, electrical) inspectors, and administrative personnel, from missile sites and air bases across the U.S. who, during the design phase, first worked from an USACE Project Engineering Office set up at the office of Brown and Root Construction Company in Houston.⁵⁸ When construction began, the USACE Project Engineering Office was first located in the NASA-leased Farnsworth-Chambers Building and then the Peachy Building, and finally relocated to Building 222 at Ellington Field, where a staff of thirty-three engineers, drafters, and clerical workers were housed. During construction, a temporary field office (Building 226) was constructed at the Clear Lake Site where the Construction Division of approximately sixty-four employees was managed by USACE resident engineer Don Mills.⁵⁹ USACE management met with contractors weekly to discuss modification, design adaption to construction, and other assorted building issues with a weekly progress report sent to NASA and the Fort Worth District Office.⁶⁰ Throughout the entirety of

⁴⁹ Dethloff, *Suddenly Tomorrow Came*, 48.

⁵⁰ “Design Work Contract is Let for Clear Lake,” *Space News Roundup* (December 27, 1961), 8.

⁵¹ “Current Plans Call for Building Bids during September,” *Space News Roundup* (April 18, 1962), 1; “Life Systems Laboratory Accepted for Occupancy,” *Space News Roundup* (March 4, 1964), 2.

⁵² *Space News Roundup* (March 4, 1964), 2.

⁵³ “Phase II Contract Goes to Bellows, Peter Kiewit, Sons,” *Space News Roundup* (October 3, 1962), 8.

⁵⁴ “Corps of Engineers Supervise Construction at Clear Lake Site,” *Space News Roundup* (March 4, 1964), 5.

⁵⁵ GRAVitate, “JSC Survey,” 23.

⁵⁶ “Bids Open on Phase 3 of Center Construction,” *Space News Roundup* (November 14, 1962), 1; “19 Million Dollar Construction Contract Signed,” *Space News Roundup* (December 12, 1962), 1.

⁵⁷ GRAVitate, “JSC Survey,” 23.

⁵⁸ *Space News Roundup* (March 4, 1964), 2.

⁵⁹ *Space News Roundup* (March 4, 1964), 2.

⁶⁰ *Space News Roundup* (March 4, 1964), 5.

construction, the USACE engineering specialists and USACE leadership inspected the Clear Lake Site.

e. First MSC Permanent Facilities

During the fall of 1963, MSC personnel began the move to the Clear Lake Site from interim facilities. By December, a group of eleven buildings were certified for operations, followed by the Technical Service Division's transfer in January 1964. The major move of approximately 2,100 MSC employees was scheduled to begin on February 20, 1964.⁶¹ Completion was scheduled for April 6, 1964, with an additional 600 employees slated for a secondary move to be completed in July of 1964. The relocation included moves from interim facilities at Ellington Field and Houston locations.⁶² The first completed building officially turned over to NASA for use was the Fire Operations Facility (Building 25), quickly followed by the Administrative Support Building (Building 12) and the Shipping and Receiving Warehouse (Building 420).⁶³

2. NASA Johnson Space Center's Manned Space Programs

a. Project Mercury (1958 to 1963)

Project Mercury (1958 to 1963) was the first U.S. man-in-space program. Its origins date to post-war government and industry developments in liquid-fueled rocketry that produced the Redstone and Atlas launch vehicles necessary to put the first U.S. personnel in space. From its official inception on October 7, 1958, Project Mercury was designed as a joint inter-service and interagency program between the DoD, ARPA, and the newly founded NASA STG.⁶⁴ Project objectives were to achieve orbital flight and safe recovery of a manned satellite and to investigate human performance capabilities in a space environment. The Mercury vehicle was designed as a ballistic capsule that could maintain static stability over the Mach number range and structurally withstand the combined impacts of acceleration, heat loads, and aerodynamic forces during boost and reentry operations.⁶⁵

In late September 1958, following findings of the Joint NASA-ARPA Manned Satellite Panel, which had examined operational requirements for the proposed manned satellite program, an agreement was reached. Gilruth, and four other NASA members, along with two ARPA representatives, formed Project Mercury's steering committee. As the young NASA took shape, T. Keith Glennan was appointed administrator, with long-time NACA Director Hugh L. Dryden as deputy. Gilruth would transition from his NACA position into the rapidly changing STG to become Director of Project Mercury. Technical management of the project would be based at NACA's former Langley Research Center. On April 9, 1959, Glennan announced the names of the agency's first group of astronauts at a news conference in Washington D.C., who became the "Original Seven" or "Mercury Seven."⁶⁶ The project's massive aerospace technology, biomedical research, astronaut training, and flight testing effort resulted in the successful launch of the Freedom 7 of Project Mercury from Cape Canaveral, Florida, on May 5, 1961, piloted by astronaut Alan Shepard.⁶⁷ The momentous occasion marked the U.S. entrance to manned space flight.

⁶¹ "Major Move to Clear Lake Begins February 20," *Space News Roundup* (January 8, 1964), 1.

⁶² *Space News Roundup* (January 8, 1964), 3.

⁶³ *Space News Roundup* (March 4, 1964), 2.

⁶⁴ Loyd S. Swenson, James M. Grimwood, and Charles C. Alexander, "This New Ocean: A History of Project Mercury," *NASA Special Publications-4201 in the NASA History Series* (Washington, DC: U.S. Printing Office, 1989).

⁶⁵ Swenson, et al, "This New Ocean," 1989, 110-111.

⁶⁶ NASA, "The Mercury Astronauts," <https://www.nasa.gov/content/the-mercury-astronauts>, (2015).

⁶⁷ James M. Grimwood, "PART III (A) Operational Phase of Project Mercury: May 5, 1961 through May 1962," *Project Mercury A Chronology NASA SP-4001* (Washington, DC: U.S. Printing Office, 1963).

Project Mercury was born into a tumultuous period in early NASA history when facilities and organizations were in flux.⁶⁸ The project was contracted to twelve companies across the country, including the prime spacecraft contractor McDonnell Aircraft Corporation. Manufacturing of the Redstone, Atlas, and smaller Little Joe rockets occurred in Huntsville, Alabama; San Diego, California; and Los Angeles, California, respectively. Aerodynamic studies were conducted at Langley and the Holloman Air Force Base in Alamogordo, New Mexico. Wallops Island, Virginia, served as the site for the unmanned Little Joe launches. The Atlantic Missile Range at Cape Canaveral Air Force Station was selected as the manned launch site and Mercury Mission Control Center, although Mercury's global tracking network operated from NASA Goddard Space Flight Center in Maryland. Additionally, astronaut training was jointly based out of Langley; Lewis Research Center in Cleveland, Ohio; and Naval Air Development Center in Johnsville, Pennsylvania.

As the push for manned space flight grew stronger, it became clear that managing the program at a second location was not feasible and strain was placed on the relationships between Gilruth, Goett, and Silverstein; thus, the push for a manned spaceflight program independent of other NASA centers began.⁶⁹ This uncomfortable management split between NASA Goddard and the STG from May 1959 to January 1961, along with other organizational issues, prompted NASA to plan for an autonomous lead center. Site selection for the new MSC hinged, in part, on deep-water transportation routes connecting the Clear Lake Site at Galveston Bay with the Michoud Plant near New Orleans—Project Mercury's new fabrication facility for large booster and vehicle stages—and the growing Cape Canaveral launch complex. On November 1, 1961, the STG was formally reconfigured as NASA MSC with Gilruth retained as Director. Following the STG transition to Houston, Mercury Project Headquarters were relocated to the Houston Petroleum Center Building; however, the Mercury Project Office and Mercury astronauts themselves remained at Langley until November 1963.⁷⁰ The most successful and critical Mercury missions, including Alan Shepard's successful space flight in 1961, were managed "amidst the suitcase environment" of the interim MSC as the Clear Lake Site developed.⁷¹

The Mercury flights proved that humans could live and work in space, paving the way for the Gemini and Apollo Programs, as well as for all further human spaceflight.⁷² Project Mercury was developed and managed prior to the origination of the MSC in Houston, but important Project Mercury individuals trained at the MSC using technology developed in buildings still on site today.⁷³ NASA's Original Seven became instant household names in the United States and worldwide celebrities; they included three Naval aviators, M. Scott Carpenter, Walter M. Schirra Jr., and Alan B. Shepard Jr.; three Air Force pilots, L. Gordon Cooper Jr., Virgil I. (Gus) Grissom, and Donald K. (Deke) Slayton; and one Marine Corps aviator John H. Glenn Jr.⁷⁴ The Original Seven helped usher in a new era of space travel that eventually led to people from the United States walking on the moon, and each of these men are renowned as pioneers in space exploration.

Project Mercury was developed and managed prior to the origination of the MSC in Houston. While the Clear Lake Site was under construction, MSC employees, including the Mercury project scientists, engineers, and astronauts, had offices at Ellington Field.⁷⁵ Additionally, as MSC employees began the move from Ellington Field to their permanent facilities at the MSC, the NASA-leased office space at Ellington Field was re-assigned to personnel still assigned to the just-

⁶⁸ Dethloff, *Suddenly Tomorrow Came*, 20-33.

⁶⁹ Dethloff, *Suddenly Tomorrow Came*, 36.

⁷⁰ Dethloff, *Suddenly Tomorrow Came*, 55-56; "Mercury Personnel to be Shifted to Other Two Projects," *Space News Roundup* (June 26, 1963), 1.

⁷¹ Dethloff, *Suddenly Tomorrow Came*, 53.

⁷² NASA, "The Mercury Astronauts" (2015).

⁷³ GRAVitate, "JSC Survey."

⁷⁴ NASA, "The Mercury Astronauts" (2015).

⁷⁵ "Astronauts Move to New Offices at Ellington AFB," *Space News Roundup* (November 13, 1963), 1.

concluded Mercury Program.⁷⁶ During this interim period, Gilruth officially closed the Project Mercury Office and transitioned Mercury personnel into the Gemini Program and Apollo Projects in November of 1963. Reappointments included Christopher C. Kraft as Director of Flight Operations and Mercury astronaut Deke Slayton as Assistant Director for Flight Crew Operations and head of the Astronaut Office.⁷⁷ Meanwhile, the MSC became focused on the imminent Gemini and Apollo Programs.

b. Gemini Program (1962 to 1966)

NASA planned the Gemini Program (1962 to 1966) to follow on Project Mercury's achievements in Earth-orbit.⁷⁸ As historians Barton C. Hacker and James M. Grimwood contend, Project Mercury was, in the most pragmatic sense, "an engineering project" designed to use efficient and expedient techniques to achieve the earliest possible orbital flight and successful recovery of a manned satellite.⁷⁹ After Mercury's demonstrable success, NASA needed a greater understanding of living, working, and maneuvering in space in order to support the future Apollo Program mission to land on the moon and return safely to Earth.⁸⁰ Gemini's project name derived from the identification between the proposed two-man spacecraft design and the celestial "twins" of the twelve-constellation zodiac. Gemini's 10 manned missions would develop rendezvous and docking operations in support of the Apollo Lunar Module's requirements for lunar launch and rendezvous and docking with the Apollo Command/Service Module. Unlike Mercury, the Gemini Program would be under autonomous NASA management, although the DoD and U.S. Air Force participated as management contractors for launch vehicle development and technical direction of space rendezvous and docking.⁸¹

Director Gilruth announced the separate formation of the Mercury, Gemini Program, and Apollo Spacecraft Program Offices on January 15, 1962, although unofficial Gemini planning and research had commenced as early as 1959.⁸² McDonnell Aircraft Corporation, the manufacturers of Project Mercury spacecraft, completed an independent advanced project study in September 1959 to improve on Project Mercury.⁸³ NASA then awarded Gemini's design study contract to McDonnell in April 1961, several months prior to the STG's transition to Houston. In January 1962, Gilruth appointed former Avro aerodynamicist James Chamberlin as project manager of the Gemini Project Office (GPO), which would lead from its Houston base for the entirety of the program. A small group of GPO members had already begun moving to Houston during the month before the GPO's formal establishment. With the Houston transition complete by February of the same year, the GPO represented one of the first MSC components assembled at the new Center.

All major Gemini systems—spacecraft, booster, target, and paraglider systems—were under contract by March 1962.⁸⁴ McDonnell received the 25-million-dollar prime spacecraft contract in April 1962. Chamberlin would work closely with McDonnell engineers over the next year to redesign the Mercury ballistic capsule into an operational spacecraft. By January 1962, the Titan II launch vehicle was contracted by the DoD's Space Systems Division of the Air Force Systems Command in Los Angeles, California, to Martin Baltimore in the amount of \$27 million. The Atlas-Agena launch vehicle construction contract was awarded somewhat later to Lockheed Missiles & Space Company in Sunnyvale, California.

⁷⁶ "Logistics Personnel Move into New Clear Lake Offices," *Space News Roundup* (October 16, 1963), 1, 3.

⁷⁷ Dethloff, *Suddenly Tomorrow Came*, 73.

⁷⁸ Jennifer Ross-Nazzal, "The Right Place," 10.

⁷⁹ Barton C. Hacker and James M. Grimwood, "On the Shoulders of Titans: A History of Project Gemini," *NASA Special Publication-4203, NASA History Series* (Washington, DC: U.S. Printing Office, 1977).

⁸⁰ Jennifer Ross-Nazzal, "The Right Place," 10.

⁸¹ Hacker and Grimwood, "On the Shoulders of Titans."

⁸² Dethloff, *Suddenly Tomorrow Came*, 79; Hacker and Grimwood, "On the Shoulders of Titans."

⁸³ Dethloff, *Suddenly Tomorrow Came*, 79; Hacker and Grimwood, "On the Shoulders of Titans."

⁸⁴ Hacker and Grimwood, "On the Shoulders of Titans."

Between January 1962 and the spring of 1963, a “Gemini management crisis” developed, involving Chamberlin’s tendency to maintain personal and private control over all McDonnell decision-making and rising program costs, creating a growing rift between the GPO and other MSC divisions.⁸⁵ Gilruth restructured MSC management in mid-1963 just as Project Mercury came to a close and the tragic events of November 22 unfolded. President Kennedy’s assassination in Dallas, Texas, sent the nation into grief and hardened NASA’s commitment to the lunar landing objective established in May 1961.

Gilruth’s reorganization created seven major functions to be managed by four assistant directors, major program managers, and the manager of MSC Florida Operations.⁸⁶ Gilruth’s vision for Gemini and Apollo transitioned veteran Mercury personnel into the new projects and reduced the number of offices directly reporting to top management. Gilruth appointed Acting Manager Charles W. Matthews as Manager of the GPO with Kenneth S. Kleinknecht as Deputy. The reorganization of the MSC was part of greater management changes implemented by the Office of Manned Space Flight at NASA Headquarters in Washington D.C. to streamline Gemini operations at the MSC, Marshall Space Flight Center (MSFC), and Launch Operations Center—as the John F. Kennedy Space Center (KSC) was known until late 1963.

NASA faced a critical decision about the location of the Gemini spacecraft control center. During Project Mercury, flight operations were centralized at the Launch Operations Center at Cape Canaveral; however, NASA’s new lead center in Houston could be designed for this responsibility. Other contenders included NASA Goddard. Gemini mission control and operations were ultimately delegated to the MSC in a move that further oriented the U.S. manned spaceflight program toward Houston.

Flight Operations Director Kraft’s experience in designing the Mercury Mission Control Center at the Cape would prove invaluable to the development of the MSC’s Mission Control Center (MCC) in Building 30.⁸⁷ Prior to Mercury, a long-distance global communications network was non-existent. Mercury required real-time voice contact between the spacecraft and ground flight control, which NASA built from the ground up. These requirements were expanded for Gemini’s more complex, maneuverable spacecraft. After Kraft’s assessment of the need to adapt Mercury’s “off-the-shelf” communications network for Gemini, NASA awarded a study contract for the MCC to Philco’s Western Development Laboratory in Palo Alto, California, in 1961.⁸⁸ Philco was awarded a second contract in March 1963 for construction and installation of electronic hardware for the MCC’s communications center, flight simulator facilities, and flight operations display.⁸⁹ The design and construction of a digital command system for Gemini and Apollo spacecraft was awarded to IBM in October 1962. This real-time computer system was installed on the first floor of Building 30 in April 1964.⁹⁰

The MSC monitored flights during the Gemini 2 mission (January 19, 1965).⁹¹ Houston operated as a backup control center for the Cape during the Gemini 3 mission (March 23, 1965), and beginning with Gemini 4 (June 3, 1963), the MSC assumed the mantle of flight control operations for all manned spaceflight missions.⁹² From Gemini 4 on, Gemini flights were controlled from two Mission Operation Control Rooms, MOCR-1 and MOCR-2, located on the second and third floors of Building 30, respectively; however, MOCR-2 was used for the majority of these flights.⁹³ At the

⁸⁵ Dethloff, *Suddenly Tomorrow Came*, 81.

⁸⁶ “MSC Structural Reorganization to Strengthen Space Programs,” *Space News Roundup* (November 13, 1963), 1.

⁸⁷ Dethloff, *Suddenly Tomorrow Came*, 84.

⁸⁸ Dethloff, *Suddenly Tomorrow Came*, 84.

⁸⁹ “Philco IMCC Pact Signed for Total of \$33.8 Million,” *Space News Roundup* (April 3, 1963), 8.

⁹⁰ GRAVitate, “JSC Survey,” 29.

⁹¹ “Real-time Computers Moved into MCC,” *Space News Roundup* (April 29, 1964), 2.

⁹² “This Is Mission Control,” *Space News Roundup* (September 20, 1993), 3.

⁹³ GRAVitate, “JSC Survey,” 29.

conclusion of the Gemini Program in November 1966, MOCR-2 underwent major renovations before transforming into the iconic Apollo-era MOCR-2 (i.e., Apollo Mission Control Center).⁹⁴

According to Charles W. Mathews, Manager Gemini Program Office, Gemini was a complex program whose success through the design, development, testing, struggling to get it to fly, and then making it operational, was all due to the teamwork of all the individuals involved, from the contractors, to the various government agencies, to the NASA sister centers all working together.⁹⁵ The Gemini Program was planned to fly twelve missions and then end. At the end of the Gemini Program, Gilruth proudly stated, "To get to the moon we had to learn how to operate in space - to maneuver, rendezvous, dock, employ large propulsion systems in space and how to work outside the spacecraft in the hard vacuum of space. We also had to learn how man could endure long duration in the weightless environment and we had to learn how one made precise landings from orbit."⁹⁶ Gilruth believed the Gemini Program's twelve missions did all of the things required as the successful and necessary prelude to Apollo.⁹⁷

c. Apollo Program (1961 to 1972)

The Apollo Program (1961 to 1972) unofficially began with a series of feasibility studies shortly after the inception of the STG.⁹⁸ In mid-1960, three design study contracts were awarded to Convair/Astronautics of San Diego, California, General Electric of Philadelphia, Pennsylvania, and the Martin Company of Baltimore, Maryland. Design aspects included trajectory analysis, guidance and control, human factors and radiation, onboard systems, and systems integration. Just prior to the feasibility study launch, NASA formed the Space Exploration Program Council under T. Keith Glennan to begin program planning and implementation, including schedules for the Saturn launch vehicle and Apollo spacecraft.⁹⁹ Apollo planning continued and began coalescing into the approval phase through Congressional hearings in 1961, which addressed issues presented by the Soviet space program. STG consensus on Apollo spacecraft development emerged in the summer 1961 under the direction of lead spacecraft designer Max Faget.¹⁰⁰ The Saturn launch vehicle would be resized to support the larger Apollo payload. Modular configurations for the "Apollo-Control Capsule" were drawn, which included a launch escape system, command module, service module, and lunar landing module.¹⁰¹ On the heels of Project Mercury's success in 1962, NASA moved forward with developing and testing Apollo hardware.

As NASA moved toward its lunar landing objective, the role of the MSC shifted from that of the Gemini Program. George Low, who served as Chief of Manned Space Flight from 1958 through January 1964 at NASA headquarters, located in Washington, D.C., indicated that during the Apollo Program the MSC became "a third and equal partner (with Kennedy and Marshall) under an overall Headquarters Program Office."¹⁰² In 1963, administrative systems were reorganized under Brainerd Holmes, who soon turned responsibility over to George Mueller and Sam Phillips, and the Office of Manned Space Flight was established as a central decision-making body for the Apollo Program. At this time, Joseph Shea headed the Apollo Spacecraft Program Office, located in temporary MSC headquarters in downtown Houston. The Office of Manned Spaceflight in Washington D.C. delineated specific roles to each of the three autonomous lead Centers. The administrative change to a three-Center model alleviated inherent weaknesses in the former top-down organization of NASA Headquarters during the Gemini Program, which had plagued the

⁹⁴ GRAVitate, "JSC Survey," 29.

⁹⁵ "Gemini Teamwork on Action," *Space News Roundup* (December 23, 1966), 1.

⁹⁶ *Space News Roundup* (December 23, 1966), 1.

⁹⁷ *Space News Roundup* (December 23, 1966), 1.

⁹⁸ Courtney G. Brooks, James M. Grimwood, and Loyd S. Swenson, "Chariots for Apollo: A History of Manned Lunar Spacecraft," *NASA History Series, NASA Special Publications-4205* (Washington, DC: U.S. Printing Office, 1979), 17-18.

⁹⁹ Brooks, et al, "Chariots for Apollo," 20.

¹⁰⁰ Brooks, et al, "Chariots for Apollo," 36-37.

¹⁰¹ GRAVitate, "JSC Survey," 36.

¹⁰² Dethloff, *Suddenly Tomorrow Came*, 107; NASA, "30th Anniversary of Apollo 11: 1969-1999" from <http://history.nasa.gov/ap11ann.html> (2002).

MSC's role as lead Center. In this way, NASA began to operate more cooperatively toward program objectives through the integration of its lead Centers. The MSC would manage Apollo spacecraft development. The MSFC would be responsible for Apollo launch vehicles, while NASA Goddard developed tracking and monitoring network, as well as scientific instrumentation and operations for manned and unmanned Apollo missions. The Launch Operations Center at KSC continued in its capacity as primary launch facility, having separated from the MSFC administration in mid-1962 under the new Launch Operations Directorate, which would respond directly to mission control in Houston.¹⁰³

In late 1964, Mueller and Phillips completed the Apollo Program Development Plan, which established the program's primary objectives as the achievement of "preeminence in space" and the development of "the ability to explore the Moon and return safely to Earth before the end of this decade."¹⁰⁴ Mission planning comprised three flight phases: unmanned suborbital and Earth-orbital flights; manned Earth-orbital and long-duration and Earth-orbital-rendezvous flights; and manned lunar flights. Launch of the first manned Apollo craft (AS-204) was planned for late 1966, less than a year from the inaugural manned test flight of the Apollo-Saturn 201.¹⁰⁵ Manned and unmanned flights using the smaller Saturn IB launch vehicle would continue throughout 1967. In 1968, manned Earth-orbital flights using the Saturn V launch vehicle would begin, followed by manned lunar orbit and lunar landing flights in 1969. The Apollo Program's magnitude cannot be overemphasized. The program required "a large segment of the United States industrial base" in order to carry out the lunar landing objective.¹⁰⁶

MSC operations in support of the Apollo Program included management of engineering design, development, and construction of the spacecraft; astronaut selection and training; and mission operations.¹⁰⁷ In February 1964, Low was transferred to Houston as Deputy Center Director under Gilruth.¹⁰⁸ Low's dynamic management and technical skills were put to work immediately in maintaining relations with Headquarters and with MSC's Systems Test and Evaluation under Aleck C. Bond.¹⁰⁹ Bond's team conducted testing in the MSC's new stress laboratories, vibration acoustic facilities, space environmental simulation laboratory, and thermochemical and structures laboratories.¹¹⁰ After the tragic Apollo 1 (AS-204) fire of January 27, 1967, Low was named Manager of the Apollo Spacecraft Program Office in April 1967, following the resignation of Joe Shea, who was devastated by the events. As Manager, Low oversaw the design, development, manufacture, and testing, of the Apollo Command and Service Module (CSM) and Lunar Module (LM).¹¹¹ By late 1967, the massive technical overhaul of Apollo spacecraft produced the Apollo-Saturn 501 or Apollo 4. Low's career spanned the first eight Apollo flights, including the historic Apollo 11 lunar landing mission of July 1969.

From 1963 to 1964, the MSC worked on three major programs, the last Project Mercury flight of the Mercury-Atlas 9 in May 1963 and spacecraft development for both Mercury and Apollo.¹¹² In January 1963, the MSC negotiated a prime contract for the Apollo Command Module (CM) to North American of Downey, California, on the order of \$934.4 million. NASA would receive eleven mockups (facsimile models), fifteen boilerplate capsules (test vehicles), and eleven flight-ready spacecraft.¹¹³ Apollo command/service module development was divided into two phases. Block 1 would support unmanned missions and the manned Apollo 1 Earth-orbit mission. The more

¹⁰³ Dethloff, *Suddenly Tomorrow Came*, 110.

¹⁰⁴ Dethloff, *Suddenly Tomorrow Came*, 103.

¹⁰⁵ Dethloff, *Suddenly Tomorrow Came*, 111.

¹⁰⁶ Dethloff, *Suddenly Tomorrow Came*, 103.

¹⁰⁷ GRAVitate, "JSC Survey," 37.

¹⁰⁸ Sylvia K. Brown, *Biography. Guide to the George M. Low Papers, 1930-1984* (Troy, N.Y.: Institute Archives and Special Collections, Folsom Library, Rensselaer Polytechnic Institute, 1988); NASA, "30th Anniversary of Apollo 11."

¹⁰⁹ Dethloff, *Suddenly Tomorrow Came*, 104.

¹¹⁰ Dethloff, *Suddenly Tomorrow Came*, 114.

¹¹¹ Brown, *George M. Low Biography*.

¹¹² Brooks, et al, "Chariots for Apollo."

¹¹³ Brooks, et al, "Chariots for Apollo."

complex Block 2 design would support integration with the Apollo lunar module. The Apollo 1 (AS-204) fire resulted in an overhaul of the Block 2 design, following determinations of the Apollo 204 Accident Review Board. Also in January 1963, the MSC awarded the prime contract for the Apollo Lunar Excursion Module (LEM)—the final piece of the Apollo “stack”—to the Grumman Aerospace Corporation for the design and production of thirteen LEMs. Major subsystems development began in late 1964, while the final spacecraft configurations were still under review. In 1965, the hardware fabrication, assembly, and testing phase began. Grumman conducted the LEM Test Program under MSC management at multiple off-site facilities. “LEM’s” were later renamed LMs by the NASA Project Designation Committee in June 1966, to more accurately reflect their lack of mobility on the moon.¹¹⁴

Despite federal budget cuts in fiscal year 1967, the Apollo Program moved forward with an operations plan. John Hodge would direct the AS-202 and AS-203 missions, while Kraft, the MSC Flight Operations Director, was slated as Flight Director for the first manned Apollo mission (AS-204). AS-204 ended in the loss of three astronauts prior to flight and the Apollo mission naming convention was subsequently pushed forward to “Apollo 4.” At this time, Houston’s new MCC was undergoing renovations in support of the Apollo Program.¹¹⁵ The Flight Control Room 1 (FCR-1) located on the second floor and the third floor MOCR-2 were designed to share the workload during the manned Gemini missions. Manned Apollo missions prior to the lunar landing mission of Apollo 11 were jointly controlled from FCR-1 and the MOCR. Following the Apollo 11 lunar landing of July 20, 1969, FCR-1 was deactivated and the remaining Apollo Program flight control work was managed from the MOCR.¹¹⁶

Apollo mission training at JSC included programmed instruction, classroom and video-tape briefings, crew station familiarization, and on-the-job training leading up to mission simulations. Test facilities at the MSC supported Apollo equipment testing and astronaut training for space environments.¹¹⁷ Crew Systems Division facilities were located across the Center developing, building, and operating engineering capabilities. Tests were conducted on every piece of equipment that went into space and every scenario the astronauts would face, such as life-support systems in replicated space environments, astronaut tolerance to acceleration and spaceflight stresses, zero-gravity, and physiological and biomedical effects to pressure suits.¹¹⁸ The MSC also played a vital role in pre- and post-flight quarantine operations for Apollo lunar flight crews and lunar materials. Following missions, astronaut crews, lunar samples, and other lunar-exposed material were placed under a twenty-one-day quarantine.¹¹⁹

Approximately one year after the AS-204 fire, unmanned test flights resumed in November 1967.¹²⁰ Early Apollo flight plans involved Earth-orbit tests of the Saturn V followed by the LM. Flight testing then progressed to lunar orbit as the precursor to a lunar landing attempt. From the outset, flight operations for Apollo differed greatly from that of Mercury and Gemini, owing to use of the new Saturn V launch vehicle and the two-stage design of the Apollo vehicle, with its objective to land on the moon, separate, and return via the Apollo CM. Apollo 7 made a successful eleven-day mission, returning on October 22, 1967, to an excited audience.¹²¹ At this time, all Apollo systems were in full production and the country’s race to the moon had officially begun. George Low accelerated Apollo flight plans in August 1968, setting Apollo 8 on lunar orbit on December 21 of the same year. Apollo 9 flew an Earth-orbit mission in March 1969 and conducted the first flight test

¹¹⁴ Helen T. Wells, Susan H. Whiteley, and Carrie E. Karegeannes, “Origins of NASA Names,” *NASA Special Publications-4402 in the NASA History Series* (Washington, DC: U.S. Printing Office, 1976).

¹¹⁵ GRAVitate, “JSC Survey,” 39.

¹¹⁶ ACI, “Mission Control Center (Building 30): Historical Documentation.” Report prepared for NASA JSC, Houston, Texas (March 2011), 17.

¹¹⁷ Dethloff, *Suddenly Tomorrow Came*, 130-131.

¹¹⁸ GRAVitate, “JSC Survey,” 42.

¹¹⁹ GRAVitate, “JSC Survey,” 42.

¹²⁰ Dethloff, *Suddenly Tomorrow Came*, 165.

¹²¹ NASA, “Apollo 7,” from <https://nssdc.gsfc.nasa.gov/nmc/masterCatalog.do?sc=1968-089A> (2017).

of a manned LM. During the Apollo 9 mission, the MCC developed procedures for contingency uses of the LM, which were later used by the flight crew during the Apollo 13 crisis. Eugene F. Kranz served as Chief of the MSC's Flight Control Division throughout the Apollo missions as Kraft moved into his new position as Assistant Director of the MSC.¹²² On July 16, 1969, Mr. Kranz locked the doors of the MCC in Houston as the Apollo 11 crew prepared to launch and the MCC's flight control crew braced itself for real-time response throughout the 195-hour lunar mission. As the Eagle—as the Apollo 11 LM was named—set down on the lunar surface, the MCC burst into applause.

The Apollo 11 mission and the Apollo Program was successful because of the many people who came together with one purpose: to land humans on the moon and bring them safely back to Earth. As said by astronaut James A. Lovell, Jr. who flew on Gemini 7, Gemini 12, Apollo 8, and Apollo 13, "The legacy of Apollo is, if you set your mind to do something, get everybody together and everybody agrees we should accomplish it, and then we go ahead, it became something we all could be proud of."¹²³ Apollo 11 astronaut Collins remarked, "We had a lot of smart people, young people, dedicated people who got to work early, stayed at work late. You didn't have to tell them they were part of a team, they knew they were part of a team."¹²⁴ The Apollo missions that put men on the moon returned a wealth of scientific data and almost 400 kilograms of lunar samples, with astronauts conducting scientific experiments collecting inimitable data about soil mechanics, meteoroids, seismic, heat flow, lunar ranging, magnetic fields, and solar wind experiments. Apollo 17 was the final Apollo mission that launched on December 7, 1972 and landed in the Pacific Ocean on December 19, 1972.¹²⁵

d. Skylab Program (1965 to 1979)

During the 1970s, the MSC entered a transitional phase as the Apollo Program came to a close and the U.S. Space Shuttle Program—then known as the Space Transportation System (STS)—entered design and development. MSC leadership shifted as Kraft replaced Gilruth as Center Director.¹²⁶ In the interim, several Apollo Applications Programs emerged.

Using Apollo systems and Apollo spacecraft, NASA developed the country's first space station "Skylab" that proved humans could live and work in outer space for extended periods of time.¹²⁷ Using Apollo Applications such as surplus Saturn IBs and Apollo spacecraft, Skylab planning began in late 1965 with a clear objective defined in 1968 to develop an Earth-orbital laboratory with science-based human space missions.¹²⁸ NASA received official approval for the Skylab Program (1965 to 1979) in July of 1969 with flight status quickly achieved in 1970.¹²⁹ Operations were divided between MSFC and the MSC. The MSFC managed the workshop, multiple docking adapter, and propulsion systems. The MSC directed astronaut training, scientific experiments, and Apollo spacecraft modifications and flight operations. Kenneth S. Kleinknecht managed the Skylab Program Office in Houston. At this time, the MSC supported concurrent program offices for Apollo, Skylab, and the Space Shuttle.¹³⁰

During the planning stages of Skylab, the MSC was established as the Center responsible for planning and execution of mission control, flight operations, and adaptation of the Apollo CSM.¹³¹ Training at JSC included programmed instruction, classroom and video-tape briefings, crew station

¹²² Dethloff, *Suddenly Tomorrow Came*, 161-164.

¹²³ NASA, "July 20, 1969: One Giant Leap For Mankind," from https://www.nasa.gov/mission_pages/apollo/apollo11.html (2014).

¹²⁴ NASA, "One Giant Leap For Mankind."

¹²⁵ NASA, "Apollo 17: Mission Objective," from http://www.nasa.gov/mission_pages/apollo/missions/apollo17.html (2011).

¹²⁶ GRAVitate, "JSC Survey," 50.

¹²⁷ NASA, "The History of Skylab," from www.nasa.gov/missions/shuttle/f_skylab1.html (2003).

¹²⁸ NASA, "The History of Skylab."

¹²⁹ NASA, "The History of Skylab."

¹³⁰ GRAVitate, "JSC Survey," 50.

¹³¹ Leland F. Belew, *Skylab, Our First Space Station* (Washington, DC: U.S. Printing Office, 1977).

familiarization, and on-the-job training leading up to mission simulations.¹³² Flight controllers trained on crew station trainers to familiarize themselves with the control and display layout, general spacecraft systems functions, and terminology in the Jake Garn Mission Simulator and Training Facility (Building 5).¹³³ Building 5 supported manned flight crew training to simulate all elements of the Skylab spacecraft. During eleven-day simulations, backup crew members performed flight tasks on five trainers, including the orbital workshop, multiple docking adapter, airlock module, Apollo telescope mount, and command module 1-g trainer.¹³⁴ JSC developed, constructed, and operated important habitability studies such as the medical experiments altitude test that was a simulation of a fifty-six-day Spacelab mission.¹³⁵ The habitability simulation involved three training astronauts who performed tasks in accordance with a schedule of events that mirrored an actual mission while support personnel manned the simulation from the mission control room, identifying and correcting problems as they arose. Mission simulation included all significant features of the Skylab environment, with the exception of weightlessness, replicating the atmosphere that was identical to that of Skylab.¹³⁶

From its launch on May 14, 1973, until the return of its third and final crew on February 8, 1974, the Skylab Program represented a major step in human spaceflight, serving as a bridge between the Apollo flights and long-duration spaceflights aboard the ISS.¹³⁷ The three Skylab crews who inhabited the station during its eight-month lifespan set successive new records for long-duration spaceflight, and conducted an array of physical science, biomedical science, Earth applications and space applications experiments.¹³⁸

MSC facilities supported Skylab equipment testing and astronaut training for all three Skylab missions. The first Skylab mission launched May 25, 1973 and was crewed by Charles Conrad Jr., Paul J. Weitz, and Joseph P. Kerwin, who spent twenty-eight days in orbit.¹³⁹ The second Skylab mission, lasting fifty-nine days in space, launched on July 29, 1973, and was crewed by Alan Bean, Jack Robert Lousma, and Owen K. Garriott.¹⁴⁰ The third and final Skylab mission launched on November 16, 1973, and was crewed by Gerald P. Carr, William R. Pogue, and Edward G. Gibson, who spent eighty-four days in space, a record not broken by U.S. astronauts until the Shuttle-Mir Program more than twenty years later.¹⁴¹ The crew of this final Skylab mission collected Earth resources observations data using Skylab's Earth resources experiment package camera and sensor array, logging 338 hours of operations of the Apollo Telescope Mount to make extensive observations of the sun's solar processes, and completing two spacewalks outside the orbital workshop.¹⁴²

Involving scientists from twenty-eight nations, Skylab demanded the highest degree of cooperative effort from the world's scientific community, as scientists, engineers, and technicians worked, observed, cataloged, and analyzed data on Earth while Skylab orbited overhead with Skylab crew making related observations and scientific measurements or conducting experiments.¹⁴³ During its manned orbital operations, Skylab represented the "greatest solar observatory of its time, a microgravity lab, a medical lab, an Earth-observing facility, and, most importantly, a home away from home for its residents."¹⁴⁴

¹³² GRAVitate, "JSC Survey," 50.

¹³³ GRAVitate, "JSC Survey," 50.

¹³⁴ "Skylab Crews Conduct 11 Days of Simulation," *Space News Roundup* (September 15, 1972), 1.

¹³⁵ Belew, *Skylab*.

¹³⁶ Belew, *Skylab*.

¹³⁷ NASA, "40th Anniversary of Skylab," from <http://www.nasa.gov/topics/history/features/skylab.html> (2013).

¹³⁸ NASA, "40th Anniversary of Skylab."

¹³⁹ NASA, "40th Anniversary of Skylab."

¹⁴⁰ NASA, "40th Anniversary of Skylab."

¹⁴¹ NASA, "40th Anniversary of Skylab."

¹⁴² NASA, "Bibliographic Data, Edward G. Gibson," from <http://www.jsc.nasa.gov/Bios/htmlbios/gibson-eg.html> (1993).

¹⁴³ Belew, *Skylab*.

¹⁴⁴ NASA, "The History of Skylab."

e. Apollo-Soyuz Test Project (1971 to 1975)

Apollo-Soyuz Test Project (ASTP) represented the last Apollo flight and the first international endeavor in human spaceflight. The Project's main goal was to design a U.S. built-docking module to demonstrate that two dissimilar craft could dock in orbit.¹⁴⁵ The ASTP (1971 to 1975) was the first spaceflight program in which spacecraft from two different nations docked in space. In late 1969, President Richard Nixon proposed a cooperative U.S.-Soviet space project to smooth foreign relations. The U.S. portion of the project utilized the Saturn IB launch vehicle and the Apollo Command and Service Module, which were modified to support experiments and additional Docking Module controls and equipment.¹⁴⁶

As in previous programs, JSC was the Center responsible for planning and execution of mission control, flight operations, and adaptation of the Apollo Command and Service Module.¹⁴⁷ Training at JSC included programmed instruction, classroom and video-tape briefings, crew station familiarization, and on-the-job training leading up to mission simulations. Prior to the launch of ASTP, U.S. astronauts and flight crew and Soviet cosmonauts and flight crew visited each other's space centers to become familiar with each other's spacecraft. Soviet flight crews made four trips to the JSC to train for the mission between July of 1973 and February of 1975.¹⁴⁸

Soviet and U.S. engineers worked together in Building 13, which housed the complex Dynamic Docking System Simulator. The Dynamic Docking System Simulator was a computer-driven system that duplicated the severe impacts and thermal conditions that could be encountered when the two docking systems were brought together in space.¹⁴⁹ Using a modified Apollo Command and Service Module, U.S. astronauts and Soviet cosmonauts also ran simulations for the ASTP in Building 35, using the Soyuz Orbital Module Mockup and a Docking Module trainer.¹⁵⁰ The ASTP mission sent NASA astronauts Thomas Stafford, Deke Slayton, and Vance Brand in an Apollo Command and Service Module to meet Russian cosmonauts Aleksey Leonov and Valeriy Kubasov in a Soyuz capsule in space.¹⁵¹

The ASTP had three main objectives: to evaluate the docking and undocking of an Apollo spacecraft with a Soyuz capsule and determine the adequacy of the onboard orientation lights and docking target; to evaluate the ability of astronauts and cosmonauts to make inter-vehicular crew transfers and the ability of spacecraft systems to support the transfers; and to evaluate the Apollo's capability of maintaining attitude-hold control of the docked vehicles and performing attitude maneuvers.¹⁵² The ASTP mission lasted nine days and successfully completed all of its objectives, as well as collecting navigation tracking data and completing numerous biomedical tasks. The ASTP crew completed nearly all of the 110 Earth-observation tasks assigned. The Earth-observation tasks were coordinated investigations made simultaneously by six groups of scientists on the ground, on ships at sea, and in aircraft, while the astronauts looked at ocean currents, ocean pollution, desert geography, shoreline erosion, volcanoes, iceberg movements, and vegetation patterns.¹⁵³ The project represented the first international endeavor in human spaceflight. When taken together with Skylab, the project moved NASA toward a future space station objective.

¹⁴⁵ Charles Redmond, "The Flight of Apollo-Soyuz," for NASA from <http://history.nasa.gov/apollo/apsoyhist.html>, (2004).

¹⁴⁶ Redmond, "Flight of Apollo-Soyuz."

¹⁴⁷ GRAVitate, "JSC Survey," 56.

¹⁴⁸ Redmond, "Flight of Apollo-Soyuz."

¹⁴⁹ Edward Clinton Ezell and Linda Neuman Ezell, "Testing Hardware" in *The Partnership: A History of the Apollo-Soyuz Test Project. NASA History Series, NASA Special Publications-4209*. (Washington, DC: U.S. Printing Office, 1978).

¹⁵⁰ Photo, "Overall view of test set-up in the Structures and Mechanics Laboratory (Building 13) at JSC during testing of the docking mechanisms for the ASTP. The cinematic check was being made when this picture was taken. The test control room is on the right where both American and Soviet engineers can be seen taking part in the docking testing," February 19, 1975, NASA Photo ID: S74-27049, JSC Digital Image Collection.

¹⁵¹ Redmond, "Flight of Apollo-Soyuz."

¹⁵² Redmond, "Flight of Apollo-Soyuz."

¹⁵³ Redmond, "Flight of Apollo-Soyuz."

f. Space Shuttle Program (1969 to 2011)

Not enough can be said about the importance of the SSP (1969 to 2011) when discussing the U.S. space program. Between the first launch on April 12, 1981, and the final landing on July 21, 2011, NASA's Space Shuttle fleet of Columbia, Challenger, Discovery, Atlantis, and Endeavour flew 135 missions, helped construct the International Space Station (ISS), and inspired generations.¹⁵⁴ The SSP broke many boundaries during its tenure, as its technological successes and international cooperation that became commonplace at the end of the SSP were unforeseen when the program began.

President Richard Nixon outlined the SSP in his speech of January 5, 1972, as a program that would follow the success of Apollo with a reusable space flight vehicle designed to transport crews, equipment, supplies, and spacecraft to and from a permanent manned space station, though budgetary challenges forced a reduction in the Shuttle Program without the presence of a space station.¹⁵⁵ Vehicle components consisted of a reusable orbiter, three reusable main engines, two reusable solid rocket boosters (SRBs), and one single-use external liquid fuel tank.¹⁵⁶ In addition to spacecraft design, NASA had to select a launch and recovery site for the program, which would be divided between KSC and alternate landing areas, such as the Vandenberg AFB in California, Edwards AFB in California, or White Sands Test Facility in New Mexico.¹⁵⁷

As NASA's first reusable spacecraft, the space shuttle carried people into orbit repeatedly, launched, recovered and repaired satellites, conducted cutting-edge research, and built the largest structure in space, the ISS.¹⁵⁸ ACI's extensive historical documentation of the SSP at JSC (2008) reported that JSC's primary responsibilities included development of the Orbiter vehicle and overall program management.¹⁵⁹ The MSFC managed propulsion requirements and developed the Space Shuttle Main Engine, SRBs, and the external liquid fuel tank (ET). Shuttle engine tests were conducted at NASA's Mississippi National Space Technology Laboratories (later Stennis Space Center) and at the U.S. Air Force Rocket Laboratory in California. The MSFC contracted Rocketdyne to design and manufacture the Space Shuttle Main Engine, Martin Marietta Corporation to design and manufacture the ET, and Thiokol Chemical Company to design and manufacture the SRBs. North American Rockwell was awarded the prime contract for the Orbiter.

In 1972, North American Rockwell was also contracted to manufacture the Enterprise, the first test Orbiter Vehicle. It was completed in September of 1976. In 1977, the Enterprise supported the Approach and Landing Test Program at NASA's Dryden Flight Research Center in California. The first Approach and Landing Test Program phase objectives were to flight test the aircraft-Orbiter combination. That same year, during the next "captive-active" phase, landing gear were deployed, mission control operations in Houston were flight tested, and the Orbiter completed its first free flight from the NASA 747 Shuttle Carrier Aircraft ferry on August 12.¹⁶⁰ Succeeding the Approach and Landing Test Program, the SSP moved into the orbital test flight phase in 1981. The first orbital test flight of the Space Shuttle Columbia (STS-1)¹⁶¹ launched from the KSC on April 12, 1981, with a two-person crew that included Mission Commander John W. Young and Pilot Robert L. Crippen. The second orbital test flight of the Space Shuttle Columbia (STS-2) launched November 12, 1981, for a two-day trip with Commander Joe H. Engle and Pilot Richard H. Truly aboard.¹⁶² Engle's and Truly's mission was to demonstrate Columbia's safe re-launch and safe return of the Orbiter and

¹⁵⁴ NASA, "Space Shuttle Era," from https://www.nasa.gov/mission_pages/shuttle/flyout/index.html (2015).

¹⁵⁵ Dethloff, *Suddenly Tomorrow Came*, 227.

¹⁵⁶ ACI, "NASA-Wide Survey and Evaluation of Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program Report," report prepared for NASA Washington, D.C. (September 2016), 3-1.

¹⁵⁷ Dethloff, *Suddenly Tomorrow Came*, 253.

¹⁵⁸ NASA, "Space Shuttle Era."

¹⁵⁹ ACI, "NASA-Wide Survey."

¹⁶⁰ Peter W. Merlin, "Free Enterprise: Contributions of the Approach and Landing Test (ALT) Program to the Development of the Space Shuttle Orbiter," in AIAA Technical Symposium, held in San Jose, California, 19-21 September, 2006, 4.

¹⁶¹ STS-1 refers to the Space Shuttle mission number.

¹⁶² NASA, "STS-2," from http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-2.html (2008).

crew and verify the combined performance of the entire Shuttle Orbiter, solid rocket boosters, and external tank.¹⁶³ During the two-day mission, President Ronald Reagan visited JSC, with President Reagan becoming the first sitting Commander in Chief to be in the MCC during a flight.¹⁶⁴ President Reagan entered the MOCR, where he was briefed on the consoles and screens and finally took a seat at CapCom to speak with Engle and Truly while they were in space.¹⁶⁵ President Reagan first humorously asked Engle and Truly for a ride to California and then said, "Let me just say, I'm sure you know how proud everyone down here is and how this whole nation, and I'm sure the World, but certainly America, has got its eyes and its heart on you."¹⁶⁶ By 1982, the Shuttle Columbia had flown three more test flights and the program was declared fully operational.

JSC handled management of engineering design, development, and construction of the Orbiter vehicle.¹⁶⁷ As with Apollo, JSC was the lead Center for SSP astronaut selection and training and mission operations. Training at JSC included programmed instruction, classroom and video-tape briefings, crew station familiarization, and on-the-job training leading up to mission simulations.¹⁶⁸ Flight controllers trained on crew station trainers to familiarize themselves with the control and display layout, general spacecraft systems functions, and terminology. JSC underwent major modifications in support of the SSP, including construction of the Shuttle Aviation Integration Laboratory (SAIL) in Building 16.¹⁶⁹ New SSP support facilities at JSC included a renovated Mission Control, new mission simulators, advanced engineering structures for testing, weightless environment training, and new laboratories and machine shops located across the Center.¹⁷⁰

The Shuttle fleet entered its operational phase with Columbia's (STS-5) launch on November 11, 1982. The SSPs operational phase came to a halt with the Challenger's fatal launch on January 28, 1986, which ended the lives of seven astronauts. Over the next two years, SSP flights were suspended pending investigation by the Presidential Commission on the Space Shuttle Challenger Accident and a later Senate subcommittee. At this time, Shuttle management temporarily transferred from the JSC to NASA Headquarters in Washington D.C. After design flaws in the SRBs and solid rocket motors were corrected and validated, return to flight operations began in September of 1988.¹⁷¹ The solid rocket motor was later renamed "reusable solid rocket motor" and contained the fuel to power the solid rocket motor.¹⁷² SSP missions recommenced with the Discovery STS-26 that launched September 29, 1988.¹⁷³ DoD missions were resumed on December 2, 1988, with the Atlantis STS-27 mission.¹⁷⁴

Every Shuttle mission became a research facility in space for conducting experiments in many of the scientific disciplines that can't all be described in this investigation. However, several missions are discussed to convey the importance of science missions in the Shuttle era. The Hubble Space Telescope (HST) was deployed during the Discovery STS-31 mission that launched on April 24, 1990, and the HST was serviced during STS-61, STS-82, STS-103, STS-109, and STS-125.¹⁷⁵ Shuttles successfully completed planetary and astronomy missions such as the launch of the Magellan and Galileo probes and the Upper Atmospheric Research Satellite. The Magellan was the first planetary spacecraft to be launched by a Space Shuttle when it was carried aloft by the

¹⁶³ NASA, "STS-2."

¹⁶⁴ "Reagan, Bush visits mark firsts at JSC," *Space News Roundup* (November 20, 1981), 1.

¹⁶⁵ *Space News Roundup* (November 20, 1981), 1.

¹⁶⁶ *Space News Roundup* (November 20, 1981), 1.

¹⁶⁷ GRAVitate, "JSC Survey," 65.

¹⁶⁸ GRAVitate, "JSC Survey."

¹⁶⁹ GRAVitate, "JSC Survey."

¹⁷⁰ GRAVitate, "JSC Survey."

¹⁷¹ John M. Logsdon, "Return to Flight: Richard H. Truly and the Recovery from the Challenger Accident," in *From Engineering Science to Big Science: The NACA and NASA Collier Trophy Research Project Winners*, NASA History Series, ed. Pamela E. Mack (Washington, DC: U.S. Printing Office, 1998).

¹⁷² Logsdon, "Return to Flight."

¹⁷³ NASA, "Mission Information," from http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/index.html, (2011).

¹⁷⁴ NASA, "Mission Information."

¹⁷⁵ NASA, "Mission Information."

Atlantis STS-30 from KSC on May 4, 1989.¹⁷⁶ Magellan was released from the Shuttle's cargo bay to orbit Venus for four years, radar-mapping 98 percent of the surface and collecting high-resolution gravity data of Venus.¹⁷⁷ The Galileo was aboard the Atlantis STS-34 that launched on August 8, 1989, with crew putting Galileo on trajectory for a six-year trip to Jupiter via gravitational boosts from Venus and Earth.¹⁷⁸ Galileo consisted of two spacecraft, an orbiter and an atmospheric probe. The orbiter made the first close-up studies of two asteroids, Gaspra and Ida. When it reached Jupiter, the orbiter sent the probe into Jupiter's atmosphere to take measurements.¹⁷⁹ Meanwhile, the orbiter made long-term observations from orbit of Jupiter, its satellites, and its magnetosphere over two years, and finally crashed into Jupiter's atmosphere on September 21, 2003.¹⁸⁰

There have been 355 fliers aboard Shuttle, which breaks down to 306 men and forty-nine women hailing from sixteen different countries, who flew on the Space Shuttle over the course of 135 missions with two disastrous accidents.¹⁸¹ The two tragic Shuttle accidents that took the lives of fourteen astronauts were deeply felt by the NASA community and by the United States broadly. The Challenger STS-51L launched January 28, 1986; seventy-three seconds after liftoff the vehicle exploded, claiming the lives of the entire crew.¹⁸² The Challenger STS-51L crew members who were killed included Payload Specialists Christa McAuliffe and Gregory B. Jarvis, Mission Specialist Judith A. Resnik, Commander Francis R. Scobee, Mission Specialist Ronald E. McNair, Pilot Michael J. Smith, and Mission Specialist Ellison S. Onizuka.¹⁸³ According to Dethloff, "The Challenger disaster forced a reappraisal of national objectives in space and helped build a stronger foundation for new initiatives in space."¹⁸⁴ The Columbia STS-107 launched January 16, 2003, and after a sixteen-day mission, the Columbia and crew were lost during reentry over east Texas, sixteen minutes prior to its scheduled touchdown at KSC.¹⁸⁵ The Columbia STS-107 crew who were killed include Commander Rick Husband, Pilot Willie McCool, Payload Commander Michael Anderson, Mission Specialists Kalpana Chawla, David Brown, Laurel Clark, and Payload Specialist Ilan Ramon.¹⁸⁶ Following the Columbia accident, the Columbia Accident Investigation Board decided "Despite efforts to improve its safety, the Shuttle remains a complex and risky system that remains central to U.S. ambitions in space. Columbia's failure to return home is a harsh reminder that the Space Shuttle is a developmental vehicle that operates not in routine flight but in the realm of dangerous exploration."¹⁸⁷ The Columbia Accident Investigation Board report led President George W. Bush to cancel the SSP and propose a more cost-effective new direction for space exploration, resulting in NASA completing the Exploration Systems Architecture Study.¹⁸⁸ Ultimately, the Exploration Systems Architecture Study prompted NASA to return to the earlier spacecraft designs used for Mercury, Gemini and Apollo — a crew vehicle atop a rocket.¹⁸⁹

g. Spacelab (1973-1998)

¹⁷⁶ NASA, "The Magellan Venus Explorer's Guide," *JPL Publication No. 90-24* from <http://www2.jpl.nasa.gov/magellan/guide.html> (Pasadena: Jet Propulsion Laboratory, 1990).

¹⁷⁷ NASA, "Magellan Venus."

¹⁷⁸ NASA, "Mission Information."

¹⁷⁹ NASA, "Galileo," from <http://science.nasa.gov/missions/galileo/> (2016).

¹⁸⁰ NASA, "Galileo."

¹⁸¹ Tariq Malik, "NASA's Space Shuttle by the Numbers: 30 Years of a Spaceflight Icon," *Space.com* from <http://www.space.com/12376-nasa-space-shuttle-program-facts-statistics.html> (2011).

¹⁸² NASA, "NASA-ST5-51L Mission Profile," from http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-51L.html (2005).

¹⁸³ NASA, "NASA-ST5-51L."

¹⁸⁴ Dethloff, *Suddenly Tomorrow Came*, 305.

¹⁸⁵ NASA, "ST5-107," from http://www.nasa.gov/mission_pages/shuttle/main/index.html (2007).

¹⁸⁶ NASA, "ST5-107."

¹⁸⁷ Space KSC, "Why Bush Cancelled the Space Shuttle," from <http://spaceksc.blogspot.com/2010/03/why-bush-cancelled-space-shuttle.html> (2010).

¹⁸⁸ Space KSC, "Bush Cancelled the Space Shuttle."

¹⁸⁹ Space KSC, "Bush Cancelled the Space Shuttle."

Beginning in 1973, NASA and the European Space Agency (ESA) began a coordinated program known as Spacelab.¹⁹⁰ Developed and built by the ESA, Spacelab was composed of a pressurized module and pallet on which equipment was mounted that could be directly exposed to space environment, while the pressurized module was administered by scientists or technicians from the Shuttle without spacesuits.¹⁹¹ Spacelab was designed for fifty missions to carry payloads needed for Earth observation, materials science, physics, life sciences, communications, navigation, and space systems. The payloads were carried from Earth's orbit in the cargo bay of the Space Shuttle and remained attached to the Shuttle throughout the mission.¹⁹² Spacelab life sciences payloads were aimed at determining the effects of the space environment on living organisms. This knowledge would be used for improving space crew health care during missions and to develop applications of space technology for clinical research to improve health care on Earth.¹⁹³ There were twenty-two Spacelab science missions that began with the STS-9 in 1983 and ended with STS-90 in 1998.¹⁹⁴ The Spacelab pallets were built by British Aerospace. The pallets also carried payloads on non-Spacelab flights, the first flying on the second Shuttle mission in 1981 and the last in 2008.¹⁹⁵

The SSP was another feat of engineering excellence for NASA for which JSC played a critical role. The SSP flew for thirty years, completing 135 missions and successfully realizing the incredible technological feat of sending humans into space for extended periods of time aboard a reusable spacecraft. The Shuttle vehicle was made up of more than a million parts designed, built, tested, and managed, by hundreds of thousands of engineers, scientists, technicians, electricians, and program administrators, who had one goal: to complete the mission and safely bring home the astronaut crew. JSC, and its assets, provided the campus to complete the rigorous training, design and build parts, and plan and execute SSP missions and flight operations.¹⁹⁶

h. Shuttle-Mir Program (1993-1998)

The Shuttle-Mir Program (1993-1998) was first announced in 1993 and designed as a collaborative space program between Russia and the United States using the Space Shuttle. On June 17, 1992, in Washington D.C., U.S. President George Bush and Russian President Boris Yeltsin signed the "Agreement between the United States of America and the Russian Federation Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes."¹⁹⁷ In this agreement, one of the areas of cooperation included a "Space Shuttle and Mir Space Station mission involving the participation of U.S. astronauts and Russian Cosmonauts."¹⁹⁸ During this meeting between Presidents Bush and Yeltsin, it was agreed Russian cosmonauts would fly aboard the Space Shuttle in 1993, a U.S. astronaut would fly a long-duration mission on Mir in 1994, and a docking mission between the Shuttle and the Mir would be completed in 1995.¹⁹⁹ On October 5, 1992, in Moscow, Daniel Goldin, Administrator of NASA, and Yuri Koptev, Director General of the Russian Space Agency, signed the "Implementing Agreement between the National Aeronautics and Space Administration of the United States of America and the Russian Space Agency of the Russian Federation on Human Space Flight Cooperation."²⁰⁰ This agreement further outlined details of U.S. and Russia cooperation that included: a Russian cosmonaut flying on the Shuttle

¹⁹⁰ ESA "Tribute to the Space Shuttle," from http://www.esa.int/Our_Activities/Human_Spaceflight/Space_Shuttle/Spacelab (n.d.); "Astronaut Henize to fly May 16 on Airborne Spacelab simulation," *Space News Roundup* (April 29, 1977), 1.

¹⁹¹ *Space News Roundup* (April 29, 1977), 1.

¹⁹² *Space News Roundup* (April 29, 1977), 1.

¹⁹³ "Spacelab simulation ends at JSC, another continues in California" *Space News Roundup* (May 27, 1977), 1.

¹⁹⁴ ESA "Tribute;" NASA, "Spacelab Payloads on Shuttle Flights," from http://www.nasa.gov/mission_pages/shuttle/main/index.html (2007).

¹⁹⁵ ESA "Tribute."

¹⁹⁶ GRAVitate, "JSC Survey."

¹⁹⁷ George C. Nield and Pavel Mikhailovich, Ed, "Phase 1 Program Joint Report," *NASA History Series, NASA Special Publication SP-1999-6108* (Washington, DC: U.S. Printing Office, 1999).

¹⁹⁸ Nield and Mikhailovich, "Phase 1," 2.

¹⁹⁹ Nield and Mikhailovich, "Phase 1," 2.

²⁰⁰ Nield and Mikhailovich, "Phase 1," 2.

mission STS-60 as a mission specialist; a U.S. astronaut launching on a Soyuz, flying more than ninety days on the Mir, and returning on a Shuttle; Russian cosmonauts on Mir being “changed out” via the Shuttle on the same flight that would return the U.S. astronaut; and evaluation of and possible contract for the Russian Androgynous Peripheral Docking Assembly developed by NPO Energia for use on the Shuttle.²⁰¹ This second agreement created the Shuttle-Mir Program.

During the Shuttle-Mir Program, seven U.S. astronauts spent nearly 1000 days living in orbit with Russian cosmonauts on board Russia’s space station Mir. The first flight was aboard the Discovery STS-60 Mission, when Sergei K. Krikalev became the first Russian cosmonaut to fly aboard Space Shuttle as he was transported to Mir. The Discovery STS-60 Mission flew from February 3 through February 11, 1994.²⁰² The final Shuttle-Mir flight occurred from June 2 through June 12, 1998, aboard the Discovery STS-91 mission.²⁰³ The Discovery STS-91 crew transferred more than 1,100 pounds of water and almost 4,700 pounds of cargo experiments and supplies between the two spacecraft.²⁰⁴ This mission also flew the Alpha Magnetic Spectrometer for the first time.²⁰⁵ U.S. Space Shuttles rendezvoused ten times with Russia’s space station Mir, which prepared the way for the ISS and began an era of international cooperation and advanced space exploration. At JSC, astronaut and cosmonaut training ensued much like the previous ASTP. Training at JSC included programmed instruction, classroom and video-tape briefings, crew station familiarization, and on-the-job training leading up to mission simulations.²⁰⁶ As in previous programs, JSC was the Center responsible for planning and execution of mission control, flight operations, and adaptation of the Shuttle vehicle. Following NASA’s decision to dock with the Russian Space Station Mir to support the ISS Program, the ASL testing facility (Building 16) was modified to accommodate changes made to Shuttle vehicle docking systems.²⁰⁷

i. International Space Station (1993-current)

Though the idea of a space station as a central NASA project had been suppressed by the Nixon administration, the subsequent Reagan administration offered renewed focus on the idea and by early 1981, both the JSC and the MSFC had developed conceptual approaches for the space station.²⁰⁸ The first Space Station Conference, scheduled for November 1981, was to outline a planning effort to accomplish this “next logical step” in space.²⁰⁹ International involvement was proposed early in the space station planning and it was announced that foreign space agency representatives were welcome at NASA. On January 25, 1984, President Reagan stood before Congress and issued a formal invitation to other countries for space station participation. By September 1988, the United States, several European countries, and Canada had a signed intergovernmental agreement on space station cooperation, with Japan joining later. The Russian government had identified the space station concept following their loss of the “moon race” in 1969 and had paved the way for an international space station with its Shuttle-Mir Program, in which separately-launched modules were connected in space. Mir operated from 1986 to 2001.

Following President Clinton’s inauguration in 1993, NASA was directed to redesign their initial space station vision, Space Station Freedom, to meet budget restrictions. At the same time, the Russian Space Agency reached out to NASA and proposed merging NASA’s Freedom and Russia’s Mir-2 projects. On September 2, 1993, Russian Prime Minister Victor Chernomyrdin and Vice President Al Gore officially merged the two projects. From late December 1994 to 2003, NASA

²⁰¹ Nield and Mikhailovich, “Phase 1,” 2.

²⁰² NASA, “STS-60,” from http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-60.html (2010).

²⁰³ NASA, “STS-91,” from http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-91.html (2007).

²⁰⁴ NASA, “STS-91.”

²⁰⁵ NASA, “STS-91.”

²⁰⁶ GRAVitate, “JSC Survey.”

²⁰⁷ GRAVitate, “JSC Survey,” 74.

²⁰⁸ John M. Logsdon, “Together in Orbit: The Origins of International Participation in the Space Station,” *Monographs in Aerospace History No. 11*. (1998).

²⁰⁹ Logsdon, “Together in Orbit.”

and Russia worked together to construct ISS using the Russian Zarya as its core element and planned service modules to follow. The Endeavour STS-88 launched on December 4, 1988, for a 12-day mission to take the first ISS component into space and begin assembly of the ISS.²¹⁰ Shuttle astronauts used the 50'-long robot arm to capture the Zarya control module from orbit and mate it to the Unity, requiring Astronauts Ross and Newman to conduct three space walks to attach cables, connectors, and hand rails.²¹¹ Zarya was the first ISS module launched into space by a Proton rocket on November 20, 1998. Unity was the first U.S.-built component of the ISS carried into orbit as the primary cargo of the Space Shuttle Endeavour (STS-88) on December 6, 1998, the first Space Shuttle mission dedicated to assembly of the ISS. Following this initial mission, the Shuttle continued to take part in assembling the ISS until the Columbia accident in 2003, which, after a two-year investigation, ended the SSP in 2011. In its place, NASA embarked on the Constellation Program; its objectives included the development of technologies to open the space frontier beyond the moon to Mars using post-Shuttle spacecraft and booster vehicles. Due to federal budget constraints, funding was pulled for the Constellation Program in February 2010. However, development of the Orion spacecraft, originally designed to support the Constellation Program, continued. The reconfigured Orion Multi-Purpose Crew Vehicle, officially announced by NASA in May of 2011, facilitated commercial cargo and crew missions to the ISS. The plan called for NASA's Orion spacecraft to be launched on NASA's new heavy-lift rocket, the Space Launch System, to take humans farther than they've ever gone before.²¹² The Orion spacecraft served as the exploration vehicle that would carry the crew to space, provide emergency abort capability, sustain the crew during the space travel, and provide safe re-entry from deep space return velocities.²¹³

²¹⁰ NASA, "Mission Information."

²¹¹ NASA, "Mission Information."

²¹² NASA, "About Orion," from <https://www.nasa.gov/exploration/systems/orion/index.html> (2016).

²¹³ NASA, "About Orion."

Part II. Structural Design Information

A. General Statement:

1. Character: Building 18 was originally designed to test the Apollo rendezvous radar and the Apollo landing radar subsystems, with the rendezvous radar first used in space during the Apollo 9 mission in March of 1969 and the landing radar first used in space during the Apollo 11 lunar landing mission in July of 1969. The full functionality of the intended antennae testing at JSC could not be realized without this facility.²¹⁴ The Radar Boresight Range Control Building had significant associations with not only the Apollo Program (1961 to 1972), but also Skylab (1965 to 1979), Apollo-Soyuz Test Project (1971 to 1975), Shuttle-Mir (1993 to 1998), Space Shuttle (1981 to 2011), and ISS (1993 to current). The Radar Boresight Range Control Building also conveys a visual sense of the overall historic environment, represents an interrelated arrangement of historically connected properties, and is united historically with numerous other buildings and events within the geography of the JSC campus.

Additionally, the Radar Boresight Range Control Building retains its original PEAFF panel walls that reflect the Modern design concept used by federal contractors in the 1960s and 1970s, designed in the style of Brutalism, which is a thick masonry variation of Modernist architecture. The PEAFF panel walls were an outstanding engineering achievement and pioneering design concept in the early 1960s and illustrate the implementation of President Kennedy's Federal Program Guiding Principles for Federal Architecture and the GSA's philosophies of engineering functionality and economical materials selection.

2. Condition of fabric: Currently, Building 18 is being prepped for demolition and all re-usable equipment and architectural features have been relocated and are being repurposed in other buildings or have been placed in storage.

B. Description:

The Radar Boresight Range Control Building (Building 18) facility consists of an access-controlled, two-story rectangular building. Construction by Scientific Atlanta Incorporated of Atlanta, Georgia, commenced on September 30, 1965, with the contract filed by NASA as complete on December 31, 1966. In 1974, the name of Building 18 changed from Radar Boresight Range Building to Radar Boresight Range Control Building as it supported Mission Control for the Antenna Test Range. Original construction features included a concrete foundation, PEAFF panel walls, and vinyl asbestos tile floors. When first constructed the building measured 28' in length and was 28' wide, covering 1,568 square feet.²¹⁵

Improvements to the building, such as installing floodlights and safety rails, upgrading fire suppression systems, and modernizing electrical wiring and plumbing, have occurred since the building was originally constructed. Major alterations to the original facility layout occurred in 1997 when a 20' x 28' addition to the north was constructed to support two new control rooms which added 1,200 square feet (Enclosure 2).²¹⁶ At the same time, outside stairs and anechoic shielding was installed on the north wall.²¹⁷

²¹⁴ Letter, Justin Kockritz to Sandra J. Tetley, "Project Review under Section 110 of the National Historic Preservation Act, Final Historic and Architectural Survey and Evaluation of Facilities at the NASA's Lyndon B. Johnson Space Center, Houston, Harris County (NASA/110, THC #201701384)," December 19, 2016.

²¹⁵ Facilities Housing Plan, Drawings No. FHP-18-1, FHP-18-2, and FHP-18-R (Houston: National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Facility Development Division: 2011).

²¹⁶ Master Data Sheet, NASA/1047/128 (n.d.)

²¹⁷ Schetz and Olanson Interview.

The first floor is subdivided into a storage supply room (Room 100), two bathrooms, and one mechanical room (Room 104).²¹⁸ The second floor is accessible via an exterior stairwell located on the northwest side of the building and consists of two sub-divided rooms (Rooms 200 and 202).²¹⁹ Room 200 maintains the original cement walls and a window overlooking the test range to the west. Two retired positioning tables are located on the roof and on a gravel ground pad extending west from the building. A concrete ground pad extends north of the building, which was the site of a now-removed positioning table. The original control equipment for these positioning tables is currently stored in Room 200, although the equipment has been decommissioned for at least the past decade.²²⁰

During Project Morpheus, Morpheus Mission Control was located on the second floor in rooms 200 and 202 with additional test facilities on the roof. Building alterations were made to support Project Morpheus (circa 2012) which included the installation of new computers, command telemetry, cables, and fiber optics.²²¹

The Outdoor Antenna Range (Building 18A) is located in a controlled area southwest (of Plant North) of Building 18. The range consists of a concrete pad measuring approximately 9' x 8' with a 50' diameter clearance area; 220 VAC power for housing an electronic positioner; and an access road. Construction by BRSP commenced in July 1998 and concluded in February 1999.²²² No alterations or additions have been noted on the Master Data Sheet or Property Records Cards.

C. Mechanicals/Operation:

The Radar Boresight Range Control Building (Building 18) was built to test the Apollo rendezvous radar and Apollo landing radar subsystems and was later modified to accommodate the development for the Space Shuttle rendezvous radar.²²³

The Apollo rendezvous radar is a space-stabilized FM/continuous wave tracking radar designed and used for the Apollo lunar missions.²²⁴ This rendezvous radar was a lightweight, highly reliable, and accurate radar subsystem that was designed to function in environments encountered on the Earth, in space, and on the moon. The Apollo rendezvous radar is a solid-state coherent tracking radar that was used in the LM for performing rendezvous with the CSM in lunar orbit. The Apollo landing radar was used to sense the velocity and slant range of the LM relative to the lunar surface by means of a three-beam Doppler velocity sensor and a radar altimeter.²²⁵ The velocity and range information was then processed and made available to the LM guidance computer. Development of the Apollo LM landing radar and rendezvous radar subsystems began when the radar subsystem for the MSC boresight tests was delivered to JSC in April of 1966, with equipment for the flight test program delivered four months later.²²⁶ The Apollo 9 (spacecraft LM-3) mission in March of 1969 was the first to use the Apollo radar subsystems in space.²²⁷ The Apollo 11 (spacecraft LM-5) mission in July of 1969 was the first to use the radar subsystems during a lunar landing.²²⁸ The Apollo rendezvous radar and landing radar were required during four space flights and two lunar

²¹⁸ Facilities Housing Plan, Drawings No. FHP-18-1, FHP-18-2, and FHP-18-R (Houston: National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Facility Development Division: 2011).

²¹⁹ Schetz and Olanson Interview.

²²⁰ Schetz and Olanson Interview.

²²¹ Schetz and Olanson Interview.

²²² Schetz and Olanson Interview.

²²³ NASA, "Telemetry and Communications Systems Division," in *Major Test Facilities of the Engineering and Development Directorate* (October 1970), 2.

²²⁴ Patrick Rozas and Allen R. Cunningham, "Apollo Experience Report: Lunar Module Landing Radar and Rendezvous Radar," (1972), 5-6.

²²⁵ Rozas and Cunningham, 2.

²²⁶ Rozas and Cunningham, 2.

²²⁷ Rozas and Cunningham, 2.

²²⁸ Rozas and Cunningham, 2.

landings.²²⁹ Although Building 18 was constructed over fifty years ago (ca. December 1966), the usage has remained relatively the same.

The Radar Boresight Range Control Building (Building 18) housed the Avionics Systems Division Laboratory and Global Positioning Systems (GPS) Test Facility that supported the testing of a new prototype planetary lander as part of Project Morpheus (Engineering Directorate).²³⁰ Project Morpheus developed and tested a prototype planetary lander capable of vertical takeoff and landing.²³¹ Morpheus was designed to be large enough to carry 1,100 pounds of cargo to the moon, such as a humanoid robot, a small rover, or a small laboratory to convert moon dust into oxygen.²³² The Morpheus lander was designed to perform all propellant burns after the trans lunar injection.²³³ Project Morpheus ran from its conception in summer 2010, through to its final test flight in December of 2014. Morpheus Mission Control was located on the second floor in rooms 200 and 202 with additional test facilities on the roof.

The exterior north wall stores large black radio frequency absorber blocks, which during antenna testing, were attached to the two freestanding steel frames located on the ground surface between Building 18 and the Antenna Test Range in order to absorb radio frequencies and prevent broadcasting during testing. Concurrently, the Instrumentation and Electronic Systems Division tested and evaluated developmental systems such as the Apollo lunar TV camera, space suit communications and telemetry, vibro-acoustic data systems, spacecraft telemetry, Apollo flush-mounted antennas and adaptive communication space systems at the Radar Boresight Range Control Building (Building 18) and Outdoor Antenna Range (Building 18A).²³⁴

The Outdoor Antenna Range was first used to test the Apollo rendezvous radar and Apollo landing radar subsystems and was later modified to accommodate the development for the Space Shuttle rendezvous radar, and more recently used for testing during Project Morpheus. The Range has supported special systems testing and development of small-scale aircraft and rockets, as well as all sorts of mechanical devices supporting the Apollo Program (1961 to 1972) through to current mission operations. The Outdoor Antenna Range has operated as the "airport" for JSC's Radio Control Club and National Association of Rocketry.²³⁵ Of note, in 1975, a geophysical study was conducted across the Range when the Western Geophysical Company placed hi-velocity blasting gelatin in 70'-deep holes drilled along a 3,500 foot line for gas and oil exploration purposes.²³⁶

D. Site Information:

The Radar Boresight Range Control Building (Building 18) is located is located on 2nd Street northeast from the controlled Antenna Test Range area, in Area 4, reserved for large land area requirements to support special systems testing and development, as well as warehousing, shipping and receiving, motor pool, logistical support, and other housekeeping operations.²³⁷ The Radar Boresight Range Control Building comprises the main building (Building 18) and the Outdoor Antenna Range (Building 18A), of which the latter will not be demolished.

²²⁹ Rozas and Cunningham, 2.

²³⁰ Brandi Dean, "Project Morpheus to Begin Testing at NASA's Johnson Space Center," Johnson Space Center Press Release, J11-009 (2011).

²³¹ NASA, "NASA dreams of future Morpheus project templates," (2015).

²³² "NASA dreams of future Morpheus project templates."

²³³ "NASA dreams of future Morpheus project templates."

²³⁴ "Co-ops Briefed on IESD Operations," *Space News Roundup* (August 4, 1967), 3.

²³⁵ "Radio Controllers Look Forward to Long Days," *Space News Roundup* (March 3, 1967), 3.

²³⁶ "SSHH, Careful It's Loaded," *Space News Roundup* (February 14, 1975), 2.

²³⁷ Brown and Root, et al, Master Plan.

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Appendix: Drawings

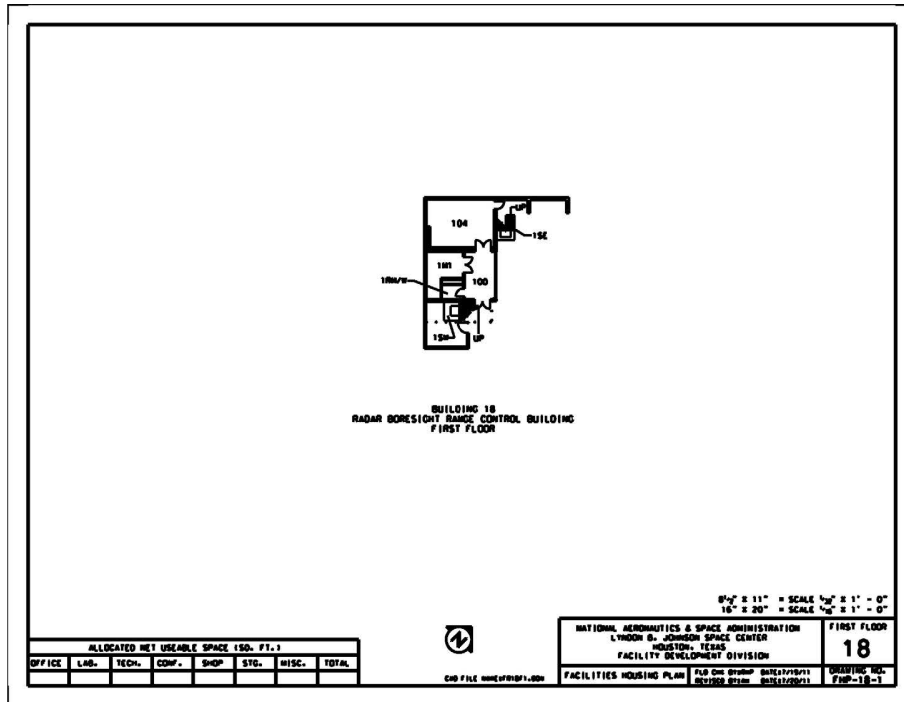


Figure One: National Aeronautics and Space Administration Johnson Space Center Drawing No. FHP-18-1, 2011.

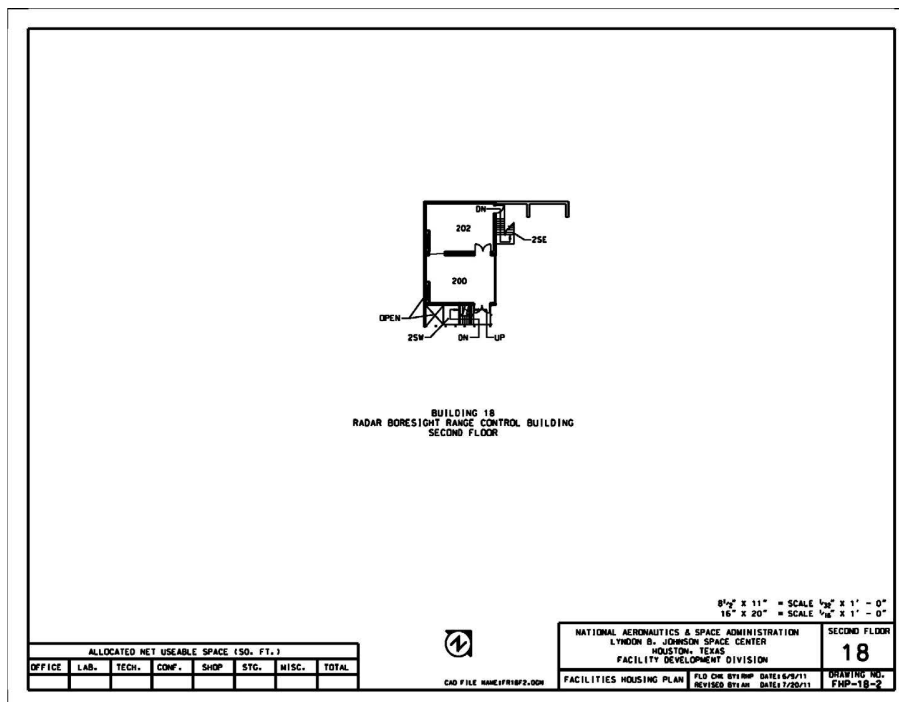


Figure Two: National Aeronautics and Space Administration Johnson Space Center Drawing No. FHP-18-2, 2011

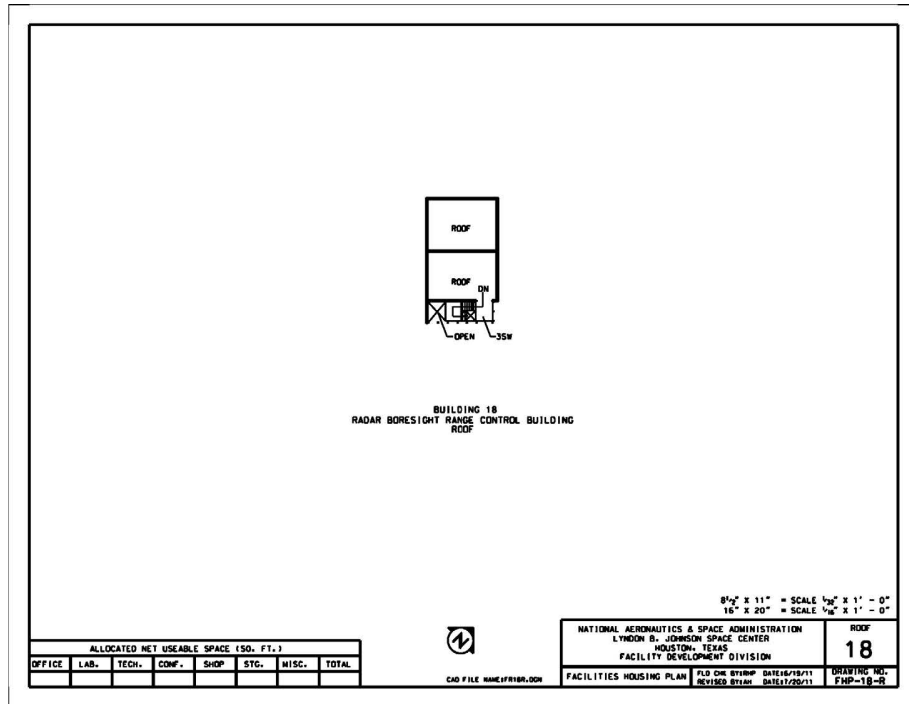


Figure Three: National Aeronautics and Space Administration Johnson Space Center Drawing No. FHP-18-B, 2011