NASA JOHNSON SPACE CENTER, APOLLO MISSION CONTROL (Building 30)
2101 NASA Parkway
Houston
Harris County
Texas

HAER TX-109-C
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PHOTOGRAPHS

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HISTORIC AMERICAN ENGINEERING RECORD

JOHNSON SPACE CENTER, APOLLO MISSION CONTROL
(Building No. 30, Apollo Mission Control Center)

HAER No. TX-109-C

Location:	2101 NASA Parkway, Houston, Harris County, Texas Latitude: 29.558195°, Longitude: -95.088562°. This coordinate is the approximate location of the Apollo Mission Control Room in the Mission Control Building complex. This coordinate was obtained on January 3, 2013 by plotting the point using TerraGo Technologies' tools applied to a digital copy of the 1:24000 League City, Texas USGS Topographic Quadrangle map. The accuracy of the coordinate is ± 12 meters. The coordinate's datum is North American Datum 1983.
Date of Construction:	1964
Builder/Fabricator	N.A.S.A.
Present Owner:	N.A.S.A.
Present Use:	Manages Aerospace Vehicle Flights
Significance:	The Mission Control Center, and especially its Mission Operations Control Room (MOCR), may be NASA's best-known historical landmark—even though very few people would recognize the outside of the building that housed the room and its sophisticated computing technologies and instruments. Most Americans are familiar with the Mission Control Center through television broadcasts of the Mission Operations Control Room during flights of the Apollo program. The MOCR is joined forever with astronaut Neil Armstrong's televised first steps on the moon and his description of the event as "one small step for man; one giant leap for mankind," which was reported to Mission Control and re-transmitted immediately around the world.

The crew of flight controllers at Mission Control provided the flight crew (astronauts) with vital information about the performance and operation of the craft. The crew at Mission Control also directed astronauts during primary or alternate missions, and during mission emergencies. In sum, the crew at Mission Control was responsible for the technical oversight and management of the spacecraft's vehicle systems, its navigation and flight dynamics (the orientation of the spacecraft), its life support systems, the flight crew activities, and the procedures to recover the spacecraft and astronauts. The Mission Control Center also directed mission simulations used to train astronauts and ground systems personnel.

At its height during the Apollo Program, NASA's Mission Control Center-Houston exercised nearly complete control over NASA's manned space flight program and missions, from mission planning, to flight ascent, and on through the spacecraft's reentry and recovery. The operations approach of Mission Control exerted a dominating influence throughout NASA especially during the Apollo program and its successive steps to a moon landing.

The facility was used subsequently to conduct the flights of Skylab, Apollo-Soyuz, and Space Transportation System (Space Shuttle) flights, including those associated with Spacelab and the International Space Station. It remains in use today to conduct the final scheduled Space Shuttle flights.

Project Information

Documentation of the Mission Control Center is part of the Historic American Engineering Record (HAER), a long range program devoted to the documentation of the engineering and industrial heritage of the United States. The HAER program is administered by the National Park Service. This project was funded by the Facilities Office of Lyndon B. Johnson Space Center (JSC), with the assistance of Sandra Tetley, Historic Preservation Officer at JSC.

Field work, measured drawings, and this historical report were prepared under the general direction of

Richard O'Connor, Chief of HAER The project was managed by Thomas M. Behrens, HAER Architect; Historian, Douglas Jerolimov, University of Virginia; and Architect John Wachtel, Iowa State University.

ACKNOWLEDGEMENTS

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Douglas Jerolimov
Project Historian
December 2011

Mission Control Center-Houston and Manned Spaceflight

After an electrical short caused an oxygen tank to explode on the spacecraft *Odyssey*, Apollo 13's Command-Service Module, Commander James A. Lovell called down to the Mission Control Center to say, "Houston … we've got a problem.." The words live on in the America's collective memory, a reminder of the heroism of the Apollo Program's astronauts and flight controllers. Although far out in outer space, astronauts Lovell, John L. Swigert, and Fred W. Haise were not alone; their vessel was integrated within an elaborate system of social and technical elements, a system focused on the site of its Mission Operations Control Room (MOCR) at the Mission Control Center (MCC) in Houston, where the vessel's Flight Controllers were located. While the flight controllers and engineers at MCC tried to find a way to bring home the crew of the *Odyssey*. Ground crew and flight crew were also joined by nearly 500 Million people worldwide, glued to their television screens, listening and watching as this dangerous drama unfolded. The episode revealed space exploration of the late twentieth century to be quite a modern and complex endeavor, one that distinguished space exploration from earlier efforts of humans to reach out and explore the world.

What is the Mission Control Center, and what role has it played in the exploration of space at the National Aeronautics and Space Administration (NASA)? What, exactly, does this center "control"? To begin answering these questions, it is useful to compare NASA's explorations with those of the classic Western explorer-scientists, such as those of Captain James Cook of His Majesty's Ship, *Endeavour* (and later of the HMS *Resolution* and HMS *Discovery*), who discovered and mapped many of the islands of the Pacific Ocean in the mid- to late-eighteenth century.

The two varieties of exploration, ocean exploration and space exploration, shared common elements. Each was complex, relying on the most advanced available technologies of travel and navigation. Each exploration was funded and carried out under the auspices of a powerful State, and each State-sponsored exploration featured strong connections to its military organizations.[1] In each case, the explorers relied on vessels (whether ships or spacecraft) for protection from a harsh and unforgiving environment, and each exploration required crews of individuals with specialized knowledge to operate the vessels. The two varieties of exploration differed dramatically, however, in the ways that participants organized themselves spatially.

The complexity of a spacecraft's technologies and navigational requirements pushed NASA to centralize its planning and supervision of space exploration from the Mission Control Center in Houston. Astronauts were nearly always in direct radio communication with the Mission Control Center, and they flew their craft following carefully scripted

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[1] John Krige, "Building Space Capability Through European Regional Collaboration," in *Remembering the Space Age*, ed. Steven J. Dick (Washington, D.C.: National Aeronautics and Space Administration, 2008), 41. Walter A. McDougall, . . . *the Heavens and Earth. A Political History of the Space Age* (Baltimore: Johns Hopkins University Press, 1985), 174.

flight plans, under the constant guidance of the mission's Flight Director, his team of expert controllers, and computers at Mission Control Center. The controllers at Mission Control, for instance, continuously tracked the spacecraft's position, and issued instructions for navigation, marking the precise moments in time when astronauts were to make navigational maneuvers. Flight controllers also carefully monitored the operation and performance of the spacecraft through advances in "telemetry," technologies that allowed remote measurement and communication of the spacecraft's on-board systems. Data was generated through numerous sensors aboard the spacecraft, and then transmitted back to ground control for processing and analysis.

By contrast, the distance and isolation of Captain James Cook's vessel required that he exercise considerable autonomy in conducting his explorations. Cook held the rank of Lieutenant in the British Navy when he was the *Endeavour*'s commander and, together with his officers and the vessel's shipmaster, maintained a complete knowledge and control over his vessel's navigation and operation.[2] In sum, while standing aft on his vessel's deck, Captain Cook's crew, equipment, and expertise were always present, before him; NASA's Apollo explorations, by contrast, relied on advanced telecommunications and computing technologies to distribute the spacecraft's crew and expertise among the on-board systems and astronauts of the spacecraft, among the Earth-bound crew of flight controllers and its computing systems, and among tracking stations located around the globe. The Mission Control Center in Houston, rather than the spacecraft's commander, coordinated and directed space missions and exploration.

The extreme conditions of travel in outer Space, and limitations on what may be carried, also helped explain the arrangements that distinguished exploration in the time of Apollo from the time of Captain Cook. One must begin with the fact that a Space traveler must carry everything needed for his own survival—including oxygen to both breathe *and* to burn the vessel's fuel—this made "manned" space flights and exploration different from any exploration that preceded it. The complexity of navigation in Space, also, could have been met with recently developed computing technologies, but these technologies needed to reliably withstand the harsh vibration environments of rocket powered vehicles, and the harsh thermal environments of space—and the difficulty of meeting these environmental constraints were compounded by limitations on "payload," how much a rocket may propel outside the Earth's gravitational pull. Limitations in payload required that engineers minimize the size and weight of all devices, and even minimize the amount of fuel for the spacecraft. To reconcile the competing goals of a minimum payload and reliable navigational equipment, engineers relied on Earth-bound computers to very precisely, and remotely, navigate the spacecraft, and they relied on telemetry to monitor its operation and to gather information, in order to pay out the vessel's "consumables" (fuel to operate the craft, and materials to support human life) within precise limits.

By the end of NASA's Apollo program, and in the NASA programs that followed it, the Mission Control Center in Houston began to lessen in prominence—although not in

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[2] Richard Hough, *Captain James Cook* (New York: W.W. Norton & Company, 1995), 45-46, 51-56.

importance. A shift from the engineering goal of landing a man on the moon gave way increasingly to goals of scientific discovery, which increased the prominence of scientists and their role in the planning and supervision of space exploration. NASA's collaborative ventures, first with scientists at home and abroad, next with the Soviet Union, and then with other nations, also spread planning and command decision-making to other NASA centers, and to other locales on Earth. Finally, the incorporation of more sophisticated computing and navigation technologies aboard the spacecraft allowed more autonomy to astronauts. Today, the Mission Control Center in Houston remains a vital hub through which space missions and exploration are organized but it no longer wields an absolute control over the process, and it has yet to regain the symbolic power it enjoyed during the Apollo program, when the American public and the World were first introduced to space flight through the young medium of television.

MCC Background and Description

In the midst of a "Cold War," the United States offered a powerful response to the Soviet Union's launch of Sputnik in 1957, and to the further successes of the Soviet space program. On 25 May 1961, President John F. Kennedy stood before a Joint Session of Congress and challenged the United States to achieve "the goal, before the decade is out, of landing a man on the moon and returning him safely to the Earth."[3] The National Aeronautics and Space Act of 1958 had already led to the creation of the National Aeronautics and Space Administration, during the Eisenhower administration. Kennedy's clear articulation of an engineering goal for NASA, however, created a "space race" in earnest.

NASA's efforts at space exploration, and especially its efforts to land an astronaut on the moon, depended on many technological breakthroughs, and led to the creation of iconic vehicles and structures. The Mission Control Center at the Johnson Spaceflight Center in Houston, and especially its Mission Operations Control Room (MOCR), may be NASA's best-known historical landmark—even though very few people would recognize the outside of the building that housed the room and its sophisticated computing technologies and instruments. Most Americans are familiar with this room through television broadcasts during Apollo flights, making an ordinary television the world's window to the MOCR, the "nerve center" of NASA's missions.[4]

The technological and symbolic importance of the Mission Control Center to NASA's missions, particularly during the Gemini and Apollo programs, makes the Mission

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[3] John F. Kennedy, "Special Message to Congress on Urgent Needs," Speech Delivered in Person before a Joint Session of Congress, 25 May 1961, http://www.jfklibrary.org/Historical+Resources/Archives/Reference+Desk/Speeches/JFK/003POF03NationalNeeds05251961.htm.

[4] Manned Spaceflight Center, National Aeronautics and Space Administration, *MCC; Mission Control Center* (Houston, Texas: Manned Spacecraft Center, National Aeronautics and Space Administration, ca. 1964).

Control Center and its Mission Operations Control Room (MOCR) an historical landmark. At its height during the Apollo Program, NASA's Mission Control Center-Houston exercised nearly complete control over NASA's manned space flight program and missions, from mission planning, to flight ascent, and on through the spacecraft's reentry and recovery. The operations approach of Mission Control exerted a dominating influence throughout NASA during the Apollo program and its successive steps to a moon landing.

The crew of flight controllers at Mission Control provided the flight crew (those aboard the spacecraft) with vital information about the performance and operation of the craft. The crew at Mission Control also directed astronauts during primary or alternate missions, and during mission emergencies. In sum, the crew at Mission Control was responsible for the technical oversight and management of the spacecraft's vehicle systems, its navigation and flight dynamics (the orientation of the spacecraft), its life support systems, the flight crew activities, and the procedures to recover the spacecraft and astronauts. The Mission Control Center also directed mission simulations used to train astronauts and ground systems personnel.

The requirement for Earth-bound monitoring and control of space missions emerged from the unprecedented technical complexity of spaceflight and spacecraft. Limitations on payload, when combined with the primitive and unreliable state of developments in computerization during the 1960s, made it impossible to carry enough equipment and crew aboard the vessel to carry out all the functions of space travel. The small flight crews of 2 or 3 astronauts aboard NASA's spacecraft simply could not gather, absorb, and analyze the voluminous and diverse information needed to make timely and sound command decisions, particularly in times of crisis. The additional crew and equipment on the ground, and the centralization of command at the Mission Control Center, made it possible to safely and reliably send astronauts into space. This centralization of control, however, would lessen as NASA matured and began to collaborate with other groups, and with the space agencies of other nations.

To tell the story of the Mission Control Center in Houston, this report will first establish the context for the decision to construct the Center in Houston, and the expectations that developed for the role of a Mission Control Center in the years during the Mercury Project and in the early years of the Gemini Program. The report will next describe the Center's role in helping astronauts of the Apollo Program to reach the moon and return safely. Finally, the report will describe the Center's changing role in succeeding programs—Skylab, the Apollo-Soyuz Test Project, and the Space Transportation System (the "Space Shuttle" program).

Mercury Control Room

The decision to send astronauts to the moon did not make the functions of a "Mission Control Center" a foregone conclusion. During the years of the Mercury Project and at the beginning of the Gemini Program, a much less complicated Operations Control Room was used to conduct missions. In the process of conducting those flights, however, important actors at NASA began to place a great deal of importance on the functions of mission control, and began to envision its role for the more complicated mission of the Apollo Program.

The first Mission Control Center and its flight controllers worked from the “Mercury Control Room,” or “Mercury Control,” which was located at NASA’s Cape Canaveral launch site and controlled the missions of Project Mercury. Eugene “Gene” F. Kranz later called the Mercury Control Room “minimal” and “primitive” (see Figure 1).

The first flight controllers at Mercury Control, according to Kranz, were drawn from among engineers and technicians with experience working at tracking stations on the Vanguard, Explorer and Pioneer missions (the first satellites launched by the United States in 1958). Many flight controllers were also drawn from engineers working on American pilotless aircraft research, many from the National Advisory Committee for Aeronautics (NACA), whose personnel and sites provided the core of the National Aeronautics and Space Administration (NASA) when it was established in 1958. Kranz himself worked in aircraft flight testing before being hired as a flight controller. The man who most shaped the role of Mission Control, Christopher “Chris” C. Kraft, Jr., worked as an engineer at NACA’s Langley Research Center at Hampton, Virginia, at its Aircraft Stabilization and Control Laboratory, before he was recruited to serve as Flight Director of the Mercury Project missions.[5]

Project Mercury, which ran from 1959 to 1963, sought to put an American in orbit, to do so using “the most reliable available boost system,” and to achieve its goal safely.[6] Project Mercury began with 20 unmanned launches, including two launches carrying monkeys and another two carrying chimpanzees, and progressed to launches with astronauts. The program survived the embarrassing “Four-Inch Flight” (the tenth Mercury launch), and went on to put John Herschel Glenn, Jr., in orbit on 20 February 1962—as well as other astronauts in succeeding flights—and to establish operational concepts that were developed and improved with each mission.[7]

The operational concepts and technological arrangements of the program were used to centralize and systematize knowledge, expertise, and decision-making, at a flight’s mission control center. NASA constructed a global network of stations to communicate with and track a spacecraft during flights. The name of the network, initially called the

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[5] Gene Kranz, *Failure is Not an Option: Mission Control from Mercury to Apollo 13 and Beyond* (New York: Simon & Schuster, 2000), 18, 19, 25; Christopher C. Kraft, Jr., “This is Mission Control,” in *Apollo Expeditions to the Moon*, ed. Edgar M. Cortright (Washington D.C.: Scientific and Technical Office, National Aeronautics and Space Administration, 1975), 130-131.
[6] “Objectives and Basic Plan,” *Minutes*, Panel for Manned Space Flight, Appendix A, 1, Warren J. North, secretary, Sept. 24 and 30, and Oct. 1, 1958. Cited in Lloyd S. Swenson, Jr., James M. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury*, NASA SP 4201 (Washington, D.C.: Scientific and Technical Division, National Aeronautics and Space Administration, 1966), 125.
[7] Kranz, 32.; Kraft, “This is Mission Control,” 131.

"Mercury Space Flight Network," would be changed by 1963 to the "Manned Space Flight Network" as the Gemini program gathered momentum.[8] The communications network allowed centralization of a flight's supervision at the mission's control room, called "Mercury Control."

The centralization of authority was also expressed in the development of "flight rules," which Kranz called "an upscale equivalent of the Go NoGo criteria we used in aircraft flight tests."[9] Kranz wrote that the flight rules he developed were the products of decisions arrived at in meetings that included "crews, controllers, and management." The rules constituted a "record of decisions" at the meetings, articulated in "flight rule format, defining each decisions as a series of conditions followed by action procedures." Kranz believed that the "value of compiling and defining rules was not in the document itself as much as it was in hashing out Go NoGo stipulations in team meetings." Decisions arrived at in Mercury meetings were sometimes modified when formally articulated between himself and Flight Director Christopher Kraft and, in any case, Kranz wrote, the "ultimate authority was the [flight] operations director, Walt [Walter C.] Williams."[10]

According to Kranz, the developing role of a Mission Control for Project Mercury meant that flight controllers, who were generally quite capable systems engineers of their individual specialties, needed to envision themselves differently to successfully control spaceflight missions, and for their new role and authority to be accepted without question. Kranz believed that the flight controller at Mission Control needed to stop thinking of himself as an engineer who could "explain how a system should work (in theory)," and to begin thinking of himself as "operator," one who knows "what the engineer knows," but also knows "how the systems tie together." This knowledge is necessary, he believed, "to get the mission accomplished." A flight controller, according to Kranz, "must make rapid decisions on fixing or working around a problem to keep the mission moving" in the event of system breakdowns.

The conditions of spaceflight, which neither allowed pilots the option of landing at a runway nor the option of ejecting, demanded that flight controllers develop a holistic knowledge of the spacecraft's operation. Astronauts, however, who were drawn from the ranks of test-pilots and accustomed to substantial autonomy during flights—and grew to trust their own judgments in life-or-death decisions—were not persuaded initially of the flight controllers' pre-eminent authority and knowledge during a mission.

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[8] Sunny Tsiao, *"Read You Loud and Clear!" The Story of NASA's Spaceflight Tracking and Data Network* (Washington, D.C.: National Aeronautics and Space Administration, 2008), 103.

[9] Kranz, 43.
[10] Kranz, 43-44.

Moving to Houston

By the middle of 1961, senior NASA administrators had decided that the growth of the size and scope of the Mercury Project required the creation of a manned spaceflight program center, one that was autonomous and distinct from the scientific and technical research of the Goddard Space Flight Center in Greenbelt, Maryland, and from that of the Langley Research Center in Hampton, Virginia. It was also thought that the manned space program should be separate from the unmanned space program, which was directed by the Jet Propulsion Laboratory in Southern California, and by Johns Hopkins University in Baltimore.

Officials decided that the site of the new manned space program center needed to meet many requirements. It should be located in a mild climate, one that featured access to water transportation and to an airport with commercial jet service, access to an a well established industrial complex and power utilities infrastructure, available technical facilities and labor pools, as well as a nearby institution of higher learning, and at least 1000 acres of land. These requirements limited the possible locations of such a facility to nine sites across Florida, Texas, Louisiana, and California.[11]

NASA's Administrator, James E. Webb, informed President Kennedy in a memorandum dated 14 September 1961 that "Our decision is that this laboratory should be located in Houston, Texas, in close association with Rice University and the other educational institutions there and in that region."[12] On 19 September 1961, NASA announced its decision to locate the new "spaceflight laboratory" in Houston, on 1020 acres of land which Rice University had donated to the federal government.[13] The decision to build the spaceflight laboratory on the coastal prairies south of Houston was not received enthusiastically by many NASA employees who were required to move from their homes around Langley in Virginia.[14] Nevertheless, at the end of 1961 and throughout 1962, thousands of personnel, contractors, and their families migrated to the new "manned spacecraft" research center, where they found an enthusiastic and supportive population that eventually won them over.[15] On 16 February 1962, NASA acquired an additional 600 acres from Rice University for $1,400,000, adding it to a site that was now called the "Manned Spacecraft Center."[16]

NASA remained remarkably productive, and enjoyed considerable success, even while many of its employees were moving from Langley to their new "Spaceflight Laboratory"

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[11] Henry C. Dethloff, *Suddenly, Tomorrow Came…A History of the Johnson Space Center* (Washington, D.C.: National Aeronautics and Space Administration, 1993), 27, 36-38.
[12] Webb, Memorandum to President Kennedy, quoted in Dethloff, 39-40.
[13] NASA News Release 61-207, September 19, 1961, as cited in Dethloff, 33.
[14] Dethloff, 40-41.
[15] Dethloff, 33, 41-44.
[16] R. A. Diaz, "Acquisition of 600 acres of additional land for the Manned Spacecraft Center," 16 February 1962, Box 062-61, Apollo Program Chron. Files, Johnson Space Center History Collection, University of Houston-Clear Lake; James E. Webb, "Conveyance of Land to NASA by Rice Univ.," 23 February 1962, Box 062-62, Apollo Program Chron. Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

at Houston. Project Mercury succeeded in launching three manned orbital flights in 1962. Flight controllers overcame tense moments to bring home John Glenn and his *Friendship 7* capsule (Mercury-Atlas 6) on 20 February, they overcame tense moments in Scott Carpenter's (Mercury-Atlas 7) three-orbit scientific mission on 24 May. And they directed Walter Schirra glitch-free six-orbit mission aboard the *Sigma 7* (Mercury-Atlas 8) on 3 October.

It soon became clear to Flight Operations Director Walt Williams and Flight Director Chris Kraft that more than the Mercury Control Center would be needed for the longer and more complicated missions of Gemini and Apollo, and the two began advocating the construction of an "Integrated Mission Control Center" (IMCC) at the Manned Spacecraft Center (MSC) in Southeast Houston. By "integrated," Williams and Kraft meant that more than simply flight control should be transferred from the Cape, they also sought to move computer programming and operations planning to MSC. Computer functions and tracking had been the responsibility of Goddard for the Mercury Project, but this was called into question.[17] NASA Administrator James Webb had agreed with Kraft and Williams that an integrated mission control should exist, though the extent of such an integration, and the corresponding division of labor among the various mission control functions were not worked out until the end of 1962.[18] On 20 July 1962, Webb announced that the "Control Center for manned flights to the moon" would be located at NASA's Manned Spacecraft Center in Houston.[19]

The new Control Center, according to a NASA press release, would include a "computer complex, communications center, flight simulations facility and flight operations displays," and planners expected to use the facility to direct the Gemini rendezvous flights in 1964.[20] The Control Center itself would be located in two interconnected three-story structures, called MSC Building 30 (see Figure 2). A windowless structure housed the Mission Operations Wing (MOW) on one side of an elaborate lobby and entrance; on the other side of the entrance would be found a more conventional three-story windowed structure which housed the Operations Support Wing (OSW).[21] Gene Kranz later described the overhead structure above the entrance as an "egg-crate" façade, one that "always sticks out as an anomaly in the four-story, featureless, window-less, boxy, pea

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[17] Courtney G. Brooks, James M. Grimwood, and Lloyd S. Swenson, Jr., *Chariots for Apollo: The NASA History of Manned Lunar Spacecraft to 1969* (Washington, D.C.: National Aeronautics and Space Administration, 1979; Reprinted Mineola, New York: Dover Publications, 2009), 114-115.
[18] Ibid., 115.
[19] Release No. 62-172, "NASA Mission Control Center to be at Houston, Texas," 20 July 1962, Box 063-14, Apollo Program Chron. Files, Johnson Space Center History Collection, University of Houston-Clear Lake.
[20] Ibid.
[21] Manned Spaceflight Center (MSC), National Aeronautics and Space Administration, *MCC; Mission Control Center* (Houston, Texas: Manned Spacecraft Center, National Aeronautics and Space Administration, ca. 1964), 3. From PDF file: MCC MISSION CONTROL CENTER MANNED SPACECRAFT CTR.pdf. PDF File in possession of Jennifer Ross-Nazzal, Historian, NASA Johnson Space Center.

gravel and concrete structure." The Operations Support Wing, he wrote, featured "windows well lit and filled with engineers moving deliberately between offices."[22]

Each of the MCC's wings was a three-story structure, including the Lobby Wing. (The windowless Mission Operations Wing also included a Mezzanine floor, which Kranz counted as a fourth story.) The two main structures were similar in footprint: MOW was 272 feet by 133 feet, and the OSW was 227 feet by 171 feet. The Lobby Wing measured 49 feet by 88 feet. Upon completion, the buildings offered approximately 261,000 square feet of usable floor space.[23] The Mission Operations Wing was planned to cost $492,192, and was constructed by the Corps of Engineers and the General Contractor, ETS-Holkin-Galvin, at an actual cost of $8,050,072.[24] The building was transferred to the control of NASA's personnel on 29 April 1964, and employees began occupying the structure over the next two months.[25]

Emergence of the Mission Control Center in Houston

In part, the functions of the Mission Control Center in Houston were shaped by the experience of flight controllers who worked at the site's precursor, the Mercury Control Center at Cape Canaveral—and especially by the experience and vision of Flight Director Chris Kraft and Flight Operations Director Walt Williams. Williams and Kraft sought to centralize the process of mission planning in order to more closely control the much more complicated hardware and flight plans of Apollo. "Apollo mission schedule calls for flights well beyond the capability of the current Manned Space Flight Network," wrote Williams, but there were many details to work out: "there will be requirements for tracking (position and velocity vector), voice, telemetry, and possibly an up-data link, all at lunar distances." Williams looked to the Jet Propulsion Laboratories' own Deep Space Instrumentation Facilities [DSIF] to help in meeting these requirements, and to provide "sufficient systems redundancy at or near each of the present DSIF longitudes to assure a contact in [the] event of [a] failure of a system or in [the] event of a requirement to support a spacecraft of a another program."[26]

Williams typified a common approach to address the problems that arose in the Gemini and Apollo programs: the effort to add capacity to ground systems and to tracking and communication systems. With the Gemini program operating alongside the Mercury Project, and with the impending need to control one mission while simulations were conducted in preparation for another mission, and with expected missions involving more

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[22] Kranz, 277.
[23] Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration, "Mission Control Center," NASA Facility Classification Code 140 10, Building 30, Real Property Record – Buildings, 27 November 1964.
[24] JSC, "Mission Control Center"; Ray Loree, "MCC History" (Draft). August 1990, 1. PDF File in possession of Jennifer Ross-Nazzal, Historian, NASA Johnson Space Center.
[25] JSC, "Mission Control Center"; Loree, "MCC History," 1.
[26] Walter C. Williams, "Support of Apollo by the DSIF [Deep Space Instrumentation Facilities]," 2 October 1962, Box 063-23, Apollo Program Chron. Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

than a single spacecraft—flight controllers and others who prepared for mission needed to increase their capacity to accomplish all that needed to be done.

Under the guidance of Chris Kraft and Robert R. Gilruth, Director of the Manned Spacecraft Center, the Mission Control Center at Houston gathered up control over most aspects of ground support and preparation, beginning with the rendezvous missions of the Gemini, and for all of the Apollo Program missions. There had been some question, for instance, over whether Goddard or the Jet Propulsion Laboratory (JPL) would assume control of the Manned Space Flight Network of communications, as each had a legitimate claim to the function (Goddard conducted the tracking and communication for the Mercury Project, while JPL established suitably long-range facilities in developing its unmanned space exploration capabilities. By March 1963, however, it had been decided that Goddard would become the technical operator of the network, and that the Mission Control Complex (MCC) at Houston's Manned Spacecraft Center would maintain operational control of tracking and communication for the Apollo Program missions.[27] Other major electronic systems were also planned for the MCC site—display, computing, and simulation and training—which would identify the MCC as the "focal point for the entire ground operational support system" behind the Apollo Program. By 28 January 1963, Philco's Western Development Laboratory at Palo Alto, California, had been chosen to "design and develop much of the equipment and tie the entire complex together into a highly integrated operational system."[28]

The title, "Integrated Mission Control Center" (IMCC), became used to describe the Mission Control Center in 1962, as officials at Houston sought to integrate and centralize control over the entire process of planning, preparing, and supervising a spaceflight mission at the Mission Control Center—rather than only the supervision of manned spaceflight operations. Gilruth explained the function of the Integrated Mission Control Center as

> the central control and direction point for all activities related to the operational support of the manned space flight missions. It will be the central hub for the ground network and will include the communications system, the simulation checkout and training system, the display system, and the computer complex.[29]

"Integration" meant more than simply moving the telecommunications and computing equipment to Houston, it also meant moving the computer programming effort to

[27] Brooks, Grimwood, and Swenson, 123-125.
[28] National Aeronautics and Space Administration, News Release No. 63-14, "Philco to Develop Manned Flight Mission Control Center at Houston," 28 January 1963, Box 063-35, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake.
[29] Robert R. Gilruth, "Gilruth At Houston Explains Astronaut Training and Equipment at Manned Spacecraft Center," *Data: Magazine of Research and Development Management* (1963): 19-27.

Houston.[30] Henceforth, manned spaceflight missions were conceived, programmed, simulated, and directed, at Houston—and using the same equipment and personnel throughout. That is, the same computers that were used to provide directions for navigation during an actual mission were also used to conduct “closed loop” simulations that involved the astronauts (practicing in spacecraft mockups) and the flight controllers, who sat at their actual stations in the Mission Operations Control Room during simulations.

The Elements of an “Integrated Mission Control Center” (IMCC)

The integration of all aspects of a mission’s planning and execution at one site may have been very efficient, but it neither limited the growing number of personnel needed, nor the growing amount of equipment required of successive missions. The increasing demands and complexity of the Gemini and Apollo programs were met through the addition of *much more* equipment—through redundancies in equipment—and with ever increasing numbers of flight controllers and support staff. The MCC included two identical Mission Operation Control Rooms, one on the Second Floor and one on the Third Floor of the Mission Operations Wing of Building 30 (see Figure 3 for the room’s layout).[31] The two Control Rooms allowed the center to manage the spacecraft of two missions simultaneously—or to direct a single mission while also directing the simulation of another spacecraft’s operation and mission. The increasingly complex and numerous missions required more staff, also. “Fewer than twenty controllers” occupied the “mission control room during a flight,” according to a NASA news release, “but upward of 250 technical and administrative people [were expected to be] “carrying on supporting functions in adjacent rooms” of the Mission Control Center.[32] The flight controllers within each Mission Operations Control Room were only the visible “tip of the iceberg” when it came to the personnel who monitored and directed a flight.

The number of support personnel extended beyond the specialists near the Mission Control Operations Room to include personnel at other NASA space centers, and even to personnel in the offices and factories of participating contractors. Glynn S. Lunney, whose career at NASA began as a Flight Controller for the Mercury Project, Flight Director on the Apollo Program and, eventually, Manager of the Space Shuttle Program, recalled that “the engineering team kind of rode along with the flight team, and they were usually organized in a room or a series of rooms close by the Control Center.” These engineering teams were “tied in by phone lines and data lines … to a lot of the factories that were involved, certainly the prime contractor factories and then other factories where things were produced.” By the time “we got to the Gemini Program,” he recalled, “there

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[30] For an excellent explanation of the differences between today’s software programming, and the hardwired programming of NASA during the Apollo Program, see David A. Mindell, *Digital Apollo: Human and Machine in Spaceflight* (Cambridge, Massachusetts: MIT Press, 2008), 145-157.
[31] MSC, *Mission Control Center*, 3-6.
[32] News Release No. 63-14, “Philco to Develop Manned Flight Mission Control Center at Houston,” 2.

was a very well-organized, well-greased system for having the engineering team follow the flight."[33]

Display Systems of the Mission Operations Control Room (MOCR)

From the earliest days of the Mission Control Center, flight controllers who worked in the Mission Control Operations Room (MOCR) have been said to work in the "front room." The label suggests a relationship between the MOCR's flight controllers and the numerous other engineers who worked in the "back rooms," the Staff Support Rooms (SSRs) on various floors of the Control Center. The support staffs employed the MOCR's sophisticated display systems to deliver data and analysis to flight controllers' consoles, and to the big screen that all flight controllers viewed. The MOCR was also called a "front room," however, because this was the room that the rest of America and the World saw during the flights of Apollo.

The ordinary television set provided a window to NASA, and to the Mission Operations Control Room and its flight controllers—and hence made the project of manned space exploration a reality for Americans and the onlookers of other nations. Perhaps the most memorable architectural feature of the Mission Control Operations Room was the room's enormous display screen. Many Americans remember the characteristic sine waves that stretched across the tripartite screen, which measures 10 feet high and totals 60 feet in length. The screen "flashed TV images, maps, trajectories and other information vital to mission controllers," stated a NASA news release, but Americans saw this for themselves.[34]

The big screen's images were made possible by a rear-projection subsystem, called the Projector Plotter Display (PPD), its equipment hidden in the "batcave," the room behind the vast screen. The Projector Plotter Display equipment received trajectory data, and used a total of seven projectors to display its images and information. One projector was responsible for the background, casting an image taken from a 1-inch slide of a world map. Two were "spotting projectors," which overlaid a symbol representing the spacecraft or target on the background. The symbol moved across the screen, based on the trajectory information received. Four "scribing projectors" were used to project alphanumeric symbols or X-Y plots, and other such important overlays of information. Each scribing projector used a diamond-tipped stylus to scratch a metallic coating on a glass slide, and the image was "then projected on the screen using xenon lamps and color tilters" (See Figure 4). The images of several such slides were superimposed upon the screen to create a complete information display. The entire system required precise

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[33] Glynn S. Lunney, interview by Carol Butler, 28 January 1999, Oral History Transcript, NASA Johnson Space Center Oral History Project, http://www.jsc.nasa.gov/history/oral_histories/k-l.htm, 6.
[34] News Release No. 65-119, "MCC-H to Handle GT-4, Subsequent Manned Flights," 28 January 1963.

alignment of the projectors and the screen.[35] This unique and marvelous use of existing technologies to create the dominant display of the Mission Operations Control Room also worked to complement the sophisticated display systems of each flight controller's console.

Each flight controller could request data, organized in charts and graphs in various pre-set formats, and have it delivered directly to his console's cathode ray tube (CRT), a television monitor. The requested data, after preparation at the buildings Real Time Computer Complex, was processed and sent along to the Display and Control System (DCS), which constructed video displays. The video displays relied on a Digital-to-Television (D/TV) element that converted the data into one of 80 formats of display for viewing on a CRT, projected onto an optical element. The background for the data was provided by creating a separate image, projected onto the optical element from a 35mm slide. A video camera captured both images, now combined on a semi-transparent optical element. This image was transmitted to the CRT, which was embedded in the panel of the flight controller's console (see Figure 5).[36] Flight controllers frequently requested such data. During a 12 hour and 45 minute period of the Apollo 11 mission, for instance, flight controllers averaged 1044.9 such requests per hour, spending approximately 5.3 minutes viewing each resulting display/transmission.[37]

In addition to its television camera, the consoles included many switches and indicator lights, all specially selected and tailored to the functions and responsibilities of each controller (see Figure 6). The consoles of the Mission Operations Control Room, as well as the room's layout, were designed to be as efficient as possible in use; they were designed to provide a quick, accurate, and convenient, means of communication among flight controllers of the MOCR, and between flight controllers and associated engineers of the Staff Support Rooms (SSRs).

Philco-Ford was the contractor in charge of the design of the consoles of the MOCR. "The original layout," said former controller Jack Knight in an interview conducted in 2007, "the sizing, the distance, how far you sat, was a human factors study done by Philco, or Philco-Ford[,] I guess it was at the time. They were in charge of the Control Center."[38] Philco-Ford designed consoles' with adjustable features to accommodate the different controllers. According to Knight,

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[35] Michael W. Kearney, III, "The Evolution of Mission Control Center," *Proceedings of the IEEE* 75, no. 3 (1987), 402.
[36] Ibid., 400-402.
[37] B. Costis, W. Ortolani, and W. Moreland, "NASA MCC Display/Control System Usage and Effectiveness, Apollo 11," PHO-TN401, Contract NAS 9-1261, Philco-Ford Corporation for the National Aeronautics and Space Administration, 24 December 1969, Box 078-65/66, Mission Documents: Apollo 11, Apollo Program, Johnson Space Center History Collection, University of Houston-Clear Lake, p. 5-5.

[38] Jack Knight, interview by Sandra Johnson, 25 October 2007, Oral History Transcript, NASA Johnson Space Center Oral History Project, http://www.jsc.nasa.gov/history/oral_histories/KnightJ/knightj.pdf, 25.

> They did desktop heights. Of course, your chairs would move up and down, and we're all different sizes, right? I was five-seven, and the other guys are six-four, so nothing is going to be perfect. But the distance here was calculated out with human factors, and the slant, the angle that you were looking at…Those things were boxed out by Ford.[39]

Not all the controllers were the same shape or size, he recalled, which made the job difficult and led to at least 3 studies to determine the best viewing angles and seating arrangements for controllers. Philco-Ford conducted at least 42 separate studies to explore the interaction between controller and console, and to explore the console's mediating role in communication at the Mission Control Operations Center.[40]

A bibliography of documents produced by Philco-Ford revealed the extensive range of studies that went into the design of the consoles at the MOCR and SSRs and the layouts of the rooms. A document titled, "Human Factors Design Sketches and Released Drawings for the integrated Mission Control Center" concerned the design of consoles and modules, as well as the layout of the MOCR. However, many more specialized studies informed the design of the consoles and control room, such as the document titled, "Bend Angle Study for MOCR Personnel."

Studies concerning the specifics of the consoles panels explored the operation of switches, such as one that concerned the "Mounting of Safety Covers on Push Button Indicators," and the benefits and drawbacks of particular configurations of the pneumatic tube subsystem ("Advantages of Desk Top Loading and Delivery of the Carrier from the Pneumatic Tube Consoles in the MOCR"). Designers even explored ways the efficiency of the rooms' lighting ("A Study of Potential Lighting Problems in Operation and Support Areas of the IMCC") and the ease with which console operators could see the console's embedded television screen ("Methods for Resolving Cathode Ray Tube glare in the IMCC"). Designers even explored compounds to reduce the glare the consoles monitor ("Agent for Anti-Glare on TV Monitor Faces"), and considered the use of color television monitors ("Human Factor Evaluation of Color TV Displays").[41] The listed document titles reveal that the rooms were designed holistically, with the interactive functions of operators and departments in mind. This was easier to do because NASA awarded Philco-Ford the entire contract to design the MOCRs and SSRs, their consoles, and the display systems that connected the different rooms.

The bibliography also reveals detailed efforts to understand and improve operators' cognition of information conveyed through the display systems. The documents reveal

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[39] Ibid.
[40] "List of Technical Reports and Memorandums Concerning Human Factors Engineering Design of NASA-MSC Equipment," n.d., File Binder, "Human Factors Engineering in Design of Mission Control Center," Box 2, Center Series, Mission Control Center and Real Time Computer Complex, Johnson Space Center History Collection, University of Houston-Clear Lake.
[41] Ibid.

studies to understand the "human information processing of televised information" through documents like, "Information Handling Rates for MOCR." Console designers at Philco-Ford sought to optimize the human "handling rates" of information through the careful control of an extraordinary range of details. To that end, designers experimented with and studied such variables as the design of displayed characters on television displays ("Design of the Characters for the Charactron System"), and the frequency of television "flicker" ("Critical Fusion Frequency").[42]

Philco-Ford conducted numerous training programs to prepare flight controllers of the Mission Operations Control Room, and to prepare the operators and engineers of the SSRs, to use the systems. The company produced four reports to study the effectiveness of the training programs—and, likely, the effectiveness of their systems.[43] But if the reports suggest a top-down approach to the design of the MOCR and SSRs, Knight's own experience suggests that the MOCR and SSR designs were accomplished through collaboration between Philco-Ford and flight controllers. "Once you were assigned a console," he recalled,

> then your group had to agree on location and size and how many lights and so on, and you had to write requirements for all of that, which we did. We were totally in charge of that. Then the displays' parameters, you had to get everybody to agree on what went where, and you argued a lot about that. And you argued about light color—green, yellow, white, red. But you established some standards, like red was bad.[44]

Knight noted that the cultural associations of the rooms' users, the flight controllers, had much to do with shaping of displays. Console engineers needed to accord their designs with the cultural references of flight controllers. "Typically stoplight, red, not good. Green, go," he said,

> …if you happen to be in the [electrical] power [utility] business, [in] their control center, red is hot, meaning that you've got voltage there; green means it's open and so that if you're on the ground, you can do work. So, it just depends on what your point of view is. But it makes a difference if you go from one [culture] to the other, because, if you go from a place where the culture is red is "stop, do something" to a culture where red is "things are okay," it takes you a while to get oriented, and if you don't get oriented real well, emergency situations can be really bad, because you will revert back to what you used to do.[45]

The design of the panels used in the Mission Operation Control Room, Knight suggested, down to decisions over the colors of switches and indicators, needed to draw upon users'

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[42] Ibid.
[43] Ibid.
[44] Knight, Interview, 25 October 2007, 25-26.
[45] Ibid.

cultural understandings. Because the flight controllers' console was an interface and part of the medium through which all controllers communicated with one another and with the engineers in the Staff Support Rooms, only a careful consideration of flight controllers' perception and understanding of the consoles' details could ensure that flight controllers understood one another quickly. These seemingly insignificant design decisions became critical during times of emergency.

While the consoles of the Mission Operations Control Room revealed the latest in networking and computer display technologies, flight controllers also relied on an anomalous technology, the nineteenth century's pneumatic tube delivery system, to send and receive copies of charts and graphs, messages, and other documents. The pneumatic tube cartridges were hollow cylinders made of aluminum, twelve inches long and three inches in diameter. The tubes were pushed directly into, and ejected from, flight controllers' consoles, and relied on differences in air pressure to carry along the tubes and their contents to the MOCR from the Real Time Computer Complex, and among the MOCR and SSRs. Of all the remarkable and distinctive characteristics of the Mission Operations Control Room during the Apollo program, the sound of the "pneumatic P-tubes coming and going," stood out for J. Milton Heflin, who became a flight controller after the Apollo Program, while the original consoles were still in place.[46]

The pneumatic tube delivery system was integral to flight controllers' analyses of flight operations, and was part of the fabric of relationships among flight controllers in the MOCR and engineers in the Staff Support Rooms. A total of 47,250 prints were transmitted by pneumatic tube to controllers for the simultaneously conducted Gemini 7 and Gemini 6 missions (often labeled "Gemini 7/6"), which had a total flight time of 13 days, 18 hours, and 35 minutes (19,835 minutes), with 1 day, 1 hour, and 51 minutes (1551 minutes) of overlap—the two separately launched spacecraft performed a rendezvous in space.[47] Technicians from the MCC's Real Time Computer Complex transmitted, on average, 2.4 prints per minute to the MOCR's flight controllers. Chris Kraft complained that flight controllers were requesting too many of the expensive prints: "the average cost per copy is $.17, resulting in a total cost per in excess of $8,000" for the mission. While the average number of prints per pneumatic tube delivered is not known, we do know that the sounds of pneumatic tubes were heard quite frequently in the MOCR. "The density of the requests," Kraft wrote, "was such that three technicians were required full time to maintain and operate the machines and to put copies into the pneumatic tube system."[48]

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[46] J. Milton Heflin, "Perspectives on Shuttle Operations" (panel presentation given at Historical Conference on Mission Control Center, 16 November 2000, held at the Mission Operations Control Room 2, 3rd Floor, Building 30, Johnson Space Center, Houston, Texas). Audio File at JSC Archives, University of Houston-Clear Lake, Houston, Texas.
[47] Manned Spacecraft Center, *Gemini VII: Gemini Program Mission Report,* NASA-TM-X-62892 (Houston, Texas: Manned Spacecraft Center, National Aeronautics and Space Administration, 1966), p. 1-1, http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19790076811_1979076811.pdf.
[48] Christopher C. Kraft, Jr., "Excessive Use of TV Hardcopiers," 3 January 1966, Box 070-128, Kraft Reading Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

The Mission Operations Control Room was also NASA's "front room" to the American public, and for the world's onlookers. During a mission, some visitors and dignitaries were fortunate enough to visit the Mission Operations Control Room itself, and watch the action through the windows of the room's viewing galleries (see Figure 3). Most, however, witnessed the goings-on of the Mission Control Center through the windows of their television sets, at home. NASA welcomed the world's onlookers into a social space that lay, figuratively and geographically, between the realm of the public and the "back rooms" of NASA (its Staff Support Rooms in an immediate sense, but also the testing laboratories, training facilities, and the offices of all its centers).

The Mission Operations Control Room, a functioning workplace that supervised missions, was thus also a stage where NASA presented itself to, and engaged, the broader American public and the world. From the beginning, NASA revealed a keen desire to maintain transparency with its ultimate clients, the American taxpayer, and the presence of television cameras into the Mission Operations Control Room may be viewed as an important expression of this desire for transparency. The television cameras in the MOCR constituted the interface of an elaborate system of social and technical elements that composed network television, bringing visitors to the room—it was a display system.

Television cameras gained admittance to NASA's Mission Control Rooms during the early days of the Mercury Control Room, though somewhat inauspiciously. Kranz writes that the press was permitted inside the control room to film the Gemini 2 launch, and planned to use "fixed cameras and lights on both sides of the room, with a roving camera coupled by an umbilical to a recorder." In the "last few seconds before the launch, the [camera crew's] lights turned on," Kranz writes, "the room momentarily bathed in brilliant white, while the cameras whirred." Unfortunately, however, the camera's lights and cameras "momentarily overloaded the circuit breakers and cut the power to the entire control center at the Cape."[49] The mission was still a success, even though "Gemini 2 was in reentry and the mission virtually over before we were able to restore electrical power." Mission over, the debriefing was brief. Kranz recalled that Chris Kraft called upon his crew to "Find out what happened, and fix it so it never happens again."[50]

Although flight controllers joined astronauts as the face of NASA for many televised missions, viewers could only watch the action in the Mission Operations Control room, communicating with flight controllers through letters, sent after missions ended. But

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[49] Kranz, 125-126.

[50] Ibid., 126. It was not the last time that power failed in the Control Room during a mission. The Mission Control Center-Houston underwent a power failure during the Apollo 7 mission, though it did not affect mission performance, as the Real Time Computer Complex (RTCC) and other systems designated critical ("Category A") were powered by a separate standalone and "uninterruptable" power generation building. The other systems of the MCC were powered commercially but, in the event of a power outage, the MCC's backup generators were able to restore power within 20 seconds. John D. Stevenson, "MCC Power Failure During Apollo 7," 30 October 1968, Box 070-45, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

Kranz also tells a poignant story of bouquets of roses that always seemed to arrive near the launch dates of Apollo missions. The bouquets came from Dallas initially, he wrote, and "subsequently from various Canadian cities, and then the eastern United States," each arriving with a card that stated simply, "from an admirer." The sender finally revealed her first name to be "Cindy." The room's controllers came to see the flowers as a "talisman," writes Kranz, and launch flight directors "wanted to know that the flowers had arrived." The bouquet and its vase were placed on a small table near an "area where [controllers] congregated to celebrate a successful mission." Doing so, writes Kranz, ensured that the "TV cameras would pick up the roses sitting there in the background, thus showing our appreciation to the unknown well-wisher."[51] Kranz writes that, "For us, [the flowers] were a tangible link with someone who represented the hopes and good wishes of the millions who cheered us on as we pushed deeper into space."[52]

Manned Space Flight Network (MSFN)

The Mission Control Center-Houston (MCC-H) continued as a central control point for communications during Apollo missions, directing all tracking and communication sites during a mission.[53] However, the greater range of Apollo flights as spacecraft approached the moon, and the additional maneuvers and navigation planned at a greater range, required more tracking and data acquisition capability than provided in the existing Manned Space Flight Network. Ultimately the MSFN needed to allow controllers to direct the various steps required for a moon landing. Controllers, for instance, needed to direct a rendezvous between the Command/Service Module and Lunar Module on multiple occasions (and in both Earth orbits and Lunar orbits). Controllers needed to guide the docked spacecraft from a parked Earth orbit to a Lunar orbit. In the maneuver, called a Trans-Lunar Injection, or TLI, the spacecraft needed the MCC's navigational assistance to execute course corrections along the way to the moon. On the homeward passage, the plan called for astronauts to jettison the Lunar Module before beginning the burn for a Trans-Earth Injection, or TEI, which also required navigational assistance from the MCC to execute course corrections.[54]

To support these maneuvers and to remain in constant communication with its spacecraft, NASA buttressed its network of earth-bound antenna coverage. The central innovation that underlay the possibility of coverage at so great a distance from Earth was the development of hardware to employ Unified S-Band (USB) signals, microwave-band

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[51] Kranz, 278-279.
[52] Ibid., 278.
[53] Ibid., 57.
[54] National Aeronautics and Space Administration, Release No. 69-83K, "Press Kit: Apollo 11 Lunar Landing Mission," 6 July 1969, Washington, D.C.: National Aeronautics and Space Administration, 26-63, http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19690022248_1969022248.pdf; Manned Spaceflight Center, *Apollo 11 Mission Report* (Houston, Texas: Manned Spaceflight Center, National Aeronautics and Space Administration, November 1969), 4.1–4.20, http://history.nasa.gov/alsj/a11/A11_MissionReport.pdf.

signals approximately 2 to 4 GHz in frequency. The hardware allowed NASA engineers to transmit tracking data, commands, telemetry, voice, and even television signals, all on the same RF carrier (the same signal).[55] The benefits of employing the USB hardware included savings in space, weight, and savings in electrical power consumption to operate separate on-board communications systems. Equally important, however, S-Band microwave signals exhibited greater range than lower frequency radio-band signal—the higher energy microwave-band signals could reach the moon.

The change to the S-Band frequencies still meant the construction of new antennas at existing sites, and the creation of entirely new tracking stations, to guarantee communication with Apollo spacecraft throughout a mission. By 1968, the Apollo network included three main 85-foot USB antenna dishes in Goldstone, California, Canberra, Australia, and in Madrid, Spain. Each of these dishes was collocated with a Deep Space Network (DSN) antenna of the Jet Propulsion Laboratory (JPL), a NASA Center which used its antennas to communicate with the Laboratory's deep space probes. These three main sites were supplemented with sites that featured smaller 30-foot dish antennas—Antigua, Ascention Islands, Bermuda, Grand Canary Island, Canarvon, Corpus Christi, Grand Bahama Island, Guam, Guaymas, Hawaii (Kauai), and Merrit Island, Florida. The Department of Defense provided most of these stations. NASA supplemented the ground stations with mobile sites, five ships and eight aircraft carrying either 30-foot or 12-foot dish antennas.[56]

Improvements in the technologies of communication made television transmissions viable, and NASA's top officials would ensure that Americans and other people of the Earth witnessed the moon landing's Extra Vehicular Activity (EVA) on television—that is, witnessed on live television the first human to walk on the moon. Among those who sought a place for the television camera on the lunar mission was Chris Kraft, former Flight Director and now Director of Flight Operations at Manned Spacecraft Center.

The idea of taking along a television camera on Apollo missions was met with resistance among NASA's engineers, who saw it as an extravagance, given payload limitations; astronauts were ambivalent about the prospect of live television coverage during a mission. To the dismay of Chris Kraft and Maxime Faget, a prominent engineer, as well as to officials of NASA's Public Affair's Office (PAO), Kraft's own engineers in the Flight Operations Division weighed the benefits and drawbacks of carrying a television camera to the moon and recommended against it in a large meeting, while the astronauts who were preparing for the Apollo 11 mission stood silent. The immediate outcry among NASA's officials quickly turned the decision. Kraft recalled standing up at the meeting to

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[55] Kathleen M. Mogan and Frank P. Mintz, *Keeping Track: GSFC Tracking and data Acquisition Networks: 1957 to 1991* (Greenbelt, Maryland: Goddard Space Flight Center, National Aeronautics and Space Administration, 1992), 44-45. See also Sunny Tsiao, *"Read You Loud and Clear!" The Story of NASA's Spaceflight Tracking and Data Network* (Washington, D.C.: National Aeronautics and Space Administration, 2008), especially 143-187.

[56] Ibid., 48-49.

respond to the negative recommendation: "*We* can't believe what we're hearing," he said, "We've been looking forward to this flight—not just us, but the American taxpayers and in fact the whole world—since Kennedy put the challenge to us. Now you're willing to exclude the people of Earth from witnessing man's first steps on the moon?" While the decision would have been reversed in any case, Kraft took the lead in this instance and proved influential in gaining support among engineers for live television coverage of the moon landing.[57]

Robert R. Gilruth, promoted from Flight Operations Director to Director of the Manned Spacecraft Center in Houston, went to great lengths to achieve live television coverage of the moon walk. Officials sought employment of the proper antennas on Earth and at the Lunar Module to transmit and capture the video signal of this event. However, all of the available options seemed to constrain the choice of launch date for Mission Control. Ultimately, Gilruth took the advice of Christopher Kraft and recommended that arrangements be made with the Australian Government to employ their 210 foot antenna dish at Canberra, Australia. Doing so allowed NASA the greatest flexibility in launch date, and obviate the need to carry an additional erectable antenna aboard the Lunar Module.[58] Use of the large antenna was expected to cost the United States Government a large sum of money—"$11,000 for the first hour and $9,000 for each additional hour"—but doing so would also "complete the TV coverage of the lunar surface and eliminate the launch window and mission time line constraints on TV communications, thus ensuring a more reliable and flexible overall system."[59] In part, the decision to employ the antenna at Canberra was a technical one, but it required close collaboration with Mission Control, and was motivated ultimately by the goal of keeping the American public informed of NASA's work.

Simulation, Training, and Checkout System (SCATS)

A successful mission depended heavily on the integrated simulations that brought together and prepared actors involved in a spaceflight mission, from its launch to the various maneuvers, to re-entry and recovery. Once the flight rules were established, astronauts, flight controllers and ground crew would begin simulations to test the responses of astronauts and flight controllers (mainly) to emergencies and systems failures. Kranz recalled that the earliest simulations of the Mercury Project were conducted by a simulation supervisor (SimSup) and "five people who played the roles of thirty." Kranz writes that they would "supply a data stream—telemetry, command, radar tracking, voice reports—and our flight controllers would have to respond."[60] The data

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[57] Kraft, "This is Mission Control," 307-308. Italics in original.
[58] Robert R. Gilruth, "Apollo Television Coverage for Lunar Landing," 11 December 1968, Box 070-54, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake; Christopher C. Kraft, Jr., "Apollo Television Coverage for Lunar Landing," 10 December 1968, Box 070-54, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake.
[59] Gilruth, "Apollo Television Coverage for Lunar Landing," 11 December 1968.
[60] Kranz, 38.

stream would be supplied using magnetic tapes, and the simulations often broke down, failing to achieve the realism of an actual flight.[61]

The methods of simulation improved quickly, however, allowing the creation of simulations that presented flight controllers with multiple problems, occurring at the same time. The development of a "Simulation, Training, and Checkout System" (SCATS) for the Mission Control Center at Houston, a computerized system, also could mimic "remote sites used for training remote site flight control personnel."[62] Like earlier simulations, the SCATS simulation control consoles supplied a data stream that introduced faults and system failures, and to mimic the outcomes of flight controllers' responses.[63] In addition, SCATS tracked and recorded the responses from flight controllers, providing data to analyze in greater depth after the simulation.[64] Moreover, upon taking control of the Gemini Program flights (flight GT-4), the simulation system at Mission Control in Houston was soon linked to Cape Kennedy, providing data exchange that allowed "the crew to fly simulated missions at Cape Kennedy while being controlled from Houston." Doing so closely imitated the conditions of an actual Saturn rocket launch, and focused the preparation for a mission and its control on the Mission Control Center in Houston.[65]

The sophisticated and "integrated" simulators, recalled Lunney, could mimic a cascading set of failures, and interacted realistically with flight controllers' responses, preparing flight controllers very well for an emergency like that of Apollo 13.[66] There were limits to the usefulness of simulating increasingly multidimensional problems, however. According to Kraft, "The 'what if' situations could not be carried to the point of actually reducing reliability by introducing confusion or complexity into the system." A simulation which led to chaos in the Mission Operations Control Room, or to paralysis among flight controllers, may not help in preparations for a mission. "This was quite often a fine line to walk" for simulation designers, recalled Kraft.[67]

Real-Time Computer Complex (RTCC)

The competence of Controllers at the Integrated Mission Control Complex depended on the accurate information and calculations of the Real-time Computer Complex (RTCC).

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[61] Ibid., 38-39.
[62] MSC, *Mission Control Center*, 14.
[63] Christopher C. Kraft, Jr., "Simulation Requirements, Saturn Launch Vehicles," 18 September 1963, Box 063-64, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake.
[64] Christopher C. Kraft, Jr., "Telemetry Recording Requirements for the Simulation Checkout and Training System," 23 September 1963, Box 063-64, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake.
[65] National Aeronautics and Space Administration, News Release No. 65-119, "Mission Control Center At Houston to Handle GT-4, Subsequent Manned Flights," 28 January 1963, Box 065-33, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake.
[66] Lunney, interview, January 28, 1999, 6.
[67] Kraft, "This is Mission Control," 137.

NASA had grand ambitions for the Mission Control's RTCC. In the Request for Proposal (RFP) for the computing complex, the function of the RTCC was defined as

> monitoring of the [spacecraft] trajectory, through the use of network tracking data, and processing of data from the spacecraft systems to precisely determine and display the current situation to the flight controllers.[68]

In effect, the designers envisioned the RTCC as a means to help flight controllers manage the spaceflight from the ground, to provide "information required for completing the mission."[69] Upon completion, the RTCC did not deviate from this goal.

IBM and Philco-Ford were the main vendors awarded the contract to design and implement the RTCC complex. IBM was awarded the RTCC contract to design the computing center and its application programming. Five IBM 7094 mainframe computers provided the computing power initially. Of these, two were used to support live missions, with one additional computer on standby. Two computers remained available to simultaneously control a second spacecraft or simulation. In addition to the mainframes, the RTCC also encompassed additional computers, magnetic tape storage units, terminals and display equipment to operate the computers and other associated support equipment.[70] Philco-Ford was awarded a contract to integrate the systems that were based upon the RTCC computers for display/control, simulations, tracking, computations associated with spacecraft maneuvers, lunar descent/ascent, and reentry, and analysis of telemetry.[71]

Located on the first floor of the Mission Operations Wing of Building 30, the RTCC provided the computational power to support each mission's flight dynamics analysis, processing of telemetry, to generate the computerized displays that flight controllers requested to answer their queries about the status of the spacecraft systems, and to learn about mission status. The main function of the RTCC, however, was to process incoming tracking and telemetry data. This vital data was used to evaluate the precise position and velocity of the spacecraft, and to allow flight controllers the ability to determine whether it was safe to continue at each step of a mission. At the end of a mission, the tracking data was used to predict where the spacecraft was expected to land on Earth, which aided recovery operations.[72]

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[68] Dave W. Lang, "Request for Proposal No. MSC-62-40 as Amended," 17 August 1962, File Folder, "Report of the Source Evaluation Board for the Integrated Mission Control Center, December 1962-January 1963," Box 7B-101, Center Series, Mission Control Center and Real Time Computer Complex, Johnson Space Center History Collection, University of Houston-Clear Lake.
[69] Ibid.
[70] MSC, "Real-Time Computer Complex," *Mission Control Center*, 9.
[71] News Release No. 63-14, "Philco to Develop Manned Flight Mission Control Center at Houston," 28 January 1963; James C. Stokes, "Managing the Development of Large Software Systems: Apollo Real-Time Control Center" August 1970, Manned Spacecraft Center, Houston, Texas, 2.
[72] "Real-Time Computer Complex, *Mission Control Center*, 9.

Guidance Systems, the RTCC, Mission Control, and Astronauts

Navigation of the Apollo spacecraft still shared some things in common with the navigation of a ship at sea before Global Positioning Systems (GPS). The spacecraft's navigator used a kind of sextant to measure angles between the earth, moon, and stars, in order to calculate the spacecraft's position. The sightings allowed the command module's on-board computer to calculate the spacecraft's position and maintain knowledge of the vessel's flight path—although this information would be used only as a backup to the existing ground-based tracking systems, and to the computing capability of the Real Time Computer Complex.[73] Captain Cook also relied on a sextant to learn of his ship's latitude when exploring the Pacific Ocean aboard the *Resolution* in the late eighteenth century. To determine his longitude, this early modern explorer also relied on the most advanced chronometer (clock) available, accurate to one tenth of a second per day and synched to what we know today as Greenwich Mean Time (GMT), the time in London.[74] Cook's isolation, however, demanded self-sufficiency in all technologies and expertise, especially navigation. Consequently, Cook enjoyed a corresponding autonomy, as did all ship commanders of the day. But neither Apollo astronauts, nor their spacecraft, could acquire such autonomy in guiding and operating their mission.

The approach to guiding the spacecraft in the Apollo program needed to reconcile conflicting visions among three groups that wanted to guide the spacecraft: flight controllers at Mission Control, the guidance engineers associated with the RTCC, and astronauts aboard the spacecraft. Guidance engineers sought a completely automatic system, a goal they justified on the possibility that astronauts themselves could become disabled. Astronauts, however, sought to navigate the spacecraft themselves—they did not trust the reliability of a computerized guidance system, nor did they like the idea of flying as passengers.[75] In opposition to astronauts, the Flight Directors of Mission Control sought used their ground-based tracking and computing systems to exercise control over navigation.[76]

In the end, hardware limitations may have shaped the approach to spacecraft guidance for the Apollo program. A completely automatic guidance system proved too complex. Instead, it was decided that astronauts would take an active role in spacecraft maneuvers and navigation measurements. The final version of the onboard guidance systems for the Apollo program (tested on Apollo 8, and launched on 21 December 1968) proved capable of navigating the vessel and controlling its flight—albeit with hundreds of manual earth and lunar horizon sightings using the spacecraft's sextant aboard the vessel. The on-board guidance system proved so precise that four of the expected seven mid-course corrections

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[73] Eldon C. Hall, *Journey to the Moon: The History of the Apollo Guidance Computer* (Reston, Virginia; American Institute of Aeronautics and Astronautics, 1996), 61.
[74] Hough, 192-193.
[75] David A. Mindell, *Digital Apollo: Human and Machine in Spaceflight* (Cambridge, Massachusetts: MIT Press, 2008)
[76] Hall, 59-60.

were not made in traveling to and from lunar orbit and earth orbit.[77] However, the on-board system would be relegated to a backup role.

The onboard computer's limited memory and questionable reliability did not allow engineers to justify doing much more than this, and so the role of Mission Control became more central to the vessel's navigation and to its maneuvers. Just as the astronauts were held in subordinate relationship to flight controllers during a mission, the onboard navigation systems had become a back-up system, placed in a subordinate relationship to the navigation functions of the RTCC at Mission Control. Navigation relied on data generated from the ground-based Manned Space Flight Network's tracking of the spacecraft, in addition to its telemetry.[78] From this information, the RTCC and its flight dynamics officers and support staff provided specific navigational instructions and guided astronauts' maneuvers.[79] The manner in which navigation was conducted, and the central role of computing and flight controllers, increased the importance of Mission Control.

Flight Controllers

At the heart of the Mission Control Center-Houston were its controllers in the Mission Operations Control Room (MOCR), a tiered room that resembled an auditorium, with an enormous screen at the room's bottom. Controllers sat at consoles which divided them into designated areas of expertise and responsibility for the mission's phases, or for some aspect of the spacecraft's operation. The controllers were officers who, like the officers of Captain Cook's sail-powered HMS *Endeavour* who explored the Pacific in the eighteenth century, supervised additional crew members in the execution of their duties. The complexity of the Apollo Command Module and Lunar Module called for an extensive division of labor to control a mission—one that far exceeded the division of labor aboard a sail-powered ship of the eighteenth century—but the functions remained similar: navigation, vessel operation and maintenance, and supporting roles, such as that of the Surgeon. Among the differences between the organization and control of a sailing expedition from the control of an Apollo flight, the most salient may have been that most crew members who participated in an Apollo flight were not aboard the spacecraft itself.

Depending on the program (Gemini, Apollo, ASTP, Skylab, STS) and specific flight, the consoles and functions of personnel in the MOCR revealed important differences, but were approximately as follows for the Apollo Program's lunar flights.[80] At the row closest to the big screen, the first row, sat the Flight Dynamics Officer (FIDO in communications among controllers and spacecraft crew, see Figure 3) and the Assistant

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[77] Mindell, 177-179. Mindell writes that a number of engineers who worked on this system left the MIT's Instruments Laboratory immediately after the flight to form their own company to write navigation software.
[78] Ibid., 180.
[79] Hall, 60.
[80] See Figure 3, although this diagram was created ca. 1964 and the numbers do not correspond to the consoles of an Apollo Program lunar flight.

Flight Dynamics Officer, the Retrofire Officer (RETRO), the Booster Systems Engineer (BOOSTER), and the Guidance Officer (GUIDO). FIDO and his assistant, and RETRO, GUIDO, were responsible for the vehicle trajectory (navigation), attitude, and maneuvers. The Booster Systems Engineer was an engineer responsible for performance of the rocket booster stage "during prelaunch and ascent phases of missions."[81]

A step up in elevation, at the second row, were the consoles for the Electrical, Environmental, and Consumables Manager (EECOM), the Flight Surgeon (SURGEON), who was charged with monitoring the life signs and health of astronauts, and the Spacecraft Communicator (CAPCOM), who was an astronaut charged with mediating communications between the controllers in the Mission Operations Control Room and astronauts in the spacecraft. The other two positions in the row were tailored to particular flights of the Apollo program. For Lunar flights, two controllers were responsible for the Lunar Module: the Telemetry, Electrical, EVA Mobility Unit Officer (TELMU), and Control Officer (CONTROL), who were the equivalents of an EECOM and GUIDO, respectively, for the Lunar Module.

Stepping up to the third and fourth rows, one would find the uppermost managers of Manned Spaceflight Center and its Flight Operations Department. On the third row, one would find the Flight Director (FD, called "Flight," position 4 in Figure 3) and the Assistant Flight Director (AFD, position 5), the Public Affairs Officer (PAO). The third floor also included the Organization and Procedures Officer (O&P), who ensured that established mission rules were applied during a flight. And, finally, stepping up to the fourth row, at the top of the room and just in front of the viewing gallery, sat NASA's managers: the Director of the Manned Spacecraft Center (later the Johnson Space Center), the Director of the Flight Operations Division (Chris Kraft during the Apollo Program), the Director of Flight Crew Operations ("Deke" Slayton during the Apollo program), and a representative of the Department of Defense.

In all, the flight controllers' responsibilities may be divided into three overlapping functional areas: command, navigation and spacecraft maneuvers, and the operation and maintenance of spacecraft systems (which included the surgeons, who were responsible for monitoring the vital signs of astronauts, an important human element of all spaceflight systems). Together flight controllers accounted for—or represented—the expertise needed to operate and maintain Apollo spacecraft.

A comparison between the ground and flight crews of the Apollo program and the crew of the HMS *Endeavour* of Captain Cook reveals striking similarities. The Flight Director of missions, for instance, performed a role most similar to that of the *Endeavour*'s commander, he managed the expertise of various flight controllers and astronauts. The Flight Director shared some power with the commander aboard an Apollo spacecraft, who functioned as commander of astronauts aboard the spacecraft. In a similar manner to that of the Apollo program's organization, the British military vessel of the eighteenth

[81] JSC, *NASA Facts: Mission Control Center*, ca. 1985, 2.

century distinguished the vessel's commander from the crew member in charge of the vessel's technical operation, the ship's "master," or "shipmaster." The "master" of the HMS *Endeavour* played a distinct role from that of the vessel's commander, Captain Cook. As a military vessel, the *Endeavour* also carried a surgeon. And the *Endeavour* carried scientific researchers (astronomers to observe a transit of the planet Venus, and a botanist), as well as a natural history painter to document voyage findings.[82]

Collectively, flight controllers of the Mission Operations Control Center—including the Flight Director—constituted a modern and distributed variation on an eighteenth century vessel shipmaster. Like an eighteenth century shipmaster, flight controllers knew more about the operation of the spacecraft's specific systems than the astronauts aboard the spacecraft, and knew more, collectively, than the Flight Director at Mission Control. The Flight Director held a great deal of expertise about the spacecraft, but he was a manager foremost, called upon to exercise judgment at critical moments. The operation and social relationships aboard the eighteenth century merchant or naval vessel were beholden to custom and tradition forged over hundreds of years. Chris Kraft and his flight controllers, by contrast, were quite influential in creating the customs and practices of Mission Control, which explained some of the heated discussions among flight controllers and astronauts, for the roles of flight controllers and astronauts were more clearly defined or modified with each mission.

"Augmentations" to the Mission Control Center

The Mercury Control Room and its philosophy of ground-based mission control proved successful. The need to plan, monitor, and direct the much more complicated Gemini and Apollo missions resulted in the creation of an "Integrated Mission Control Center," Mission Control Center (MCC-H), at the Manned Spaceflight Center in Houston, Texas. The Mission Control Center remained fairly stable in its configuration of flight controllers and hardware, but efforts were undertaken to "augment" the center's ability to handle still more complicated missions, and to undertake the planning, training and simulation, and operation of multiple missions, simultaneously. As Apollo program engineers gained planning and operations experience in the succession of missions/steps toward a moon landing, demands for still greater capacity at MCC-H came from a variety of actors and motivations.

A proposal for hardware improvements at the MCC looked beyond the moon landing, to the proposed programs of the Apollo Applications Program (AAP), which sought to prepare for the expected efforts to create a manned space station and to more thoroughly explore the moon. In his memorandum to Robert Gilruth on 11 November 1965, NASA's Assistant Administrator for Manned Space Flight, George Meuller, acknowledged that the "MCC-H was designed with considerable capability and versatility," and praised Gilruth, writing that, "with only a few months experience, you have devised ways of employing it for support of a Gemini and an Apollo mission." Mueller went on to suggest

[82] Hough, 48-55.

that "other changes internal to the present building could increase our capacity to the point of adequate support for AAP."[83]

The impending budget cuts—which were visible to NASA administrators long before NASA reached the moon—also motivated an effort to "augment" the capability of the Mission Control Center to achieve goals beyond those of the Apollo Program. NASA "has no assurance that it will receive sufficient appropriations, in Fiscal Year 1967 and 1968," wrote Mueller, "to allow us to augment the MCC-H through new construction." He suggested "the possible conversion of the display system to a directly computer-driven digital system," such as systems currently employed at the Kennedy Space Center and at the Air Force.[84]

Chris Kraft also advocated augmentation of the Mission Control Center's Simulation Capabilities. In a proposal to NASA Headquarters in Washington, D.C., Kraft recommended changes at MCC to improve the Apollo program's capacity to simulate its training, especially for the AS-204 mission (Apollo 1), and for the AS-205 mission (later designated Apollo 7). Kraft warned on 13 January 1966 that, "AS-204 training would contain no computer simulation of the Command/Service Module (CSM)," and that "limited Apollo remote site training will be achieved prior to AS-205 simulations."[85] To gain the operational requirements for simulation, Kraft called for more computing power, specifically, "five IBM 360 computers."[86]

Outwardly, computing hardware changes and configuration changes grouped personnel and equipment functionally, into "appropriate physical proximities."[87] Ray Loree, was a Branch Chief of the System Development Division of the Flight Operations Directorate during the mid-1980s, traced these changes meticulously in an informal history titled, "MCC Developmental History."[88] Loree explained the updates in MCC's computing hardware as "partially due to the increased complexity of the trajectory functions of a

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[83] George E. Mueller, "Proposed Augmentation of MCC-H," 11 November 1965, Box 066-33, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake, 1. Christopher C. Kraft, Jr., "MCC-H for Apollo Applications Program (AAP)," 13 December 1965, Box 060-128, Kraft Reading Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

[84] Mueller, "Proposed Augmentation of MCC-H," 11 November 1965, 2.

[85] Christopher C. Kraft, "Recommended Change to the Mission Control Center-Houston (MCC-H) Apollo Simulation Computer Acquisition Plan," Box 066-44, 13 January 1966, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake, 1-2.

[86] Kraft, "Recommended Change to the Mission Control Center-Houston (MCC-H) Apollo Simulation Computer Acquisition Plan," 13 January 1966.

[87] Christopher C. Kraft, Jr., "Report on MCC-H/AAP Meeting, September 29-30, 1966," 25 October 1966, Box 070-129, Kraft Reading Files, Johnson Space Center History Collection, University of Houston-Clear Lake. Quote taken from the minutes included in the Kraft memorandum, Dennis E. Fielder, "Minutes: MCC-H/AAP Meeting," September 29-30, 1966, Advanced Planning Support Office, Flight Operations Directorate, Manned Spacecraft Center, 14.

[88] Ray Loree, "MCC Development History," August 1990, See its Appendix B, p. B-2, for a reference to one of Loree's positions at NASA's Johnson Space Center.

lunar mission," but also to "a change in the type of data being processed." He added that "[t]here was an increased emphasis on mission planning and decision-making support."[89] The changes made to the Mission Control Center between 1966 and 1969 were "to support higher density flight scheduling, longer duration missions, multiple spacecraft/launch vehicle missions, and increased experiments activity," as one memorandum was titled.[90] Given the budget constraints confronting NASA and the MCC after 1966, however, NASA leaders ultimately agreed to utilize existing facilities MCC to its fullest, to "provide maximum use of the facilities."[91] While the changes did not require much new construction, the augmentations nonetheless reflected the dominating role of Mission Control during the Apollo program, a dominance that would be emphasized in the aftermath of the mission never flown, AS-204.

AS-204 (Apollo 1) and its Aftermath

The fire that occurred during tests for AS-204, a tragedy which took the lives of astronauts Virgil "Gus" Grissom, Edward White, and Roger Chafee on 17 January 1967, led NASA to reaffirm and deepen its commitment to the integration of flight-related preparations and operations at Mission Control. The accident—and the resulting congressional hearings—led to a highly publicized crisis within NASA, and Chris Kraft's operations-oriented emphasis acquired a dominant influence over the conduct of the Apollo program for the remainder of the program's life.[92] AS-204 was renamed "Apollo 1" in honor of the fallen astronauts.

The accident occurred on the launch pad, where the astronauts were participating in a launch simulation. The three astronauts sat fully dressed in their spacesuits, in the spacecraft's capsule, atop their assembled rocket. All astronauts were fully instrumented, wearing their biomedical sensors, fully interfaced with the craft's environmental systems, and linked to one another and to Mission Control at Canaveral. The hatch was bolted shut and, as would occur in an actual launch, their spacesuits and the cabin were purged of all gases except for oxygen. In the test that caused the fire, all electrical, environmental, and ground checkout cables were disconnected to confirm that the spacecraft and launch vehicle could operate on internal power alone, once the umbilical lines were released.[93]

An explosion caused a fiercely burning fire in the oxygen-rich environment of the spacecraft's cabin. Investigators could not determine the source of ignition. Autopsies revealed second and third degree burns that were not severe enough to cause death; the

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[89] Ibid., 14.
[90] This unread memorandum title was referenced in Henry E. Clements, "MCC-H Augmentation II," 12 October 1966, Box 070-129, Kraft Reading Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

[91] Ibid.
[92] Mindell, *Digital Apollo*, 173.
[93] Brooks, Grimwood, and Swenson, 213.

astronauts died of asphyxiation and by the inhalation of toxic gases.[94] The ensuing investigation and Congressional hearings attributed the tragedy to a number of design and construction flaws, and noted the ignorance and carelessness in the design and construction of the vehicle by the prime contractor North American Aviation, but determined that the most important and lacking element was "oversight."[95]

To ensure a more rigorous program control, George M. Low, formerly Chief of Manned Space Flight at NASA's Headquarters in Washington D.C., but recently appointed manager of the Apollo Spacecraft Program, had created a configuration control board in June 1967. The board prominently featured Chris Kraft, Flight Operations Director of Mission Control, and Donald "Deke" Slayton, Head of Astronaut Selection, as well as Maxime Faget, Kenneth Kleinknecht, William Lee, Thomas Markley, and George Abbey. The board included additional members of medical and scientific expertise, when needed, and met each Friday for several hours. While Low himself made the final decisions, the board's members gained the authority to carry out the board's decisions.[96]

NASA recovered from the delays associated from the investigation into the Apollo 1 tragedy and renewed its commitment to excellence in all aspects of the design and construction of spacecraft and rockets, and now exhibited an "extreme" level of attention to crew safety and to the details of mission operations. With little time remaining to the end of the decade, George E. Mueller, NASA's Director of the Office of Manned Space Flight, successfully championed an "all-up" testing approach when flights resumed in 1967 with Apollo 4—that is, flights tested all of the Saturn V rocket's stages in something approaching its final configuration, rather than test each stage incrementally, the preferred approach among Wernher von Braun's experienced team at the Marshall Space Flight Center.[97] The successful tests seemed to shift attention to spaceflight operations, which was the responsibility of Mission Control.

Indeed, with so little time remaining in the decade, and with the promise of the first "all-up" Saturn V tests, NASA's Headquarters in Washington proposed that only four manned missions precede the first attempt at a moon landing.[98] Kraft, however, warned George Low that a number of preliminary flights would still be required beyond "the first flight that leaves the earth's gravitational field." Kraft cited numerous important and untested operational problems to be addressed, among them, "navigation and control during translunar flight [flights between the Earth's orbit and the Moon's orbit], communications and tracking at lunar distances, lighting conditions and other flight experiences affecting astronaut activities in the vicinity of the moon, lunar orbit an rendezvous techniques,"

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[94] Ibid., 213-218.
[95] Ibid., 221.
[96] Ibid., 230.
[97] Roger E. Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, D.C.: National Aeronautics and Space Administration, 1980), 347-350.
[98] In any case, the engineers at Wernher von Braun's Marshall Space Flight Center would still need to solve a "pogo" vibration problem associated with the rocket's F-1 launch stage engine, which became painfully apparent during the Apollo 6 mission.

among others.[99] Each of the required steps to achieve a successful moon launch would require dedicated flights to ensure the safety of astronauts and the success of the mission. The close attention to operations dictated that astronauts and controllers carefully master each step toward the moon, which focused all preparations on the Mission Control Center.

Apollo Missions 4, 5, 6, 7, 8, 9, and 10

The unmanned missions of Apollo 4, 5, and 6, and the manned Apollo missions that followed, demonstrated the primacy of Mission Control to a successful mission, but also revealed how the guidance and navigation technologies incorporated into the command capsule allowed the possibility of greater autonomy for astronauts. Apollo 7 was launched using the smaller Saturn IB rocket, and astronauts' first goal was to test the performance of the spacecraft's Guidance-Navigation-Control System (GNCS). While the mission was a technical success, friction developed between the spacecraft's commander, Walter "Wally" M. Schirra, and Mission Control, over Schirra's initial refusal to unpack and begin operation of a television camera aboard the spacecraft. Later, Schirra and his flight crew also refused to wear their space helmets during reentry. All three astronauts were suffering from head colds and would not have been able to blow their noses, but Flight Operations Director Kraft considered the behavior insubordinate and ensured that none of them flew another Apollo mission.[100] The spacecraft's commander was understood to have final say aboard his vessel, but Kraft made it clear that Mission Control was ultimately in charge.

The Apollo program would take more significant steps toward a moon landing in the missions that followed. The technical success of Apollo 7 allowed the daring plan of a translunar injection and lunar orbit for Apollo 8, a mission which further tested and demonstrated the capability of the Apollo spacecraft's onboard guidance and navigation system, while gathering better navigation data for succeeding missions.[101] As mentioned above, the guidance and navigation system proved its accuracy and allowed the possibility of autonomous navigation for the flight crew, but the navigation would be used only in case of emergency, providing a backup to the data and directions provided by flight controllers and their Real Time Computer Complex at Houston's Mission Control Center. Apollo 9 did not leave the Earth's orbit, but the mission did test the engines of the Lunar Module (LM) and docking maneuvers, which led to the next mission. Apollo 10 achieved a lunar orbit of the Command Module and Lunar Module, and practiced the Lunar Module's toward the lunar surface, and re-docking with the Command Module, before traveling homeward to Earth. Apollo 10 could have landed, but NASA's managers wanted to see how the LM's guidance system worked in the

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[99] Christopher C. Kraft, Jr., to Magr., ASPO, "Requested comments on Apollo Flight Program Definition, 1 June 1967, cited in Brooks, Grimwood, and Swenson, 231.
[100] Chris Kraft, *Flight: My Life in Mission Control* (New York: Dutton, 2001), 290-291.
[101] Kranz, 240-245. See also Neil B. Hutchinson, interview by Kevin M. Rusnak, 5 June 2000, Oral History Transcript, Johnson Space Center Oral History Project, http://www.jsc.nasa.gov/history/oral_histories/HutchinsonNB/hutchinsonnb.pdf, 23-24.

moon's uneven gravity field, and also to investigate and solve the LM engine's "chugging" problem—a cyclical variation in the engine's thrust.[102]

Mission Control Center at its Height: Apollo 11

Apollo 11, the first moon landing mission, revealed the apex of the MCC's increasingly detailed supervision of manned space flight missions. The people and hardware of the Manned Space Flight Network and the Real Time Computer Complex made it possible for flight controllers at the Mission Control Center to monitor and direct the operation and maneuvers of Apollo spacecraft. However, as the Lunar Module approached the moon's surface, control over navigation and maneuvers were ceded to the on-board computing capabilities of the odd-looking Lunar Module, and to its pilot.

All missions before Apollo 11 had been designed to learn and master the successive steps to accomplish Kennedy's goal of "landing a man on the moon and returning him safely to the Earth." Chris Kraft's flight operations team now drew on the experience of a vast body of missions to prepare the flight rules and mission techniques needed to actually take that final step, to land a man on the moon. Yet this mission differed from the others in that it called upon at least one astronaut to take a much greater role controlling the Lunar Module in its descent to the surface of the moon—in this mission the astronauts would be much more than "systems managers" who closely monitored the complex, and greatly automated, Apollo spacecraft en route to the moon. For the final one or two minutes of the trip to the moon, Astronaut Neil Armstrong would depend on both instruments and hand-eye coordination to *fly* the craft—which resembled a spider and flew most similarly to a helicopter—and land it on the surface of the moon.[103]

To prepare for this task, Armstrong spent many hours flying the Lunar Landing Training Vehicle (LLTV), a free-flying and non-aerodynamic craft which had neither wings, nor fuselage, nor rudder. The LLTV was an ungainly cage that looked like a four-legged pedestal in outline, with an astronaut's compartment and a symmetrically positioned counterweight appended to its top, and a gimbal-mounted jet engine held captive at its center (see Figure 7). Other variously pointed jets that attached to the feet and body helped steer the vehicle and adjust its attitude, and all with the assistance of an on-board computer which simulated the LM's movements and the moon's gravitational field (1/6th that of the Earth's gravity). Despite nearly perishing while using the contraption (Amstrong needed to eject to save himself) Armstrong stated that his training in the LLTV provided "the confidence in your own knowledge that you can fly the job in."[104]

As Armstrong guided the Lunar Module, named *Eagle*, to the moon's "Sea of Tranquility" during Apollo 11, he saw that the surface was rockier than expected, and so maneuvered the vessel to find a smooth landing site. Flight controllers at Mission Control began a 60 second countdown to mark the time before the *Eagle*'s fuel level fell below

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[102] Brooks, Grimwood, and Swenson, 300-301.
[103] Mindell, 1-41, 181-261.
[104] Minutes of Meeting, Flight Readiness Review Board, Lunar Landing Training Vehicle, Houston, Texas, January 12, 1970, UHCL Chronological Files, cited in Mindell, 215.

the amount needed to ascend and rendezvous with the Command-Service Module. Mission Control announced that 30 seconds remained, and waited. Finally, Armstrong announced that "Houston, Tranquility Base here. The *Eagle* has landed." Mission Control responded, "Tranquility, we copy you on the ground. You've got a bunch of guys about to turn blue. We're breathing again."[105] Once the *Eagle* landed, Flight Rules called for immediate preparations for departure, in case the LM was damaged during the landing, or in case the craft suddenly began to lose stability on the moon's surface, or because of any other condition that might threaten the LM's ascent and docking with the Command-Service Module, called *Columbia*.[106]

With the *Eagle* safely resting on the moon's surface and flight preparations complete, the crew of Apollo 11's Lunar Module waited three hours for confirmation from Mission Control—which was closely monitoring telemetry for any sign of trouble—for clearance to exit the spacecraft. All well, Armstrong requested clearance for egress 45 minutes earlier than planned, and Mission Control gave consent. Astronaut Neil Armstrong took his famous "small step for man and giant step for mankind" onto the surface of the moon. "Buzz" Aldrin followed.

After a flag ceremony and a long-distance telephone call from President Nixon, the astronauts began the scientific experiments that were planned for the mission. Included among the experiments were a Passive Seismic Experiments Package (PSEP) for measuring meteoroid impacts and moonquakes, in order to learn of the interior structure of the moon, and a Laser Ranging Retroreflector (LRRR), which would allow observatories on Earth to bounce a laser off the installed target and acquire precise measurements of earth-moon distances.[107] With time short, Mission Control reminded Aldrin that scientists were expecting him to collect two core-tube specimens of the moon's surface.[108] Before even astronauts could celebrate the engineering achievement of their moon landing, the emphasis of Apollo had begun to shift toward scientific objectives.

A Reaffirmation of the Mission Control Approach: Apollo 13

Apollo 11 represented the high point of the Mission Control Center's approach to integrating the planning, simulation, and supervision of manned spaceflight missions, and the high point of its role in organizing American spaceflight. Apollo 13, launched on 11 April 1970, reaffirmed that approach in the eyes of its participants. It also produced what may have been NASA's most dramatic mission.[109]

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[105] Eric M. Jones, "The First Lunar Landing," *Apollo 11: Lunar Surface Journal*, http://www.hq.nasa.gov/alsj/a11/a11.landing.html.
[106] Ibid.
[107] Appendix D: "*Apollo* 11 Experiments," in Brooks, Grimwood, and Swenson, 394-395.
[108] Brooks, Grimwood, and Swenson, 348.
[109] Harry Hurt III, Interviews by Al Reinert, *For All Mankind* (New York: Atlantic Monthly Press, 1988)

In the final days leading up to the mission, mission organizers experienced an unexpected complication. It was announced on 6 April 1970 that both the primary and secondary flight crews were exposed to the measles—and all crew members were found immune to illness except for Thomas Kenneth "Ken" Mattingly of the primary crew, and Charles Duke of the secondary crew, who had actually contracted rubella (German Measles). NASA learned of the situation less than a week before the scheduled launch date, and so were faced with the difficult decision of whether to delay the mission (at great cost) or to replace the command module pilot with the pilot of the secondary crew, John L. "Jack" Swigert. Replacing the entire flight crew was not an option.

NASA favored the last minute replacement of Mattingly with Swigert. After analyzing the performance and communications of the newly assembled crew in simulations on 9 April 1970, officials of the Flight Operations Crew Branch at the Manned Spaceflight Center were convinced that Swigert would work well as a replacement.[110] The Flight Crew Operations Branch of the Flight Operations Directorate decided to go with the flight crew of commander James A. Lovell, command module pilot Swigert, and lunar module pilot Fred W. Haise. The launch went off as scheduled, on the 11th of April, without incident, as did the first two days of the mission. The Command-Service Module, *Odyssey*—while docked to the Lunar Module, *Aquarius*—coasted along its translunar injection trajectory, en route to the moon.

The mission turned quickly for the worse, however, when a warning signal indicated low pressure in the command service module's hydrogen tank No. 1. Mission Control asked the flight crew to activate the tank's cryogenic fans and heaters, and ninety seconds after turning on the fans and heaters the crew heard a large "bang" and observed a low voltage condition on d.c. main bus 'B.' Swigert then called down to Mission Control, saying, "OK, Houston. Hey, we've got a problem here." To confuse matters further, the quantity gauge for oxygen tank 2 fluctuated, returning to an off-scale high reading, and the vessel began to repeatedly fire its attitude control thrusters. These thrusters, it was believed in the post-mission investigation, fired automatically to compensate for the ruptured and venting oxygen tank. Mission Control, however, focused on another threatening development: the electrical output from two of the spacecraft's fuel cells had dropped to zero. The spacecraft's fuel cells combined liquid hydrogen and oxygen to make electricity and water, which meant that the Command-Service Module could not produce electricity or water.[111]

The incident led flight controller Gene Kranz to abort the mission. With the fuel cells out, and to conserve what little battery power remained, Kranz ordered the Command-Service Module (CSM) powered down and gave the order to "seal off" the CSM's three oxygen tanks for use during reentry. The astronauts debarked *Odyssey* and entered the Lunar Module (LM), using it as a "lifeboat." According to Kraft, the strategy had been considered in simulations, but no one had imagined a situation in which "an explosion

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[110] Charles D. Benson and William Barnaby Faherty, *Moonport: A History of Apollo Launch Facilities and Operations* (Washington, D.C.: National Aeronautics and Space Administration, 1978), 488-489.
[111] Benson and Faherty, 490.

wrecked the oxygen tanks, the fuel cells were gone, sensors and instruments were destroyed, and nobody could tell if the SPS engine [which was used to propel the CSM into and out of lunar orbit] was still good or not."[112] All of Mission Control studied the spacecraft's telemetry to diagnose the situation and to find a way to bring home the astronauts.

Millions of people watched the television to learn of the unfolding crisis. Battery power remaining aboard the CSM and Lunar Module was too low to allow a direct television feed, so television networks used models to convey the developments to their audience. Meanwhile, Controllers at Mission Control, NASA's engineers, and NASA's contractors, all worked to devise ways to recharge the CSM batteries for reentry, to transfer water to the Lunar Module for both drinking water and to supply its cooling system, and to filter carbon dioxide from the Lunar Module's cabin—the Lunar Module was designed to sustain two astronauts for two days, not three astronauts for four days.

With the guidance of flight controllers and their engineering colleagues at NASA, astronauts executed "workarounds" to bring themselves home. Engineers on the ground devised a way to recharge the CSM's re-entry batteries using the LM's electrical system. Engineers at Grumman and North American Aviation at Kennedy Space Center arrived at a way to transfer water to the Lunar Module, drawing on the supply of the Command-Service Module's portable life support system. Filtering carbon dioxide from the air of the Lunar Module proved more difficult. Both CSM and the LM used canisters of lithium hydroxide (LiOH) to remove the carbon dioxide from the air of compartments, but the Lunar Module did not include enough for its now larger crew, and the Command-Service Module's canisters were not compatible with those of the Lunar Module. Engineers on the ground "jury-rigged" a space-suit hose as an adaptor between the CSM canisters and the LM's canister sockets, testing the solution on the ground before supervising assembly of the adaptor in the spacecraft.[113]

Without the highly disciplined organization of the Mission Control Center, and especially its ability to marshal expertise and knowledge through earlier missions and countless simulations, Apollo 13 would not be remembered today as a "successful failure."[114] Astronauts remained essential, of course, they provided valuable information about the functioning of spacecraft, they could operate the craft at those moments in which the spacecraft was out of the reach of Mission Control, and astronauts could implement strategies and fixes not possible with automated systems. But astronauts could not alone sufficiently master their extraordinarily complicated spacecraft to overcome the problems encountered in this mission.

Astronauts were neither capable of diagnosing problems aboard their spacecraft nor of devising "jury-rigged" solutions to solve identified problems. By contrast with the

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[112] Kraft, *Flight*, 336.
[113] Benson and Faherty, *Moonport*, 491.
[114] NASA, "The Apollo Missions: Forty Years Later," http://www.nasa.gov/mission_pages/apollo/index.html.

explorers and crew of the Earth's oceans in the days of Captain Cook, English naval and merchant marine officers of Captain Cook's era took great pride in jury-rigging their disabled ocean-going vessels and navigating them safely to port. For NASA's spaceflight programs, technologies of communication, tracking, and telemetry were used to displace and distribute an analogous expertise among flight controllers, tracking stations, and the computing complexes of the Mission Control Center, a hub which also drew upon the expertise of engineers at NASA and among its contractors.

While Apollo 13 reaffirmed the Mission Control approach that centralized its control over mission planning, training, and operations, a shift in emphasis had become remarkably clear: away from the engineering goals of designing and operating spacecraft to land an astronaut on the moon, and toward scientific goals among dispersed scientific communities. By the time of Apollo 13, Chris Kraft recalled, the word "*post-Apollo* entered our vocabulary," but that NASA did not "get much guidance" about what to do next.[115] NASA's budget, already cut each year of the Johnson administration, was cut further during the Nixon administration, and Apollo missions 18, 19, and 20 were cancelled in August 1967. For the missions that remained, wrote Kraft,

> Scientists had all but free rein to design experiments to be set up by astronauts and left on the moon. We gave them their limits in size and weight, then let the scientists and their communities argue it out. The final word was NASA's, but we knew that we'd bend every way we could to accommodate them…That boundless future in space suddenly had very real bounds, after all. And we had a very real responsibility to get every bit of data and every piece of new knowledge that we could before our time ran out.[116]

Skylab

In anticipation of the moon landing—and the possibility that many of the 400,000 employees associated with the Apollo program may lose their jobs soon afterward—NASA had already begun planning for a post-Apollo period as early as 1965. As funding for NASA began to decline during the Johnson Administration, NASA looked to find ways to employ Apollo program hardware for scientific uses. In 1965 it established the Apollo Applications Program (AAP) to study the possibility of extended stays on the moon, lunar mapping, and the establishment of a lunar base, as well as the creation of a

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[115] Kraft, *Flight*, 331.

[116] Ibid., 332. Kraft already recognized by 1965 that, for the post-Apollo period, the Marshall Space Flight Center "will probably have a major payload responsibility," and that the scientific community would have a greater say in the flight plans mission after the Apollo program: "'Experimenters' will have the major input to the flight plan." Christopher C. Kraft, Jr., "Operations Philosophy for Apollo Applications Program (AAP)," 13 December 1965, Box 060-128, Kraft Reading Files, Johnson Space Center History Collection, University of Houston-Clear Lake. This recognition is echoed in 1966, when he wrote that "future programs this type of support will continue to grow, particularly in the experiments and spacecraft systems areas," Christopher C. Kraft, Jr., "Control of Real-Time Mission Support Activities," 11 March 1966, Box 010-129, Kraft Reading Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

space station.[117] NASA was determined to launch a space station, using the now available Saturn V boosters designated for the cancelled Apollo missions 18, 19, and 20.

Building 30's second floor Mission Operations Control Room conducted each of the four flights that established the space station laboratory. The initial unmanned mission, which launched on 14 May 1973, relied on a Saturn V booster stage to launch the station itself, a flight which damaged the Laboratory's "micrometeoroid shield" and sun shade, and one of its main solar panels. The second flight, launched on 25 May 1973, required that astronauts undertake extensive spacewalks to repair the shield and to deploy a parasol to protect the orbiting workshop from the sun's rays, and to repair the solar panel. The mission lasted 28 days. The third mission (launched 28 July 1973) and fourth mission (launched 16 November 1973) lasted 59 and 84 days, respectively. Each successive mission set a record for the duration of time that astronauts spent in space.

Skylab would also feature a change in the technologies used to display information to flight controllers at Mission Control Center-Houston. The new system, tested on the last three Apollo missions, would become operational for Skylab, the future Apollo-Soyuz Test Project (ASTP), and the Space Transportation System (STS). Previously, the console displays used a cathode ray tube (CRT) to display images of computer-generated data that was superimposed upon the projected background image of a 35mm slide (the console user selected from among 80 pre-defined backgrounds).[118] This "Digital-to-Television" subsystem (D/TV) would be replaced by a "Digital Television Equipment" subsystem that still required the console operator to select the background, but the new system digitized the background, feeding and superimposing both the background and the data on the same CRT—rather than displaying a second-hand image of the data and background as it appeared in the Real Time Computer Complex.[119]

Operationally, however, Skylab also revealed an increased emphasis on the scientific goals of missions—as the name "Skylab" suggests—rather than the clearly defined engineering goals of landing an astronaut on the moon. The program foreshadowed the loosening grip of Houston's Mission Control over the planning and supervision of missions. The orbiting laboratory's major scientific project, and its most prominent feature, was its Apollo Telescope Mount (ATM), a windmill-shaped array of four solar panels, a device that was trained on the Sun and was used to measure the wavelength and intensity of x-rays and ultraviolet radiation (these were not measureable from the surface of the earth), scientists could determine specific characteristics of the sun for the region examined: its composition, its density, and temperature (see Figure 8).[120] The planning and design of the space-borne observatory was negotiated from 1967 through 1969 between engineers at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama, and engineers at the Manned Spacecraft Center in Houston. Engineers and scientists at

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[117] W. David Compton and Charles D. Benson, *Living and Working in Space: A History of Skylab* (Washington, D.C.: National Aeronautics and Space Administration, 1983), 20.
[118] Kearney, "Evolution of Mission Control Center," 401-402.
[119] Ibid., 403.
[120] Compton and Benson, 166.

Marshall sought greater autonomy and remote control of the space laboratory's technical operations.

The Skylab mission's different character from those of the Apollo program—and especially the mission's origins at Marshall, and Marshall's deep involvement in the design of the space station and in the space station's operation—would portend changes in the division of responsibilities among NASA's centers. The Apollo program's missions demanded careful attention to a series of time-critical events, creating contingency plans that left little to chance, and placed control over all aspects of the mission in the hands of Houston's Mission Control. In the case of Skylab, the orbiting laboratory itself would also be out of contact with ground stations for much of the time. And the Skylab program called for missions lasting months rather than missions of two weeks, and called for much more flexibility in the planning and conduct of operations while in space.

During the planning of Skylab, Flight Operations Director Chris Kraft agreed to an expanded role for Marshall's engineers, who developed the hardware for Skylab and expected an important and autonomous role in this program's flight operations. Kraft sought to integrate Marshall's engineers into his organization, but Marshall's engineers and officials rejected those terms. Ultimately, the two centers agreed that program managers from both Huntsville and Houston would jointly set policy for the Skylab program (although Houston had more representatives). Houston would again maintain control over daily flight operations, but the Flight Director could seek help to solve hardware problems from an MSFC engineering team stationed at the Flight Operations Management Room of the Mission Control Center. The MSFC engineers at MCC would liaise for a much larger engineering team located at Huntsville's own operations center. And an elaborate communications network would be constructed between MSC and MSFC, meant to keep Marshall's engineers continually apprised of the operation and status of Skylab.[121]

More significant for future programs was the conduct of scientific experiments aboard Skylab. Flight controllers at Mission Control—who typically created a detailed script for a flight plan, and exercised complete control over communications with astronauts, now confronted astronomers' desire to talk directly with astronauts, and astronomers' desire to change the flight plan of experimentation each day, and even more often, in order to follow the sun's arbitrarily timed and located "flares."[122] Carl B. Shelley became the inaugural Chief of Space Science and Technology Branch of the Flight Control Division, which would later be called the Space and Life Sciences Directorate. "Kranz asked me to go set up an experiments branch for Skylab experiments," he recalled.[123] NASA was primarily concerned with medical experiments to understand longer-term effects on astronauts in space. "The whole idea, of course, was we're going to go for thirty days,

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[121] Ibid., 214-215.
[122] Ibid., 177-178.
[123] Carl B. Shelley, interview by Carol Butler, 17 April 2001, Oral History Transcript, NASA Johnson Space Center Oral History Project, http://www.jsc.nasa.gov/history/oral_histories/s-t.htm, 23.

and we'll look at that data, and if it's safe, we'll go for sixty, and if that's okay, then we'll go for ninety on the third increment."[124]

But there other experimenters, especially those associated with the Apollo Telescope Mount (ATM) who "wanted to have routine access to the crew, voice access to the crew," he recalled, something that was resisted by flight controllers. Even the flight crew "wasn't too keen on having all these undisciplined scientists calling them all the time," preferring they communicate through the CAPCOMs, or "Capsule Communicators." (At Mission Control CAPCOMs, who were usually astronauts themselves, exclusively engaged in voice communications with flight crews, acting as intermediaries for the rest of the flight controllers.) Kranz sought to allow only a weekly teleconference to go over the weekly activities.[125] In the end, Mission Control did allow frequent and even impromptu communication between its astronauts and the ATM's Principal Investigators, who were located in the first Payload Operations Control Rooms of Building 30, near the Mission Operations Control Rooms. "We had one for the ATM guys," recalled Shelley, "one for the medical people, and there was one for the Earth Resources people. So that's how that all got started."[126]

Apollo-Soyuz Test Project (ASTP)

Apollo-Soyuz Test Project was the first joint mission conducted between the United States and the Soviet Union. It is the last mission to use the Apollo spacecraft and is informally referred to as "Apollo 18."[127] The Apollo Command Module was launched on 15 July 1975 and docked with a Soyuz spacecraft on 17 July 1975. As the Soviet Union's General Secretary Leonid Brezhnev explained it, "détente and positive changes in the Soviet-American relations have made possible the first international spaceflight." He also, correctly, called the mission "a forerunner of future international orbital stations" although, at the time, the mission seemed more significant as a means to express détente between the two superpowers.[128] The mission was still a challenge, however, because the programs were quite different in their approach to spaceflight. As Chris Kraft wrote later, "the philosophies of spacecraft design, development, and operations were so widely separated that a great chasm of differences had to be bridged before the technical work could begin."[129]

The differences were also operational, and these operational differences turned, in part, on differences of language. It was decided that Houston's Mission Control would have

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[124] Ibid., 24.
[125] Ibid., 25.
[126] Ibid., 27.
[127] For instance, NASA's Public Affairs Office web site, "Apollo-Soyuz," calls it "Apollo 18 Soyuz 19." http://www.hq.nasa.gov/office/pao/History/apollo/soyuz.html.
[128] ASTP mission commentary transcript, SR 72/1-2, 17 July 1975, cited in Edward Clinton Ezell and Linda Neuman Ezell, *The Partnership: A History of the Apollo-Soyuz Test Project* (Washington, D.C.: National Aeronautics and Space Administration, 1978), 329.
[129] Christopher C. Kraft, Jr., Forward to Ezell and Ezell, *The Partnership, vii*.

basic responsibility for all things associated with the Apollo spacecraft, and that the Soviet version of mission control, in Moscow, would be responsible for its Soyuz spacecraft. But there were also planned interactions between the two control centers, through the two control center's flight directors and their interpreters.

Flight control was integrated or, at least, jointly conducted, in other ways. Each nation's control center provided the other nation's control center with a team of experts who were tasked with promptly resolving technical questions while the mission was in progress. The teams were each located in staff rooms near each nation's operations control room. The spacecraft would also communicate with their own control centers through the other nation's ground tracking stations, which expanded the reach of Moscow's Mission Control Center (MCC-M) particularly, as the ASTP trajectory took the Soyuz spacecraft away from existing Soviet ground stations. Communications among spacecraft and control centers were also densely interwoven. Ten voice channels were devoted to retransmitting communications between spacecraft and crews, and for transmitting facsimiles of documents and computer printouts.[130]

Communications among astronauts, cosmonauts, and the two Mission Control Centers of Houston and Moscow were held in English and in Russian, so each nation underwent language training to minimize misunderstandings due to language difficulties. American Astronauts Thomas P. Stafford, Vance D. Brand, and Donald "Deke" K. Slayton underwent language training in Russian. Stafford and Slayton, particularly, expected that 300 hours of training in the Russian language would suffice for the mission, but after reaching the 300-hour milestone, both astronauts felt that many more hours were needed to sufficiently master the Russian language for the mission. The two programs prepared a "Glossary of Conversational Expressions between Cosmonauts and Astronauts during ASTP," and Soviet cosmonauts spent a great deal of time listening to tape recordings of Apollo's conversations between Mission Control Center-Houston and astronauts to get a better idea of what to expect during the mission.[131]

In order to create a joint mission control, however, each nation overcame profound differences in spacecraft design philosophy, differences that far surpassed language difficulties. One important and telling difference was that the Soviet technologies developed for Soyuz were designed for automatic and ground control of flight and docking—Soviet cosmonauts acted as systems monitors to a greater extent than did American astronauts, who themselves piloted spacecraft in docking operations. One item of tension concerned the role of Apollo astronauts during the docking maneuver itself, a moment in particular when astronauts were called upon to turn off the Apollo command module's thrusters, which were used as "brakes" in the docking operations. Soviet engineers called on Apollo engineers to automatically terminate operation of the thrusters during docking, because the thrusters threatened to burn the Soyuz' external insulating

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[130] Ezell and Ezell, 289, 291.
[131] Ibid., 253, 256.

blanket. In the end, Soviet engineers and cosmonauts reluctantly agreed to American astronauts' manual control of this operation.[132]

Perhaps the biggest differences in philosophy concerned public relations and, specifically, the timing and extent to which NASA and the Soviet space program would divulge information about the mission to the world. The Soviet space program carefully guarded the details of its earlier flights until after mission completion, while NASA included a Public Affairs Officer in Mission Operations Control Room during a mission, and flight directors at Mission Control held frequent press conferences during missions. The different practices became apparent in mission planning. Lunney wrote that the problem arose almost immediately, when Soviet and American planners sat down to write summaries of their meetings for public consumption. "We found that we had to spend a fair bit of time working on that," he recalled, "because we at NASA and in the United States had a different set of constraints and realities that we dealt with in terms of public information than they did on their side."[133] For the public relations aspect of the ASTP mission itself, NASA initially proposed that a "Public Information specialist" would be present at Mission Control Centers in Houston and Moscow, "to provide an explanatory commentary of mission events as they occur in flight," and stated that "[s]uch commentary will be immediately released to the news media through the press centers in each country." The proposal draft "recommended that the USSR side consider establishing a similar commentator position."[134]

This early draft proposal explicitly presented the roles of Mission Control Center-Houston and at Mission Control Center-Moscow as hubs through which the world would learn of the mission's details transparently, and as soon as events occurred. "All mission related information available in the Mission Control Centers may be released to the news media," stated the proposal, and "[t]his includes in-orbit communications between the two spacecraft, air-ground communications from both spacecraft, television and other communications as appropriate." NASA expected release of such unprocessed information to be "augmented by explanations and summaries of mission status by the commentator." Moreover, the document explicitly stated that, "[if] problems occur in flight, they will be reported promptly in both countries based on all facts known at the time."[135] NASA's Public Affairs Office believed that "the USSR should be aware at the outset of our responsibilities to conduct an open program," just as NASA had for all of its missions.[136]

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[132] Ibid., 275-276.
[133] Glynn S. Lunney, interview by Carol Butler, 18 October 1999, Oral History Transcript, NASA Johnson Space Center Oral History Project, http://www.jsc.nasa.gov/history/oral_histories/LunneyGS/GSL_10-18-99.pdf, 7.
[134] John W. King, "Draft-ASTP Public Information Plan – Part II," 14 January 1974, ASTP Public Information Plan, 1973-75, n.d., Box 1, ASTP Case Study, Public Affairs Office, Center Series, Johnson Space Center History Collection, University of Houston-Clear Lake, 3.
[135] Ibid.
[136] Ibid. See also Lunney, interview, 18 October 1999, 38.

The adversarial tone of the proposal suggested that many at NASA expected these American conditions to be anathema to Soviet mission planners, who customarily withheld information until after a mission's completion. NASA may have caused some consternation among Soviet officials. Perhaps surprisingly, however, the minutes of the joint Public Information Working Group revealed that the Soviet Union agreed to establish a Press center near its own Mission Control Center in Moscow, and to the presence of a public affairs specialists (increased from three to four in the meeting) and agreed to interpreters to provide the public with a running commentary. The final agreement concerning news reporting would make the language more precise, defining the extent of television coverage—which was to specify "real-time television coverage" to be "exchanged simultaneously between control centers, along with appropriate operational voice communication, during major mission events."[137]

The Soviet space program, however, did not allow news reporters access to their launch facility, which created a number of disgruntled American newsmen, including some who wrote to express their dissatisfaction that NASA did not fight for media access to the Soviet launch site. In response to one such letter, NASA Administrator James C. Fletcher replied with a strongly worded statement stressing that the agreement NASA had arrived at with its Soviet counterparts "only covers joint US/USSR mission activities," and that "decisions related to independent activities…are the unilateral responsibility of each country, in accordance with its own practices and traditions." The letter is particularly careful to note that, while they regretted that the Soviet Union would not permit media representatives to attend the launch of the Soyuz spacecraft, there were many breakthroughs in international news coverage on Soviet soil:

> The public affairs agreement between NASA and the Soviet Academy of Sciences provides the most complete, comprehensive release ever to the U.S. news media of real-time information related to the Soviet space mission. It provides among other things for the exchange and release of live airborne and ground-based television; for the transmission to and release by our control center of air-to-ground commentary between Soviet control center and its spacecraft; for a running description by a Soviet commentator of mission events as they occur; for the operation of a press center to which U.S. correspondents will be registered to cover the mission; and for the exchange between press centers of public affairs officers and interpreters to assist the press in its coverage of the activities as they take place. All of those are firsts for the Russians.[138]

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[137] USA-USSR, "Public Information Plan-Post Flight; Apollo Soyuz Test Project," 8 March 1974, ASTP Public Information Plan 1975-75, n.d., Box 1, ASTP Case Study, Public Affairs Office, Center Series, Johnson Space Center History Collection, University of Houston-Clear Lake, 8.

[138] James C. Fletcher to Wes M. Gallagher, Associated Press, 22 October 1974, ASTP Public Information Plan 1975-75, n.d., Box 1, ASTP Case Study, Public Affairs Office, Center Series, Johnson Space Center History Collection, University of Houston-Clear Lake, 1.

ASTP re-affirmed the Mission Control Center at Houston as a hub through which the world gained access to the details of spaceflight missions, but the mission also featured the participation of non-American actors in the design and control of a mission. News coverage was also internationally driven, and distributed from two foci: Mission Control in Houston, and at the Soviet Union's Mission Control Center located in Moscow. Scientists drawn from across the United States and Soviet Union also joined to participate in the design and conduct of the mission, as astronauts and cosmonauts of ASTP conducted sixteen experiments designed by principal investigators from such far-flung places as Berkeley, Frankfurt, Munich, and Moscow. The centrality of Mission Control in Houston remained for the Apollo spacecraft—Mission Control was still held the ultimate responsibility to execute a mission, and to solve problems as they arose. Significantly, the success of Mission Control Center in Houston had begun to *appear* routine, even to those in Mission Control. Years later, when asked about the details of the flight, Flight and Project Director Glynn Lunney expressed the complete confidence he had in his team of flight controllers—"I knew how well they did it, so I didn't have a great deal of concern about that. I kind of sat back and enjoyed the whole flight."[139]

The National Space Transportation System (STS), Spacelab, and the International Space Station (ISS)

The National Space Transportation System (STS), popularly called the "Space Shuttle," was conceived as a sociotechnical arrangement that included ground control, tracking, spacecraft, launch facilities, and a space station. Budgetary goals for post-Apollo NASA programs in the first administration of President Richard Nixon (1969-1973), however, pushed NASA to decide between a "space plane" and a space station, and then to phase out all expendable rockets and make the Shuttle into NASA's *only* payload-carrying platform. NASA continued to pursue the goal of a space station for use with Shuttle flights, joining the international ventures of Spacelab and the International Space Station (ISS). The role of the Mission Control Center changed with the different demands of the Shuttle program and its associated projects, as the Johnson Space Center (JSC)—renamed from the Manned Spaceflight Center—began to share the management of mission planning and supervision with other NASA centers and international space agencies.

To gain funding for its Shuttle program, NASA presented STS to Congress and the President as a transportation infrastructure that operated cost-effective reusable spacecraft. It was to be a program to serve many different clients: agencies of the United States Government, including the Department of Defense (and in particular, the Air Force), commercial entities seeking to deploy communications satellites, government entities of other nations that hoped to launch satellites. In order to achieve economies of scale that would make the Shuttle feasible to officials in the President's Office of Management and Budget, and to spur the development of satellites and other payloads for space, the goal was to create a service that flew like a commercial airline, with weekly

[139] Lunney, interview, 18 October 1999, 18-40.

service.[140] The President's Office of Management and Budget (OMB) was not unanimous in its support for the Shuttle program, but the arguments of George Shultz, OMB head, prevailed and he persuaded President Nixon to support the Shuttle in order to develop a national capacity to deliver large commercial and government payloads in space and to "reduce substantially the cost of space operations."[141]

The success of Apollo raised expectations for the possibility of a frequent, reliable, and low-cost service to deliver payloads into space. Among the most important tasks remaining to achieve such a low-cost service was the development of an improved "checkout and control system"—understood to be highly computerized and automated—which would "provide autonomous operation by the [spacecraft's flight] crew, without major support from the ground," and which would "allow low cost of maintenance and repair."[142] This understanding of the Shuttle's operations seemed to fly in the face of experience at Houston's Mission Control Center, but by the end of the Apollo it appeared that MCC had routinized control of, at least, the ascent and descent stages of missions.

In planning the Shuttle's Orbiter, its designers provided it with highly redundant and sophisticated onboard systems that eclipsed those of Apollo's spacecraft, and also supported the Shuttle with more sophisticated ground and tracking systems. The increasing complexity of the "launch stack"—the orbiter, the reusable liquid propellant tank, and the solid rocket boosters—required that, at launch, MCC-Houston and MCC-Kennedy dedicate a comparable attention to the launches of Apollo missions. During flights, however, it is the Shuttle flight crew that monitors many spacecraft systems, using the Orbiter's on-board computers. This was unlike the Apollo program spacecraft, whose crews relied on MCC direction except during breaks in communication and tracking with ground support, when on-board systems became primary. However, even in the case of the Shuttle orbiter, Mission Control still continues to carefully monitor the shuttle's navigation and trajectory; this is particularly important when deploying satellite payloads to specific locations in earth orbit. Mission Control still monitors consumables, and remains in constant voice communication with flight crews. The flight crew flies the Orbiter, but Mission Control follows the Orbiter's progress and stands by to assist in case of emergency, or to guide scheduled activities during a mission.[143]

The planned uses of the Shuttle, however, elevated the importance of a new set of responsibilities: Mission Control in Houston would also manage the deployment, and

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[140] T. A. Heppenheimer, *The History of the Space Shuttle, Volume 1: The Space Shuttle Decision, 1965-1972* (Washington, D. C.: Smithsonian Institution Press, 2002), 257-259.
[141]Richard M. Nixon, "Statement about the Future of the United States Space Program," John T. Woolley and Gerhard Peters, *The American Presidency Project* [online]. Santa Barbara, CA. Available from World Wide Web: http://www.presidency.ucsb.edu/ws/?pid=2903, cited in Heppenheimer, *History of the Space Shuttle*, 391-392.
[142] George Mueller, "Opening Remarks," Proceedings, NASA Space Shuttle Symposium, October 16-17, 1969, 3-8, cited in T. A. Heppenheimer, 246.
[143] Jack Knight, interview by Jennifer Ross-Nazzal, 10 July 2009, Oral History Transcript, NASA Johnson Space Center Oral History Project, http://www.jsc.nasa.gov/history/oral_histories/KnightJ/knightj.pdf, 43-44.

sometimes the use, of payloads loaded into the Shuttle orbiter's 15 by 60 foot cargo bay. These impending responsibilities in NASA's space program were not lost on Chris Kraft, who became Director of the Johnson Space Center in 1972 and, in the mid-1970s, sought to secure the new business of "payload development" for his Center—that of helping clients develop payloads to be carried aboard the shuttle and deployed into earth orbit. Rather than help develop and design payloads for the Shuttle, however, JSC's task turned out to be the difficult one of finding ways to accommodate a diversity of payloads. Payloads would originate, mainly, from NASA itself, the Department of Defense, and from telecommunications companies.[144]

Most of the Shuttle's missions have been controlled from the Mission Operations Control Rooms (MOCR) on either the second or third floors of Building 30. In the first Shuttle mission, STS-1, the orbiter *Columbia* was launched on 12 April 1981, returned on 14 April, and tested the orbiter's systems and design in operation. The next three Shuttle missions continued to test the orbiters' performance and conducted various scientific experiments. Only on the fifth mission, launched on 11 November 1982, did the Shuttle begin carrying payloads to be delivered into earth orbit, two commercial communications satellites.[145]

The seventh Shuttle mission, launched on 18 June 1983, deployed the first satellite of the Tracking and Data Relay Satellite System (TDRSS), which would be eventually composed of three satellites (two operated in synchronous orbit, and one was a spare), making NASA much less reliant on the crew and equipment of ground-based tracking stations.[146] The TDRSS became operational in 1984, replacing the Spaceflight Data Tracking Network (STDN) and replacing most of the ground-based tracking stations used to assist the Mission Control Center-Houston.[147]

Spacelab

NASA used the ninth Shuttle mission, STS-9, launched 28 November 1983, to begin assembly of the space station Spacelab.[148] Construction of this space station led to the creation of a Payload Operations Control Center (POCC) at MCC-Houston to monitor and direct Spacelab's extensive scientific experimentation and activities, and to coordinate the communications between principle investigators and the astronaut crews

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[144] Glynn S. Lunney, interview by Roy Neal, 26 April 1999, Oral History Transcript, NASA Johnson Space Center Oral History Project, http://www.jsc.nasa.gov/history/oral_histories/k-l.htm, 69-70.
[145] NASA, STS-5, Space Shuttle Mission Archives. Retrieved on October 3, 2010 at http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-5.html.
[146] NASA, STS-7, Space Shuttle Mission Archives. Retrieved on October 3, 2010 at http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-7.html.
[147] Judy A. Rumerman, *NASA Historical Data Books, Volume VI: NASA Space Applications, Aeronautics and Space Research and Technology, Tracking and Data Acquisition/Support Operations, Commercial Programs, and Resources, 1979-1988* (Washington, D.C.: National Aeronautics and Space Administration, 1999), 299-303.
[148] NASA, STS-9, Space Shuttle Mission Archives. http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-9.html.

executing experimental work. The POCC was arranged like the Mission Operations Control Room (MOCR), except its consoles were dedicated to individual principal investigators and their experiments, and to a Mission Manager who oversaw payload operations. The POCC was located in a series of rooms located across the hall from the second floor MOCR in Building 30, and the POCC communicated with the Shuttle mission Flight Director through a representative in the MOCR, the Payload Officer.[149]

Mission Control in Houston would not exercise complete control over the Spacelab missions, as it had for Apollo missions. Aspects of mission control associated with Spacelab were distributed among facilities constructed at Marshall Space Flight Center (MSFC) and at Goddard Space Flight Center (GSFC). Just as for Skylab, Marshall took on an important role in the management of the orbiting Spacelab. MSFC was assigned the role of payload project management, overseeing the engineering and systems integration of Spacelab itself, and providing technical support for the Spacelab spacecraft and its equipment during missions.[150] The Mission Control Center at Building 30 made room for the MSFC Spacelab Program Manager and his staff.[151] Goddard was assigned the task of processing the voluminous data transmitted from Spacelab—more than 50 megabits per second—a function it already provided many of NASA's unmanned spacecraft. GSFC would build a new operational complex for Spacelab, the Goddard Spacelab Data Processing Facility.[152] Moreover, the Tracking and Data Relay Satellite System (TDRSS), once operational, would relay Spacelab experimental data directly to Goddard.[153] Scientific investigators at the Mission Control's POCC would only receive "snapshots" data at 1 Megabit per second, though Goddard did resend some data directly to consoles at the POCC.[154] The organizational and technological developments of new programs entailed redistribution of some mission control to the flight crew, and to the facilities of Marshall and Goddard.

International Space Station (ISS)

The international cooperation that funded and underlay the design, development and construction of space stations worked to further loosen the grip of the MCC-Houston on NASA's spaceflight missions. Spacelab was a project initiated by a "Memorandum of Understanding" signed in 1973 between the NASA and the European Space Research Organisation (ESRO) to build a science laboratory for use with Space Shuttle flights.[155] The International Space Station (ISS) appeared two decades later, its planning begun in 1993 and its construction in 1998. The roots of this collaboration may be found in two

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[149] NASA News Release No. 82-016, "Payload Operations Control Center (POCC)," March 21, 1982, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration, Houston, Texas.
[150] Douglas R. Lord, *Spacelab: An International Success Story* (Washington, D.C.: National Aeronautics and Space Administration, 1987), 127-128, 133
[151] Ibid., 340.
[152] Ibid., 320, 323-324.
[153] Ibid., 321-322.
[154] Ibid., 130, 319-320.
[155] The document is reproduced in Lord, *Spacelab*, 437-459.

failed efforts to build national space stations: those of the NASA project *Freedom* (initiated during the Reagan Administration, and cancelled during the Clinton Administration) and the Soviet *Mir*-2 (initiated by the USSR, but unfunded by the Russian Federation in the economic turmoil after the fall of the Soviet Union in 1991). In the plan arrived at between American Vice President Al Gore and Russian Prime Minister Victor Chernomyrdin, the ISS brought together proposed space stations from the world's space agencies: NASA's *Freedom*, the *Mir*-2 of the Russian Space Agency (RSA), the *Columbus* of the European Space Agency (ESA, the successor organization to ESRO), and the *Kibo* Laboratory of the Japanese Aerospace Exploration Agency (JAXA). ISS is an international successor to Skylab, Spacelab, and ASTP—albeit much delayed.

Delivering payloads to space stations and into earth orbit required precise control of the Orbiter's trajectory, which continued to fall under the purview of the Flight Director at the Mission Control Center-Houston, but the functions of Mission Control now clearly divided between flight operations and payload operations, especially for Shuttle missions to the ISS. To meet the needs of this increasingly important function, the Payload Operations Control Center (POCC) at Mission Control Center-Houston was discontinued after Spacelab, and a new Payload Operations Center (POC) was eventually created at the Marshall Space Flight Center. The POC functions with more or less autonomy during missions relating to the ISS, but defers to Mission Control in all matters concerning flight safety. Marshall Space Flight Center has taken charge of payload operations for ISS, coordinating the payload activities of NASA and its international partners, including the Russian Space Agency, the European Space Agency, the National Space Development Agency of Japan, and the Canadian Space Agency. Each of NASA's partners also maintain payload control centers.[156] MSFC's Payload Operations Center is structured hierarchically, in a manner similar to that of Mission Operations Control Room (the Flight Control Room) in Houston. At the POC, for instance, the Payload Operations Director (POD) maintains an analogous role to that of the Flight Director at Mission Control, overseeing the control room. Moreover, the POC's Payload Operations Director and Payload Rack Officer (PRO) together maintain a command link to the Flight Director at Houston's Mission Control.[157]

Changes in nomenclature also expressed the emerging division between management of the mission's flight and management of its payload operations. The Mission Operations Control Room 1 (MOCR1, located on the second floor of Building 30) was renamed "Flight Control Room 1" (FCR1), while the Mission Operations Control Room 2 (MOCR2, third floor of Building 30) was renamed "Flight Control Room 2" (FCR2). Shuttle flights have been supported by either FCR1 or FCR2; FCR2 was used for Shuttle flights carrying classified payloads. But the changes at Houston's "nerve center" went further, revealing substantive changes in technological arrangements, ambience, and culture.

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[156] Marshall Space Flight Center, *Payload Operations Center: Marshall Space Flight Center's Role in Development and Operations* (Huntsville, Alabama: Marshall Space Flight Center, 2005).
[157] Ibid. See also Knight, interview, July 10, 2009, 11-12.

Culture and Technology in FCR1 and FCR2

In the early 1990s, engineers at the MCC began to update the computing and communications arrangements of the Mission Operations Control Room, implementing a gradual replacement of its mainframe-based computing system with stand-alone workstations at each console, connected to one another on an Ethernet-based Local Area Network (LAN). Some functions, such as telemetry and trajectory, continued to rely on the existing mainframe well into the 1990s. The mainframe was finally "retired" in 2002, according to former Systems Division Chief Jack Knight.[158] The standalone workstations now clicked with the sound of typing on computer keyboards when controllers retrieved tables and graphs of data for viewing on their computer monitors.

Indeed, the newly dubbed "Flight Control Rooms" of MCC became quieter and cleaner than the former "Mission Operations Control Rooms." Gone were the pneumatic tubes, the twelve-inch long by three-inch diameter aluminum cartridges resembling artillery shells that were noisily pushed into, and ejected from, controllers' consoles. Milt Heflin recalled that the change, from the use of pneumatic tubes to electronics to convey information to the controller's computer monitors, was part and parcel of a change in the feeling of the Mission Operations Control Rooms. "When I go in that room [FCR1, formerly MOCR1]," Heflin said on 16 November 2000 at a conference held in Building 30's third floor MOCR2 (FCR2), "the sound, the ambience, in that room has changed from 'muscled voices' to the clicking of keyboards and mouses….the ambience in this room used to be these pneumatic P-tubes coming and going, this is a little song in this room that we no longer have."[159]

And the Flight Control Rooms also became somewhat cleaner with the elimination of the pneumatic-tube delivery system. When controllers of the Gemini and Apollo programs fell behind in exchanging messages with the Staff Support Rooms, writes Kranz, the unused canisters accumulated, and lay "scattered on the floor about the consoles."[160] From their stand-alone computer workstations, which were connected to one another by a local area network, flight controllers quietly typed and exchanged messages with one another, and with engineers in the renamed "Multipurpose Support Rooms" (MPSRs)—they were no longer called Staff Support Rooms (SSRs).[161] The clouds of smoke *inside* the Control Room also disappeared during the years of the Shuttle program. Neil Hutchinson recalled that, "We used to smoke cigars in the Control Center. In fact, back in Gemini and Apollo, when we built the Control Center, we had ashtrays built into the consoles and the like."[162]

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[158] Knight, interview, 10 July 2009, 39-40.
[159] Heflin, "Perspectives on Shuttle Operations," 16 November 2000.
[160] Kranz, 141.
[161] Knight, interview, 25 October 2007, 29.
[162] Neil B. Hutchinson, interview by Kevin M. Rusnak, 28 July 2000, Oral History Transcript, NASA Johnson Space Center Oral History Project, http://www.jsc.nasa.gov/history/oral_histories/HutchinsonNB/hutchinsonnb.pdf, 30.

The personnel of Mission Control also began to look and behave differently. According to Jack Knight, NASA began recruiting non-white and women flight controllers in the late 1970s, during the planning of the Shuttle program.[163] When the flight controllers stopped being exclusively all-white and all-male, and stopped drawing on the customs and practices of the military, the culture of the flight control room also changed. At flight controllers' parties, remembers Knight, controllers drank less and smoked less, "So now you see floating a keg, but not three kegs."[164] The changes seemed to be related primarily to the presence of women, thought Knight: "I think the language mellowed out, and some of the jokes became more appropriate as females—mostly the females, not the minorities so much, but the females[,] were added."[165]

The cultural changes in the control room might have happened even without the addition of female and minority flight controllers, Knight speculated, and even if the controllers remained white and male, because of the new flight controllers' different background: "a lot of them coming out [of college] hadn't gone through the military and didn't get exposed to that kind of an environment."[166] And even the older controllers were changing. Fewer of the older controllers smoked during the Shuttle program, thought Knight, and noticeably so after the "Surgeon General's thing came out" (a warning label appeared on American cigarette packages in 1966, and a more strongly worded warning label in 1970). "[P]eople were just quitting," he recalled.[167] "[I]n terms of how the culture went," summarized Knight, the trends among flight controllers, and in the flight control room, were "less smoking, less drinking, more appropriate language. Probably not as many 'shouting matches' as you might have had in the old days."[168]

Change: From Centralized Control to a Network Model of Control

Mission Control still controlled the flight operations and many payload operations for Shuttle flights, though the task became considerably more complicated with the increasingly international character of spaceflight, and with the increasingly important role of "new constituencies"—each with different and sometimes competing objectives—in the planning and operation of spaceflight missions. After Apollo, no clear-cut and agreed-upon engineering goal joined together participating actors (like the goal of landing a man on the moon and returning him safely). Flight controllers' work became more complicated with participation of scientific communities in the flight operations and planning of Skylab.[169] Neil B. Hutchinson, former Apollo flight controller, and a flight

[163] Jack Knight, interview by Sandra Johnson, 28 November 2007, Oral History Transcript, Johnson Space Center Oral History Project, http://www.jsc.nasa.gov/history/oral_histories/KnightJ/knightj.pdf, 16.
[164] Ibid., 16.
[165] Ibid., 16.
[166] Ibid., 18.
[167] Ibid., 16.
[168] Ibid., 18.
[169] Hutchinson, interview, 5 June 2000, 41.

director during the post-Apollo and Shuttle programs, recalled the simpler days of Apollo, by contrast:

> So the complexion of what went on in the control center, there were, in essence, a whole new set of players who got a lot of votes. It used to be, you sit in the control center, you're flight director in Apollo, and the [scientists] that did [lunar] surface ops [operations] had some of this, I admit, in Apollo, but in general, you know, you're a flight director in Apollo, you're on your way to the Moon, you're going around the Earth, you're doing a rendezvous or something, it's pretty much a spacecraft contained thing. You've got the fighter pilots up there. You've got all the guys in the control center and it's kind of a little club. It's all engineering and spacecraft systems and trajectories and that kind of stuff.[170]

Scientific experiments had been undertaken on missions as early as the Gemini Program, and on the Apollo program, but the planning and mission operations control remained centrally controlled by the Mission Control Center. Skylab initiated a trend toward a more distributed model for the planning and control of spaceflight. That is, the Mission Control Center centralized the planning and control of spaceflight during the Apollo program, creating something like a centrally controlled and hierarchical "system" of spaceflight—something more akin to a military organization. After Skylab, the planning and operation of spaceflights relied increasingly on collaboration among a network of autonomous (groups of) actors and institutions. As Hutchinson put it,

> Skylab changed that whole scene and, of course, that was carried over into Shuttle… So the nice, crisp, "yes sir, no sir, turn it on, turn it off," rigid, disciplined flight operations mentality had to take a real side step when we got to Skylab, to accommodate this new cadre of people who were going to have an input that you'd better listen to, because if you're a flight director, they're your customer.[171]

This different approach foreshadowed the missions of the Space Transportation System (the Shuttle program), which featured the growing participation of other NASA centers and international actors in the design and planning of missions—missions which served diverse national and international "customers," including the US Department of Defense and commercial clients drawn from around the world.

The flexible nature of the Shuttle complicated the role of Mission Control and its Flight Directors. Speaking at an historical conference on the Mission Control Center 16 November 2000, Milt Heflin, then Deputy Chief of the Flight Director's Office and a former flight director earlier in the Shuttle program, echoed Hutchinson's comment. "[W]e began in the Shuttle program to have multiple customers—'customers'—the term

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[170] Ibid., 39.
[171] Ibid., 39-40.

'customer' was foreign to us and the flight control team," Heflin recalled. Flight Directors now watched "multiple different disciplines/customers come in and fly hardware on the Shuttle...and the integration role of the flight director and the flight ops team was beginning to change as we had more and more customers to deal with." Indeed, stated Heflin, "there are more cooks in the kitchen today than there were in the days when Glynn [Lunney] was doing his job [as a Flight Director during the Apollo Program]."[172]

Heflin believed that the development and operation of the International Space Station challenged the Flight Directors of Mission Control more than in the days of Apollo, for Flight Directors now also shared control of the Station's operations, especially with the Russian Space Program's own Mission Control Center in Moscow. "In a way," said Heflin,

> I think that what the men and women [Flight Directors and Controllers of Houston's Mission Control] are called upon to do today in this business is somewhat harder in a certain sense than what Glynn and these folks back then did in the Apollo days ….[those] gentlemen had control and total support of what they could do…we're having to turn into a United Nations on orbit, our flight directors are having to become statesmen ….to become folks who are trying to work this out between partners…and it is hard.[173]

Most troubling to Heflin are the dangers and uncertainties that accompany negotiations over flight operations between nations with different philosophies. "[O]ur role today in the flight control business," said Heflin,

> is to try to sort out what battles we need to fight with them [Russian Space Agency], and what things we need to let go and just watch…this is a very different thing that we are doing today…. My Flight Directors in the Control Center…it is very difficult for them to be Flight Directors today…[but] so far so good."[174]

The character and role of the Mission Control Center in spaceflight planning and operation had changed substantially from the end of the Apollo program to the Shuttle program and the International Space Station. The Mission Control Center still performed an essential and centrally focused role in the flight operations of ascent, descent, and in the delivery of payloads into earth orbit (and in the retrieval, and repair, of payloads in earth orbit). But, especially for the International Space Station, Mission Control sometimes appeared more a coordinator than an agency that centralized control in mission planning and operation. This was a true departure from the days when a Flight Director like Chris Kraft and his flight controllers could exercise considerable influence over a mission's preparation and execution.

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[172] Heflin, "Perspectives on Shuttle Operations," November 16, 2000.
[173] Ibid.
[174] Ibid.

Ironically, the successes of MCC flight control during the Apollo program, and those of the early Shuttle program, may have inspired the confidence of NASA administrators—who faced perpetual budget crises after Apollo—to undertake collaborative projects with the space agencies of other nations. But the task of coordinating the spaceflight planning and activities, and of reconciling the goals of numerous actors, both American and those of other nations, has led to challenges that could be as daunting as those of the Apollo program, despite the more advanced technologies available to flight controllers.

…and Continuity

In a NASA document distributed in 1990, "System Engineering and Integration Processes of the National Aeronautics and Space Administration," Gene Kranz and Chris Kraft sought to update the very successful operations approach of Apollo for the Shuttle era. They described a process of flight planning and conduct that maintained a role for Mission Control that was similar to its role in the Apollo Program, only now, that role became subsumed within a more general "systems engineering and integration" (SE&I) process. Just as did the Mission Control Center during the Apollo Program, the SE&I process relied on the creation of flight rules to codify the integration of flight procedures, mission goals, and the responsibilities of actors who participated in planning and conducting missions. "Flight Rules," write Kraft and Kranz, "are the fundamental risk/gain policy document for mission conduct."[175]

The difference between the Apollo program and that of the Shuttle program was that Shuttle involved many more actors in the process of planning and conducting a mission, and the missions were much more diverse and free-standing, no longer focused on a single and overarching engineering objective, such as landing an astronaut on the moon and returning him safely. Kraft and Kranz acknowledged this difference when they pointed out in their document's abstract that

> Major flight programs involve operational and political attributes, priorities, international prerogatives … [t]he combination of technical, operational, economic and political attributes demands an effective SE&I process that spans and involves all elements involved in program development.[176]

The greater emphasis on scientific experimentation, and the many overlapping and different missions of the Shuttle program, has apparently led to a dispersal of control over the planning and conduct of missions, it has led to the creation of a network of responsible actors where there was once a centrally controlled system.

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[175] Eugene F. Kranz and Christopher C. Kraft, Jr., "System Engineering and Integration Process of the National Aeronautics and Space Administration (NAS)," 19 December 1990, Box 7A, Center Series, Mission Operations, Johnson Space Center History Collection, University of Houston-Clear Lake, 36.
[176] Ibid., 1.

What survives of the earlier operations approach, it seems, is the kernel of the Mission Control Center, the idea and process of precisely codifying the relationships and decisions of a mission—however difficult that has become, given the countervailing desire for flexibility in the operation of Shuttle missions, and the necessity of collaboration to achieve the goals of space exploration. "The most complex, difficult, and critical of the integration processes provided by the Flight Director Office," write Kraft and Kranz, "is 'flight rules' development."[177] This ideal of the Mission Control Center continues to hold together the planning and conduct of NASA's space exploration, even if the "Control" is no longer recognizably centered in one of the old Mission Operations Control Rooms of Building 30.

A National Historic Landmark

On 15 May 1984 the National Park Service nominated the Mission Control Center to the National Register of Historic Places Inventory.[178] The document cited the significance of the site's "close association with the manned spacecraft program of the United States." It also noted the important symbolic value of the Mission Operations Control Room for Americans: "Through the use of television and the print news media," the nomination states, "the scene of activity at the Apollo Mission Control during the first manned landing on the moon was made familiar to millions of Americans."[179] The United States Secretary of the Interior designated the "Apollo Mission Control Center" as a National Historic Landmark on 3 October 1985, giving it the registration number, 85002815.[180] The Mission Control Center was designated an historic landmark while still in use, and while undergoing the profound changes associated with the post-Apollo period. The goals of preservationists, who sought for posterity to fix the site's configuration in the time of Apollo, were not easily reconciled with the goals of NASA administrators, who sought to update the hardware and arrangements of the Mission Operations Control Rooms for the Shuttle program's emerging requirements.

The Mission Control Center's new status soon elicited regret and resistance from NASA by 1987; some officials would have preferred to remove the designation. Its national landmark status made modifying the Mission Control Center a difficult and long process, one that NASA officials hoped to avoid when adding another wing to the building to house a new control room for the planned U.S. space station.[181] A battle ensued in 1989, fought on Capitol Hill, over whether to update the consoles and hardware of the Apollo Mission Control Operations Room used during Apollo 11, the MOCR2 on the third floor of Building 30's Mission Operations Wing. The Texas Historical Commission wanted to

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[177] Ibid., 36.
[178] National Park Service, "Nomination of Apollo Mission Control Center to the National Register of Historic Places," 15 May 1984, http://www.nps.gov/history/nhl/themes/Scanned%20Nominations/Aviation/Apollo.pdf .
[179] NPS, Nomination of the Apollo Mission Control Center.
[180] National Park Service, "National Historic Landmarks Program, Quick Links: Apollo Mission Control Center," http://tps.cr.nps.gov/nhl/detail.cfm?ResourceId=1932&ResourceType=Building.
[181] Jerry Laws, "JSC Honor Stands in Way of Addition," *Houston Post,* 25 November 1987.

preserve the room in its Apollo configuration and to preserve as many original components as possible. Short of this, the Commission sought creation of a replica control room at the JSC Visitors Center, one that would feature the original hardware of the Apollo Mission Control Room. NASA balked at the request, for it had only the two control rooms to conduct Shuttle flights and simulations. "We cannot agree to [keep the room's consoles as they are]," said Billie McGarvey, an administrator of facilities at the Johnson Space Center, "we have to upgrade them just to keep abreast of manned flight programs."[182]

Ultimately, however, another wing was added to the Mission Control Complex—with new Flight Control Rooms—and MOCR2, the third floor Mission Operations Control Room, was restored to something approaching its configuration during the Apollo 11 mission, with reinstalled Apollo-era consoles.[183] It remains that way today, a historic shrine to NASA's Apollo Program. The "Apollo Flight Control Room" was last used operationally in 1995 to guide Shuttle flights.[184] FCR1 (formerly second floor MOCR, Building 30) was remodeled and has functioned as the ISS Flight Control Room since 2006. Shuttle flight control now resides in another control room, one located in a recently added wing to Building 30 (called "30 South") that began control of Shuttle flights beginning in 1998.

Conclusion

In naming all five of its Shuttle orbiters after prominent ships of ocean and marine exploration (two of the ships were commanded by Captain James Cook: the HMS *Endeavour* and HMS *Discovery*), NASA pays homage to a long tradition of scientific exploration that relies on advanced technologies.[185] This tradition has inspired NASA's

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182 Dan Carney, "Control Room's Future Debated; NASA, Preservationists At Odds Over Apollo 11 Facility," *Houston Chronicle*, 3 April 1989.

183 Jack Knight makes the point that the hardware in the historically preserved Apollo Mission Control Room looks like that of the Apollo program, but a close inspection of the consoles and their components reveals it to be hardware drawn from Skylab and Shuttle programs. Jack Knight, interview, 28 November 2007, 13; National Park Service, "National Historic Landmarks Program, Quick Links: Apollo Mission Control Center."

184 JSC, *Mission Control, Houston: Mission Control Center and Flight Operations* (Houston, Texas: Johnson Space Center, National Aeronautics and Space Administration, 2006), 2. Retrieved on October 10, 2010 at http://www.nasa.gov/centers/johnson/pdf/160406main_mission_control_fact_sheet.pdf.

185 "Orbiter Vehicles," http://science.ksc.nasa.gov/shuttle/resources/orbiters/orbiters.html. The Orbiter *Columbia* was named for the Massachusetts-based sloop that was used to explore the Columbia river of the Northwest United States and Canada in the early 1790s. *Challenger* was named after the HMS *Challenger*, which sailed the Atlantic and Pacific Oceans in the 1870s, engaging in deep-sea marine exploration. *Endeavour* takes its name from the HMS *Endeavour*, a vessel captained by James Cook, who set out in 1768 to chart the islands of the South Pacific and to arrive at a better position to observe the infrequent occurrence of planet Venus passing between the Earth and the Sun. Captain Cook also captained the namesake of the orbiter *Discovery*, the HMS *Discovery*, another of the ships that Captain Cook used to chart the islands of the Pacific in the late eighteenth century. The orbiter *Atlantis* is named for a research vessel of the Woods Hole Oceanographic Institute in Massachusetts. The earlier *Atlantis*, a 460-ton ketch, was employed in oceanographic research between 1930 and 1966.

mission “to pioneer the future of space exploration, scientific discovery and aeronautics research.”[186] NASA’s explorations bear a resemblance to ship-based explorations of the past. However, the role of a Mission Operations Control Room in supervising missions in “real time,” and especially the role of a “Mission Control” in planning and conducting flights, reveals space exploration to be a profoundly different enterprise than exploration in the days of the Orbiters’ namesakes.

The technological arrangements arrived at during the Apollo Program has provided the model of flight control for all space travel and experimentation that has followed. But the technological artifacts alone cannot convey the idea of the Mission Control Center, a living entity composed of people as well as technological artifacts. Perhaps the ideal which inspires the Mission Control Center is embodied in the man who did so much to establish and define the relationships among the MCC’s staff and technological artifacts, as well as the corresponding values of the many flight directors and controllers who worked for him: Christopher C. Kraft, Jr. In one sense, the original flight director of the Mercury Project and Gemini Program appears as a recent incarnation of another archetypal figure, the captain of the nineteenth century transatlantic steamship liner, who managed the most technologically advanced vehicle of its day. Kraft, a captain of the first space-era, exemplified the values of this earlier technological hero: brave and clear-thinking in crisis, vigilant and disciplined always, a leader by force of example, and master of the most sophisticated technologies of his time.[187] Succeeding Flight Directors and Flight Controllers may be more likely to emphasize teamwork and leadership in equal parts, but it is a measure of Kraft’s influence that he imbued the culture of the Mission Control Center with these ideals, and successfully institutionalized the same ideals in a process of flight planning and supervision.[188]

During the Apollo Program, the Mission Control Center stood at the center of a process to define and articulate the details of a mission’s operation, and to control that operation from the ground. To the engineers and scientists of NASA, the Mission Control Center in Houston was the site where they collaborated to plan and execute the exploration of space. To the world, it was much more than that. During the Apollo Program, Americans and people of the world experienced space exploration through television broadcasts, and the MCC’s Mission Operations Control Room provided onlookers with a direct link to the astronauts in space—it made NASA’s missions a reality to the world. To the astronauts, the Flight Director and Flight Controllers of the Mission Operations Control Room were vital crewmembers. Although not present physically, flight controllers watched over their ship, ensuring that the vessel was safe and sound, and traveling in the right direction. En route to the moon to be the first humans in lunar orbit during Apollo 8, Frank F. Borman, II, asked of Ken Mattingly, the CAPCOM on duty in the Mission Operations Control Room, “anything exciting happen today?” Mattingly replied, “Oh, I

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[186] National Aeronautics and Space Administration, “About NASA,” http://www.nasa.gov/about/highlights/what_does_nasa_do.html.
[187] Charles Algernon Dougherty, “The Transatlantic Captains,” *Harpers’ New Monthly Magazine* 73 (1886): 375-391.
[188] Kranz, *Failure Is Not An Option*, 375-376.

think you know about all the things that are exciting on your end, and it's real quiet down here…Everybody's smiling … we're in a period of relaxed vigilance." Borman responded, "We'll relax; you be vigilant."[189]

[189] "Apollo 8: Day 5—The Maroon Team," in *Apollo Flight Journal*, ed. W. David Woods and Frank O'Brien, http://history.nasa.gov/ap08fj/19day5_maroon.htm.

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Appendix

Flights Controlled by the Second and Third Floor "Mission Operations Control Rooms" (MOCRs)
(Renamed "Flight Control Rooms" (FCRs) before the Space Shuttle flights)

Flight (Control Room) Ctrl Room Floor *Orbiter Name*	[Launch Date] to [Return Date]	Astronauts	Mission Summary[190]
Gemini 3 (MOCR2) Third Floor control	23 March 1965	Grissom/Young	This was a three-orbit flight. Control was exercised from Mission Control Center-Kennedy (MCC-K) with Mission Control Center-Houston (MCC-H) monitoring data and communications.
Gemini 4 (MOCR2) Third Floor control	3 June 1965 to 7 June 1965	McDivitt/White II	MCC-H assumed prime control responsibility for this 4-day flight. MCC-H proved that it was operational. The first American Extra Vehicular Activity (EVA) was performed on this flight.
Gemini 5 (MOCR2) Third Floor control	21 August 1965 to 29 August 1965	Cooper/Conrad	MCC controlled this 8-day flight.
Gemini 7 (MOCR2) Third Floor control	4 December 1965 to 18 December 1965	Borman II/Lovell, Jr.	This was a two-week flight; the vehicle provided the target for the first rendezvous (with Gemini Third Floor control room used for both flights).

[190] Each Shuttle mission described included too many scientific experiments to be adequately described in such a brief format. A few of the important experiments are mentioned below.

Gemini 6 (MOCR2) Third Floor control	15 December 1965 to 16 December 1965	Schirra, Jr./Stafford	This 26-Hour flight accomplished the first space rendezvous (with Gemini 7).
Gemini 8 (MOCR2) Third Floor control	16 March 1966 to 17 March 1966	Armstrong/Scott	This 7-revolution flight, with first Agena docking, was aborted because of failure of the Orbital Attitude Maneuvering System.
Gemini 9 (MOCR2) Third Floor control	3 June 1966 to 6 June 1966	Stafford/Cernan	This 3-day flight established a new Extra-Vehicular Activity (EVA)— "spacewalk"—record of over 2 hours.
Gemini 10 (MOCR2) Third Floor control	18 July 1966 to 21 July 1966	Young/Collins	This 3-day flight featured a dual rendezvous with Agenas 8 and 10, and two EVAs.
Gemini 11 (MOCR2) Third Floor control	12 September 1966 to 15 September 1966	Conrad, Jr./ Gordon, Jr.	This 3-day flight featured two EVAs.
Gemini 12 (MOCR2) Third Floor control	11 September 1966 to 15 September 1966	Lovell, Jr./Aldrin, Jr.	This was a 4-Day flight. The flight completed MCC support for the Gemini program. Reconfiguration began to support the Apollo 500 series on the first and third floor.
Apollo Program			
AS-201 (MOCR2) Third Floor control Second Floor support	26 February 1966	Unmanned	This was the first flight of Saturn 1B launch stage and Command-Service Module (CSM); it was a suborbital flight. The MCC second floor was first used in support of this flight.

AS-203 (MOCR1) Second Floor control	5 July 1966	Unmanned	This Saturn 1B flight tested the hydrogen tank. A boilerplate spacecraft was used.
AS-202 (MOCR1) Second Floor control	25 August 1966	Unmanned	This flight was launched using a Saturn 1B rocket, and included a CSM to study spacecraft performance; the flight was suborbital.
AS-204 (Apollo 1)	27 January 1967	Grissom/White II/ Chafee	Three astronauts were killed in an Apollo spacecraft fire during a pad test. The flight was re-designated "Apollo 1" in honor of its fallen crew.
Apollo 4 (MOCR2) Third Floor control	9 November 1967	Unmanned	This was the initial flight of Saturn V (AS-501). It included a CSM and boilerplate (mockup) Lunar Module (LM).
Apollo 5 (MOCR1) Second Floor control	22 January 1968	Unmanned	This was the first flight that featured a working LM aboard Saturn 1B (AS-204/LM-1). The flight test ended in 11 hours; atmospheric drag caused the spacecraft orbits to decay and re-enter the atmosphere in 2 days.
Apollo 6 (MOCR2) Third Floor control	4 April 1968	Unmanned	This second flight of the Saturn V (AS-502) featured a working CSM, and a boilerplate LM.
Apollo 7 (MOCR1) Second Floor control	11 October 1968 to 22 October 1968	Schirra/Eisele/ Cunningham	This was the first manned Apollo (AS-205) CSM flight, and last use of the Saturn 1B until Skylab/ASTP (Apollo-Soyuz Test Project).

Apollo 8 (MOCR2) Third Floor control	21 December 1968 to 27 December 1968	Borman II/Lovell, Jr./ Anders	This was the second manned Apollo flight, and first aboard the Saturn V. It featured a lunar fly by. an operational LM was not carried. This flight and the remaining Apollo flights were controlled from the third floor.
Apollo 9 (MOCR2) Third Floor control	3 March 1969 to 13 March 1969	McDivitt/Scott/ Schweickart	This was the first flight to feature a manned LM, and also achieved the first active docking between LM and CSM.
Apollo 10 (MOCR2) Third Floor control	18 May 1969 to 26 May 1969	Stafford/Young/ Cernan	In this Lunar orbital mission, an LM crew transferred from the CSM to LM in lunar orbit, and descended to 50,000 feet before returning to the CSM.
Apollo 11 (MOCR2) Third Floor control	16 July 1969 to 24 July 1969	Armstrong/Collins/ Aldrin, Jr.	This was the first manned lunar landing. While on the moon, astronauts deployed the Early Apollo Scientific Experiment Package (EASEP) and conducted experiments. Upon successful completion, the Second Floor MOCR was ordered mothballed. The mission is best known for Neil Armstrong's words, "The *Eagle* has landed," and, soon after, "[That's] one small step for [a] man, one giant leap for mankind."
Apollo 12 (MOCR2) Third Floor control	14 November 1969 to 24 November 1969	Conrad, Jr./ Gordon, Jr./Bean	This flight achieved a second lunar landing; astronauts deployed the Apollo Lunar Experiments Package (ALSEP), conducting experiments. No significant discrepancies were reported in any equipment.

Apollo 13 (MOCR2) Third Floor control	11 April 1970 to 17 April 1970	Lovell, Jr./Swigert/ Haise	This mission was aborted during translunar flight due to onboard failure. Safe landing was achieved in 6 days after using LM as a "lifeboat." The mission is remembered by the well-known words of astronaut Jack Swigert, "Houston, we've got a problem."
Apollo 14 (MOCR2) Third Floor control	31 January 1971 to 9 February 1971	Shepard, Jr./Rossa/ Mitchell	This was the fourth manned lunar exploration. Astronauts deployed an ALSEP package, conducting experiments on the moon's surface. Several changes to the CSM had been made as a consequence of the Apollo 13 abort.
Apollo 15 (MOCR2) Third Floor control	26 July 1971 to 7 August 1971	Scott/Worden/ Irwin	This lunar landing featured the first extended lunar exploration using the Lunar Roving Vehicle (LRV), TV, extended life support systems, and extensive SIM (Scientific Instrument Module) bay experiments from lunar orbit. The astronauts deployed another ALSEP package and P&FS 1 (Particles and Fields Subsatellite 1) to conduct experiments.
Apollo 16 (MOCR2) Third Floor control	16 April 1972 to 27 April 1972	Young/ Mattingly, Jr./ Duke	This lunar landing featured the second extended lunar exploration with LRV/LCRU (Lunar Communications Relay Unit). Astronauts deployed an ALSEP package and P&FS 2 to conduct experiments.
Apollo 17 (MOCR2) Third Floor control	7 December 1972 to 19 December 1972	Cernan/Evans/ Schmitt	This was the last lunar exploration by the Apollo program, and featured use of LRU/LCRU & an ALSEP package. The mission also featured the first night launch of a Saturn V rocket.

The MCC Third Floor MOCR and Staff Support Rooms (SSRs) were deactivated after Apollo 17 and remained inactive from May 1973 until the start of Shuttle.			
Skylab			
Skylab 1/2 (MOCR1) Second Floor control	14 May 1973 to 22 June 1973	Conrad, Jr./Weitz/ Kerwin	The first Skylab mission primarily oriented to conduct earth resources and biomedical experiments. A solar wing and the meteorite shield was lost. The other solar panel did not deploy. The remaining solar wing and temporary heat shield were manually deployed by astronauts. First mission supported by the NASA/Houston Mass Data Storage Facility (MDSF), Military Operations Planning System (MOPS), Digital Television Equipment (DTE) display systems and Earth resources Precise Positioning Service (PPS). The Skylab flights were controlled from the reactivated second floor (79 consoles, 319 cabinets of electronics, 60,000 feet of cable and 120,000 cross connects).
Skylab 3 (MOCR1) Second Floor control	28 July 1973 to 25 September 1973	Bean/Lousma/Garriott	The second Skylab mission was primarily oriented to conduct earth resources and biomedical experiments. Temporary heat shield replaced.
Skylab 4 (MOCR1) Second Floor control	16 November 1973 to 8 February 1974	Carr/Pogue/ Gibson	Third Skylab mission conducted the following types of experiments: earth resources, biomedical, ATM, and corollary. EVA total on this flight was over 22 hours. Observations were made of the Comet Kohoutec.

Apollo-Soyuz Test Project (ASTP)			
ASTP (MOCR1) Second Floor control	15 July 1975 to 24 July 1975	Stafford/Brand/ Slayton & Leonov/ Kubasov	First joint American/Russian earth orbital mission. An Apollo spacecraft and Soyuz spacecraft, launched from their separate countries, docked in orbit. Visits were exchanged through a common docking adaptor and scientific experiments were conducted. Last use of the Apollo MCC ground systems.
Skylab Re-entry			
Skylab (MOCR1) Second Floor support	13 July 1979		Skylab reentry was supported by the MCC with a small group of MOD/MSD personnel, with a special limited data system (PDP 11-45) and voiced commands to the sites.
Space Transportation System (Space Shuttle)			
CA-1A Second Floor control	18 June 1977	Haise/Fullerton	This was the first manned Captive-Active flight of the Shuttle and the carrier plane.
CA-2A Second Floor control	28 June 1977	Engle/Truly	This was the second manned Captive-Active flight of the Shuttle and the carrier plane.
FF-1 Second Floor control	12 August 1977	Haise/Fullerton	This was the first free flight of the Orbiter.

FF-2 Second Floor control	13 September 1977	Engle/Truly	This was the second free flight of the Orbiter.
FF-3 Second Floor control	23 September 1977	Haise/Fullerton	This was the third free flight of the Orbiter.
FF-4 Second Floor control	12 October 1977	Engle/Truly	This was the fourth free flight of the Orbiter.
FF-5 Second Floor control	26 October 1977	Haise/Fullerton	This was the fifth free flight of the Orbiter.
STS-1 (FCR-1) Second Floor control *Columbia*	12 April 1981 to 14 April 1981	Young/Crippen	This was the first Orbital flight of the Space Shuttle launched from KSC. Landed at Edwards AFB, California.
STS-2 (FCR-1) Second Floor control *Columbia*	12 November 1981 to 14 November 1981	Engle/Truly	This was the second orbital flight of the Space Shuttle. Landed at Edwards AFB, California.
STS-3 (FCR-1) Second Floor control *Columbia*	22 March 1982 to 30 March 1982	Fullerton/Lousma	This was the third orbital flight of the Space Shuttle. Landed at Northrup Strip, White Sands, New Mexico.
STS-4 (FCR-1) Second Floor control *Columbia*	27 June 1982 to 4 July 1982	Mattingly/Hartsfield, Jr.	This was the fourth orbital flight of the Space Shuttle. Landed at Edwards AFB, California.
STS-5 (FCR-2) Third Floor control *Columbia*	11 November 1982 to 16 November 1982	Brand/Overmyer/ Lenoir/Allen	This was the fifth orbital flight of the Space Shuttle. Landed at Edwards AFB, California. First satellites (SBS-C/PAM-D and Telesat-E 3/PAM/D) launched from the Orbiter.

STS-6 (FCR-2) Third Floor control *Challenger*	4 April 1983 to 9 April 1983	Weitz/Bobko/ Peterson/Musgrave	This was the sixth orbital flight of the Space Shuttle. Landed at Edwards AFB, California. A TDRS satellite (Tracking and Data Relay Satellite-1/IUS) was launched on this mission.
STS-7 (FCR-2) Third Floor control *Challenger*	18 June 1983 to 24 June 1983	Crippen/Hauck/ Ride/Fabian/Thagard	This was the seventh orbital flight of the Space Shuttle with five crew members, including the first American woman, was completed with a successful landing at Edwards AFB, California. In addition to launching 2 communications satellites (Telesat-F/PAM-D and Palapa-B1/PAM-D), the crew deployed a SPAS free flyer with the manipulator arm and obtained the first pictures of the Shuttle in orbit.
STS-8 (FCR-2) Third Floor control *Challenger*	30 August 1983 to 5 September 1983	Truly/ Brandenstein/ Bluford/Gardner/ W. Thornton	This was the eighth orbital flight of the Space Shuttle with five crew members was completed with a successful landing at Edwards AFB, California. The mission marked the first night launch and landing. Satellite INSAT-1B was deployed, TDRS was tested, and the manipulator arm was tested with a 5000 pound test article.

STS-9 (FCR-2) Third Floor control *Columbia*	28 November 1983 to 8 December 1983	Young/Shaw/Parker/ Garriot/Lichtenberg/ Merbold (ESA)	This was the ninth orbital flight of the Space Shuttle with six crew members was completed with a successful landing at Edwards AFB, California. On satellite (INSAT-1B/PAM-D) was deployed. This was the first Spacelab flight and the first use of the JSC POCC. The second floor payload support rooms were full to overflowing with scientists and their equipment from 11 European countries, Japan, Canada, and the United States. Experiments were run 24 hours a day as the crew worked in shifts (3 people on 12 hours each). Approximately 720 billion bits of data was processed by the POCC and over 8,800 command were issued during the flight. The POCC ground support team for the MCC was located in room 210.
STS-10/41-B (FCR-2) Third Floor control *Challenger*	3 February 1984 to 11 February 1984	Brand/Gibson/ McNair/Stewart/ McCandless II	This was the tenth orbital flight of the Space Shuttle with five crew members was completed with a successful landing at Kennedy Space Center landing site. Two satellites were deployed (Westar-VI/PAM-D and Palapa-B2/PAM-D) and the first untethered spacewalk using the Manned Maneuvering Unit (MMU) was demonstrated.
STS-11/41-C (FCR-2) Third Floor control *Challenger*	6 April 1984 to 13 April 1984	Crippen/Scobee/ Hart/Nelson/ van Hoften	The Long Duration Exposure Facility (LDEF-1) was deployed. The MAX SOLAR Max satellite was retrieved (using the RMS, repaired and redeployed.

STS-12/41-D (FCR-1) Second Floor control *Discovery*	30 August 1984 to 5 September 1984	Hartsfield, Jr./Coats/ Resnik/Hawley/ Mullane/Walker	Three satellites were deployed: SBS-4/PAM-D, Syncom IV-2/UUS (Leasat-2), and Telstar 3-C/PAM-D.
STS-13/41-G (FCR-2) Third Floor control *Challenger*	5 October 1984 to 13 October 1984	Crippen/McBride/ Ride/Sullivan/ Leestma/ Garneau/ Scully-Power	The crew contained a Canadian and two women, one of which was the first American woman to walk in space. An Earth Radiation Budget Satellite (ERBS) was deployed.
STS-14/51-A (FCR-1) Second Floor control *Discovery*	8 November 1984 to 16 November 1984	Hauck/Walker/ Allen/Fisher/Gardner	This flight retrieved and returned two satellites that had been in a useless orbit. Telsat H/PAM-D and Syncom IV-1/PAM-D (Leasat-1) were deployed and placed in geosynchronous orbit.
STS-15/51-C (FCR-2) Third Floor control *Discovery*	24 January 1985 to 27 January 1985	Mattingly/Shriver/ Onizuka/Buchli/ Payton	This was a DOD mission that deployed the DOD 85-1/IUS satellite. This was the first use of the control mode hardware and software which allowed the MCC to support secure classified operations for DOD.
STS-16/51-D (FCR-2) Third Floor control *Discovery*	12 April 1985 to 19 April 1985	Bobko/Williams/ Seddon/Hoffman/ Griggs/Walker/Garn	This flight deployed the Syncom IV, Telesat I/PAM-D and Syncom IV-3 satellites. U.S. Senator E. J. Garn was aboard.
STS-17/51-B (FCR-1) Second Floor control *Challenger*	29 April 1985 to 6 May 1985	Overmyer/Gregory/ Lind/ Thagard/ W. Thornton/ Van den Berg/Wang	This was the Spacelab-3 flight and included experiments with 2 monkeys and 24 rats. The NUSAT satellite was deployed.
STS-18/51-G (FCR-2) Third Floor control *Discovery*	17 June 1985 to 24 June 1985	Brandenstein/ Creighton/Fabian/ Lucid/Nagel/ Baudry/ Al-Saud	Three satellites were deployed: Morelos-A, Telstar-3D, Arabsat-A. The Spartan-1/MPESS satellite was deployed and retrieved.

STS-19/51-F (FCR-1) Second Floor control *Challenger*	29 July 1985 to 6 August 1985	Fullerton/Bridges, Jr./Musgrave/England/ Henize/Acton/Bartoe	Spacelab 2 was included in the payload. The Plasma Diagnostics Package (PDP) satellite was deployed.
STS-20/51-I (FCR-2) Third Floor control *Discovery*	27 August 1985 to 3 September 1985	Engle/Covey/ van Hoften/Lounge/ Fisher	A number of satellites were deployed: ASC-1/PAM-D, Aussat-1/PAM-D, Syncom IV-4/UUS (Leasat-4). Syncom IV-4 failed to function after attaining geosynchronous orbit.
STS-21/51-J (FCR-2) Third Floor control *Atlantis*	3 October 1985 to 7 October 1985	Bobko/Grabe/ Hilmers/Stewart/ Pailes	This was a DOD mission and all activities were classified.
STS-22/61-A (FCR-1) Second Floor control *Challenger*	30 October 1985 to 6 November 1985	Hartsfield, Jr./Nagel/ Buchli/Bluford/ Dunbar/Furrer/ Messerschmid/ Ockels (ESA)	This was a dedicated Spacelab flight and was supported from ESA's remote POCC in Germany. One satellite was deployed, the Global Low Orbiting Message Relay (GLOMR).
STS-23/61-B (FCR-2) Third Floor control *Atlantis*	26 November 1985 to 3 December 1985	Shaw Jr./O'Connor/ Cleave/Spring/Ross/ Vela/Walker	Three satellites were deployed on this flight: Morelos-B, Aussat-2, Satcom Ku-2.
STS-24/61-C (FCR-1) Second Floor control *Columbia*	12 January 1986 to 18 January 1986	Gibson/Bolden, Jr./ Chang-Diaz/Hawley/ G. Nelson/Cenker/ Nelson	US Congressman Bill Nelson was aboard. One satellite was deployed, Satcom KU-1.
STS-25/51-L (FCR-2) Third Floor control *Challenger*	28 January 1986	Scobee/Smith/ Onizuka/Resnick/ McNair/McAuliffe/ Jarvis	The twenty-fifth Space Shuttle flight ended in disaster when the orbiter and the External Tank exploded at 1 minute and 13 seconds, killing all astronauts aboard.

STS-26 (FCR-1) Second Floor control *Discovery*	29 September 1988 to 3 October 1988	Hauck/Covey/ Lounge/Hilmers/ Nelson	The twenty-sixth Space Shuttle flight with a crew of five was completed with a successful landing at Edwards AFB, California. TDRS-3/IUS was deployed during the flight.
STS-27 (FCR-2) Third Floor control *Atlantis*	2 December 1988 to 6 December 1988	Gibson/Gardner/ Sheperd/Ross/ Mullane	This was a DOD mission and all activities were classified.
STS-29 (FCR-1) Second Floor control *Discovery*	13 March 1989 to 18 March 1989	Coats/Blaha/Bagian/ Springer/Buchli	The Tracking Data and Relay Satellite-D (TDRS-4) was deployed, allowing almost complete communications coverage during Shuttle flights. The Orbiter Experiments Autonomous Supporting Instrumentation System (OASIS-I) recorded environmental data for the Shuttle's primary payloads.
STS-30 (FCR-1) Second Floor control *Atlantis*	4 May 1989 to 8 May 1989	Walker/Grabe/ Thagard/Cleave/Lee	The Magellan Probe was deployed, beginning its flight to the planet Venus. The FEA modular microgravity chemistry/physics laboratory was used to process samples of indium in a float-zone mode, examining the application of floating zone processin on crystal quality.
STS-28 (FCR-2) Third Floor control *Columbia*	8 August 1989 to 13 August 1989	Shaw, Jr./Richards/ Brown/Adamson/ Leestma	Two military satellites were deployed, STS 2 (USA 40) and USA 41. This was a classified DOD flight and the first of *Columbia* in four years after an extensive upgrade.

STS-34 (FCR-1) Second Floor control *Atlantis*	18 October 1989 to 23 October 1989	Williams/McCulley/ Lucid/Baker/ Chang-Diaz	The Galileo probe/orbiter was deployed, beginning its flight to Jupiter via gravity assists past Venus and Earth. Experiments were conducted to compare observations of several ozone-measuring instruments aboard National Oceanographic and Atmospheric Administration Satellites and other Earth-monitoring spacraft.
STS-33 (FCR-2) Third Floor control *Discovery*	22 November 1989 to 27 November 1989	Gregory/Blaha/ K. Thornton/Musgrave/ Carter	This was a classified DOD Flight.
STS-32 (FCR-1) Second Floor control *Columbia*	9 January 1990 to 20 January 1990	Brandenstein/ Wetherbee/Dunbar/ Ivins/Low	This flight deployed a communications satellite for the Navy, SYNCOM IV-F5 and retrieved the LDEF (Long Duration Exposure Facility) in orbit since 1984. Life sciences experiments were conducted to determine if Neurospora (a bread mold) circadian rhythms persisted in microgravity in the absence of cues from Earth.
STS-36 (FCR-2) Third Floor control *Atlantis*	28 February 1990 4 March 1990	Creighton/Casper/ Mullane/Hilmers/ Thuot	Satellite KH-11-10 (AFP-731) was deployed on this flight. This was a classified DOD flight.
STS-31 (FCR-1) Second Floor control *Discovery*	24 April 1990 to 29 April 1990	Shriver/Bolden/ Hawley/ McCandless/ Sullivan	The Hubble Space Telescope was deployed on this flight.
STS-41 (FCR-1) *Discovery*	6 October 1990 to 10 October 1990	Richards/Cabana/ Melnick/Shepherd/ Akers	This flight deployed Ulysses, PAM, and IUS.

STS-38 (FCR-2) *Atlantis*	15 November 1990 to 20 November 1990	Covey/Culbertson, Jr./ Springer/Meade/ Gemar	Deployed an SDS communications relay satellite (USA-67). This was a classified DOD mission.
STS-35 (FCR-1) *Columbia*	2 December 1990 to 10 December 1990	Brand/Gardner/ Hoffman/Lounge/ Parker/Durrance/ Parise	The main purpose of this flight was astrophysics observations using Astro-1.
STS-37 (FCR-1) *Atlantis*	5 April 1991 to 11 April 1991	Nagel/Cameron/ Godwin/Ross/Apt	Deployed Gamma ray Observatory (CGRO). Conducted protein crystallization experiments in microgravity of space.
STS-39 (FCR-1) *Discovery*	28 April 1991 to 6 May 1991	Coats/Hammond, Jr./ Harbaugh/ McMonagle/Bluford/ Veach/Hieb	Deployed CRO-B/C, MPEC (USA-70), CRO-A. Deployed SPAS 2-01/IBSS on 1 May and retrieved it on 2 May. This was an unclassified DOD mission.
STS-40 (FCR-1) *Columbia*	5 June 1991 to 14 June 1991	O'Connor/Gutierrez/ Bagian/Jernigan/ Seddon/Gaffney/ Hughes-Fulford	The primary objective of this flight was the study of body systems: cardiovascular, cardiopulmonary, renal/endocrine, blood, immune systems, musculoskeletal, and neurovestibular. The test subjects were humans, rodents, and jellyfish.
STS-43 (FCR-1) *Atlantis*	2 August 1991 to 11 August 1991	Blaha/Baker/Lucid/ Low/Adamson	Deployed TDRS-E/IUS satellite. Conducted microgravity experiments in heat transfer.
STS-48 (FCR-1) *Discovery*	12 September 1991 to 18 September 1991	Creighton/Reightler, Jr. / Gemar/Buchli/ Brown	Deployed UARS satellite. Collected data on cosmic ray energy loss spectra, neutron fluxes, and induced radioactivity. Also conducted experiments on physiological and developmental adaptation of rodents to microgravity.

STS-44 (FCR-1) *Atlantis*	24 November 1991 to 1 December 1991	Gregory/Henricks/ Voss/Musgrave/ Runco/Hennen	Deployed DSP-16/IUS (USA-75) satellite. Evaluated effectiveness of Military Man in Space real-time visual observations of terrestrial and oceanic targets. This was an unclassified DOD mission.
STS-42 (FCR-1) *Discovery*	22 January 1992 to 30 January 1992	Grabe/Oswald/ Thagard/Readdy/ Hilmers/Bondar/ Merbold (ESA)	Conducted life sciences research with the IML-1. Conducted experiments on the human nervous system's adaptation to low gravity and the effects of microgravity on other life forms, such as shrimp eggs, lentil seedlings, fruit fly eggs, and bacteria.
STS-45 (FCR-1) *Atlantis*	24 March 1992 to 2 April 1992	Bolden/Duffy/ Sullivan/Leestma/ Foale/Frimout/ Lichtenberg	Conducted atmospheric research using the ATLAS-1.
STS-49 (FCR-1) *Endeavour*	7 May 1992 to 16 May 1992	Brandenstein/ Chilton/Thuot/ K. Thornton/Hieb/ Akers/Melnick	Retrieved Intelsat VI, fitted it with an Orbus motor and redeployed it. Conducted experiments on growth of protein crystals.
STS-50 (FCR-1) *Columbia*	25 June 1992 to 9 July 1992	Richards/Bowersox/ Dunbar/Baker/ Meade/DeLucas/ Trinh	Conducted broad-ranging microgravity research using USML-1, a pressurized Spacelab module.
STS-46 (FCR-1) *Atlantis*	31 July 1992 to 8 August 1992	Shriver/Allen/Ivins/ Hoffman/ Chang-Diaz/ Nicollier (ESA)/ Malerba (ISAA)	Tested operation of the Tethered Satellite System (TSS), and deployed the European Space Agency (ESA) Eureca 1. Conducted experiments on the reaction rate of atomic oxygen, which is present in Earth orbit, to measure erosion of materials. Also conducted life science experiments and evaluated composite material candidates for future space vehicle structures.

STS-47 (FCR-1) *Endeavour*	12 September 1992 to 20 September 1992	Gibson/ Brown, Jr./Lee/ Apt/Davis/Jemison/ Mohri (JAXA)	Conducted materials and life sciences research using Spacelab-J.
STS-52 (FCR-1) *Columbia*	22 October 1992 to 1 November 1992	Wetherbee/Baker/ Veach/Shepherd/ Jernigan/ MacLean (CSA)	Deployed LAGEOS II/IRIS and operated USMP-1. Conducted fluids, materials, and metallurgical research.
STS-53 (FCR-2) *Discovery*	2 December 1992 to 9 December 1992	Walker/Cabana/ Bluford/Clifford/ Voss	Deployed an SDS communications relay satellite (USA-89). This was a classified DOD mission. This was the last flight controlled by FCR-2. It was subsequently restored to its Apollo-era configuration and preserved for historical purposes.
STS-54 (FCR-1) *Endeavour*	13 January 1993 to 19 January 1993	Casper/McMonagle/ Runco, Jr./Harbaugh/ Helms	Deployed TDRS-6/IUS. Studied X-rays radiation from distant sources in deep space.
STS-56 (FCR-1) *Discovery*	8 April 1993 to 17 April 1993	Cameron/Oswald/ Foale/Cockrell/ Ochoa	Deployed and retrieved SPARTAN-201. Studied relationship between Sun's energy output and Earth's middle atmosphere and effect on ozone layer.
STS-55 (FCR-1) *Columbia*	26 April 1993 to 6 May 1993	Nagel/Henricks/ Ross/Precourt/ Harris/ Walter (Germany)/ Schlegel (Germany)	Conducted microgravity research using the German Spacelab D-2. Studied growth of GaAs, and Gallium-doped Germanium crystal growth, in microgravity. Studied other materials' characteristics in microgravity.
STS-57 (FCR-1) *Endeavour*	21 June 1993 to 1 July 1993	Grabe/Duffy/Low/ Sherlock (Currie)/ Wisoff/Voss	Retrieved EURECA and conducted biomedical and materials science experimentation using the SPACEHAB module.

STS-51 (FCR-1) *Discovery*	12 September 1993 to 22 September 1993	Culbertson, Jr./ Readdy/Newman/ Bursch/Walz	Deployed ACTS; deployed and retrieved ORFEUS-SPAS.
STS-58 (FCR-1) *Columbia*	18 October 1993 to 1 November 1993	Blaha/Searfoss/ Seddon/ McArthur, Jr./ Wolf/Lucid	Conducted Spacelab Life Sciences research, including experiments to learn about cardiovascular/cardiopulmonary and physiological behavior in space.
STS-61 (FCR-1) *Endeavour*	2 December 1993 to 13 December 1993	Covey/Bowersox/ Musgrave/ K. Thornton/ Nicollier (ESA)/ Hoffman/ Akers	This was the first Hubble Space Telescope servicing mission. This mission set records for Extra-Vehicular activity, with 5 spacewalks totaling 35 hours, 28 minutes.
STS-60 (FCR-1) *Discovery*	3 February 1994 to 11 February 1994	Bolden, Jr./ Reightler, Jr./Davis/ Sega/Chang-Diaz/ Krikalev (RSA)	First mission of the Shuttle-Mir Program. Conducted experimentation using WSF-1, a satellite facility that was operated at the end of the orbiter's manipulator arm. Conducted biotechnology and materials processing experiments using the SPACEHAB 02 experimental payload.
STS-62 (FCR-1) *Columbia*	4 March 1994 to 18 March 1994	Casper/Allen/Thuot/ Gemar/Ivins	Conducted experimentation using USMP-2 and OAST-2 to investigate materials processing and crystal growth in microgravity.
STS-59 (FCR-1) *Endeavour*	9 April 1994 to 20 April 1994	Gutierrez/Chilton/ Godwin/Apt/ Clifford/Jones	Studied the Earth's global environment using SRL-1, and imaging radar device used for geoscientific studies of the Earth in different seasons.
STS-65 (FCR-1) *Columbia*	8 July 1994 to 23 July 1994	Cabana/Halsell, Jr./ Hieb/Walz/Chiao/ Thomas/ Naito-Mukai (JAXA)	Conducted life sciences and microgravity research using a number of facilities and apparatus.

STS-64 (FCR-1) *Discovery*	9 September 1994 to 20 September 1994	Richards/ Hammonds, Jr./ Linenger/ Helms/ Meade/Lee	Experimentation using LIDAR LITE to measure the vertical profile of atmospheric parameters, and deployment and retrieval of the SPARTAN-201 satellite.
STS-68 (FCR-1) *Endeavour*	30 September 1994 to 11 October 1994	Baker/Wilcutt/Jones/ Smith/Bursch/ Wisoff	Used imaging radar to engage in geoscientific study of the Earth's different seasons. Used SRL-2 to image sites for geology, hydrology, vegetation science, and oceanography. Studied vegetation types and extent, deforestation, water storage and flux, ocean dynamics, wave fields, wind fields, volcanism, tectonic activity, soil erosion, desertification, topography.
STS-66 (FCR-1) *Atlantis*	3 November 1994 to 14 November 1994	McMonagle/ Brown, Jr./Ochoa/ Tanner/ Clervoy (ESA)/ Parazynski	Conducted research using ATLAS-3 (measured Sun's energy output and chemical makeup of Earth's middle atmosphere); deployed and retrieved the CRISTA-SPAS satellite.
STS-63 (FCR-1) *Discovery*	3 February 1995 to 11 February 1995	Wetherbee/Collins/ Harris, Jr./Foale/ Voss/Titov (RSA)	Conducted experiments using SPACEHAB-3 (experiments in biotechnology and materials development); deployed and retrieved SPARTAN-204 satellite. This was the first flight of Phase 1 of the International Space Station program.
STS-67 (FCR-1) *Endeavour*	2 March 1995 to 18 March 1995	Oswald/Gregory/ Grunsfeld/Lawrence/ Jernigan/Durrance/ Parise	Researched using Astro-2 to make ultraviolet observations of stars, galaxies, magnetospheres, and quasars.
STS-71 (FCR-1) *Atlantis*	27 June 1995 to 7 July 1995	Gibson/Precourt/ Baker/Harbaugh/ Dunbar	The first Shuttle-*Mir* docking was achieved on this flight. Conducted life science and microgravity research with *Mir*.

STS-70 (Ascent/Entry: FCR-1) (Orbit: WFCR) *Discovery*	13 July 1995 to 22 July 1995	Henricks/Kregel/ Currie (Sherlock)/ Thomas/Weber	Deployed TDRS-G satellite; conducted experiments to grow mammalian cells in fluid growth medium in microgravity. The "White" Flight Control Room (WFCR), a new state-of-the-art control room found in a newly constructed wing to building housing FCRs, jointly controlled missions with FCR-1 until STS-76 (1998, see below). FCR-1 was converted to a "Life Sciences Center" for the International Space Station (ISS) Payload control operations. In 2006, an extensively remodeled FCR-1 became the primary control room for the International Space Station (ISS).
STS-69 (Ascent/Entry: FCR-1) (Orbit: WFCR) *Endeavour*	7 September 1995 to 18 September 1995	Walker/Cockrell/ Voss/Newman/ Gernhardt	Deployed and retrieved SPARTAN 201-03 and WSF-2 satellites.
STS-73 (Ascent/Entry: FCR-1) (Orbit: WFCR) *Columbia*	20 October 1995 to 5 November 1995	Bowersox/ Rominger/Coleman/ Lopez-Alegria/ K. Thornton/Leslie/ Sacco, Jr.	Conducted research using the USML-2. This was the second United States Spacelab mission dedicated to microgravity research.
STS-74 (Ascent/Entry: FCR-1) (Orbit: WFCR) *Atlantis*	12 November 1995 to 20 November 1995	Cameron/Halsell, Jr./ Hadfield (CSA)/ Ross/McArthur, Jr.	The second Shuttle-*Mir* docking was achieved on this flight. Conducted structural dynamics experiments on the *Mir* solar arrays during the docked phase of the mission.
STS-72 (Ascent/Entry: FCR-1) (Orbit: WFCR) *Endeavour*	11 January 1996 to 20 January 1996	Duffy/Jett, Jr./Chaio/ Scott/Wakata (JAXA)/ Barry	Deployed and retrieved SPARTAN OAST-Flyer; retrieved Japanese Space Flyer Unit.

STS-75 (Ascent/Entry: FCR-1) (Orbit: WFCR) *Columbia*	22 February 1996 to 9 March 1996	Allen/Horowitz/ Hoffman/ Chili (ESA)/ Nicollier (ESA)	The mission undertook the flight of U.S./Italian TSS-1R satellite, which was lost during the mission; microgravity research was conducted in materials science and condensed matter physics.
STS-76 (Ascent/Entry: FCR-1) (Orbit: WFCR) *Atlantis*	22 March 1996 to 30 March 1996	Chilton/Searfoss/ Sega/Clifford/ Godwin/Lucid	This flight featured the third Shuttle-*Mir* docking; conducted research and transfer of supplies using SPACEHAB-Single Module.
The "White" Flight Control Room (WFCR), located in a newly constructed wing of Building 30 (the building whith housed the older FCR-1 and FCR-2), supported all subsequent shuttle flights. In 2006, an extensively remodeled FCR-1 became the primary control room for the International Space Station (ISS).			

APPENDIX B

FIGURES

Figure 1: "View of Mercury Control Center prior to MA-8 [Mercury-Atlas 8] Flight," 3 October 1962. Source: NASA Images Archive, http://www.nasaimages.org/luna/servlet/detail/nasaNAS~7~7~31618~135485:View-of-Mercury-Control-Center-prio

Figure 2: “Mission Control Center.” Source: Manned Spacecraft Center, “NASA Facts: Mission Control Center,” 1972, Box 080-31, Apollo Program Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

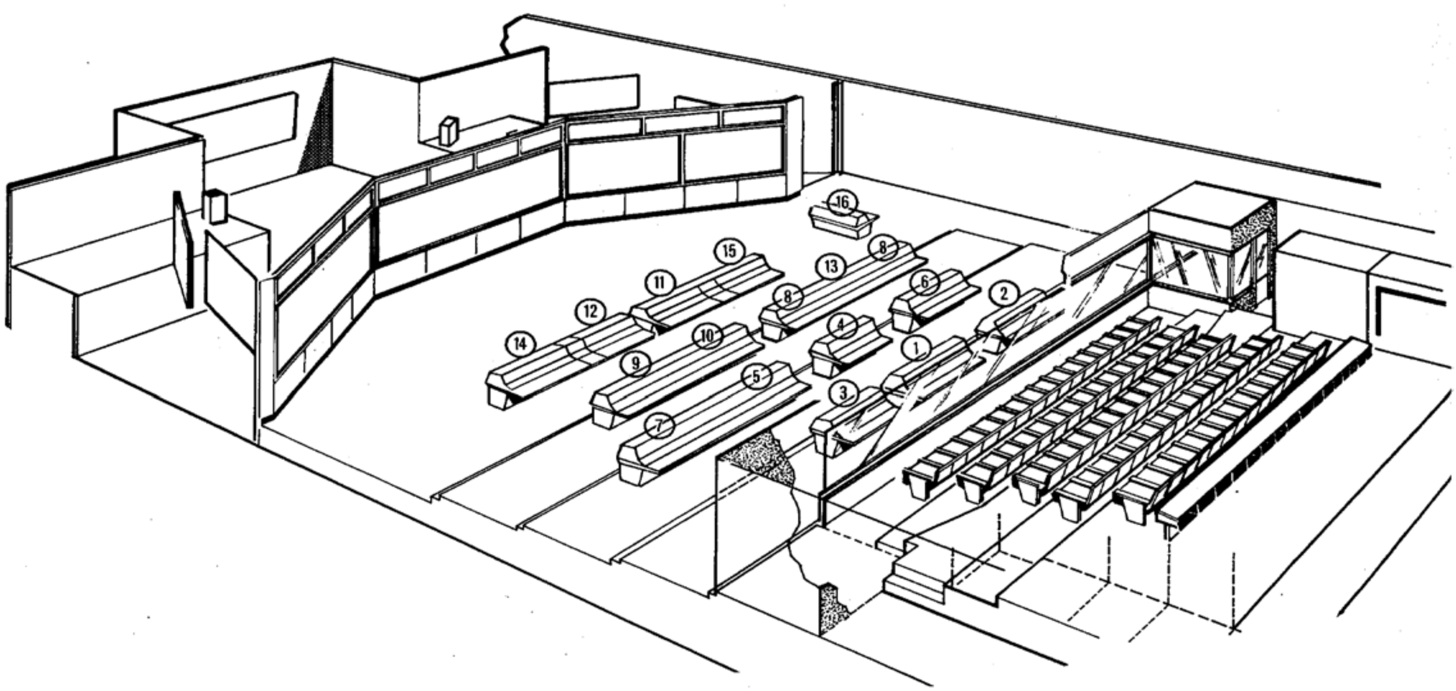

Figure 2: "Mission Control Center Diagram." Source: Manned Spacecraft Center, National Aeronautics and Space Administration, *MCC; Mission Control Center* (Houston, Texas: Manned Spacecraft Center, National Aeronautics and Space Administration, ca. 1964).

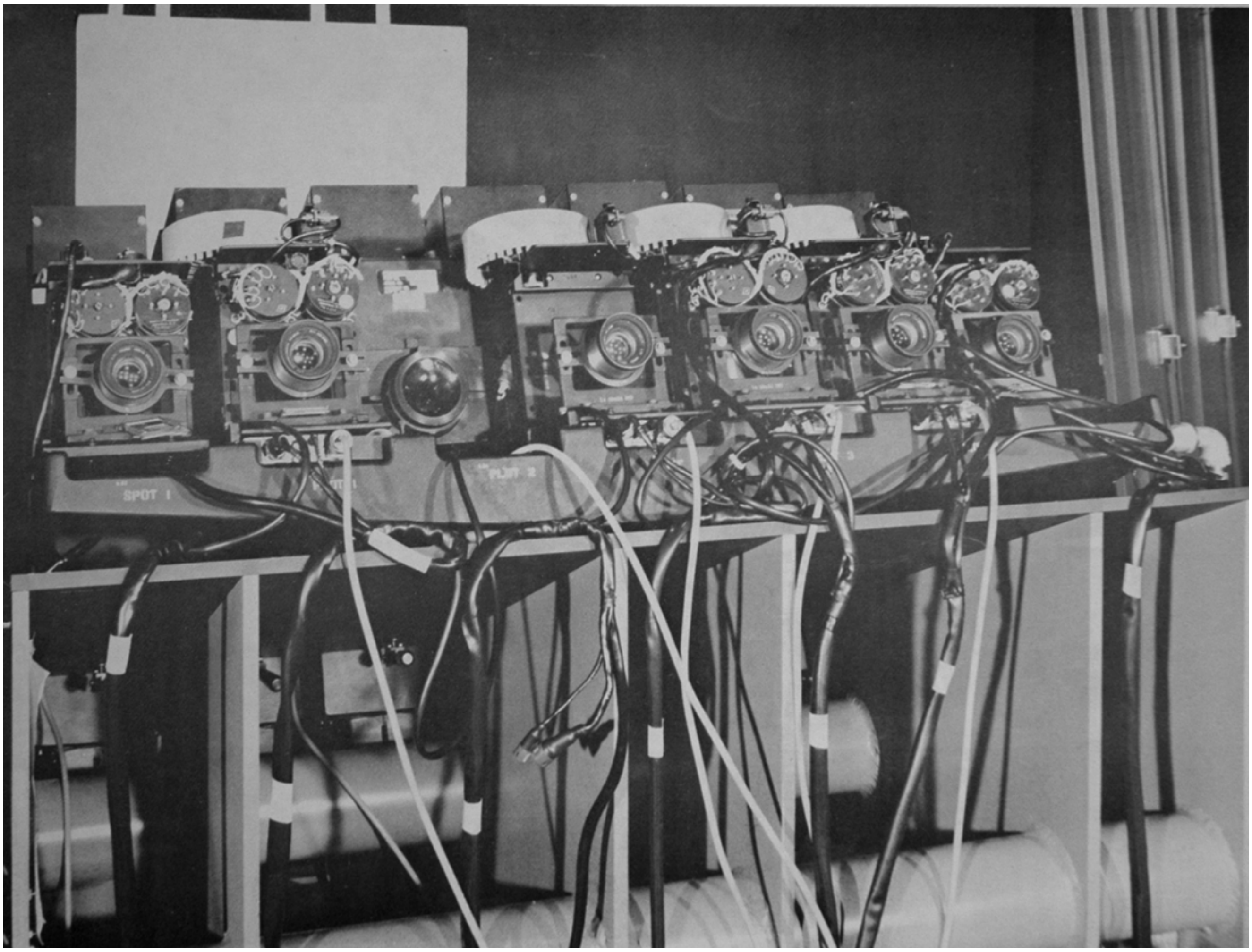

Figure 4: "'Batcave' Projectors" (ca. 1965). Source: Manned Spacecraft Center, "MCC-H Consoles and Display Systems: Lesson Plan and Handout, Apollo Network," June 6, 1966, Box 067-13, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

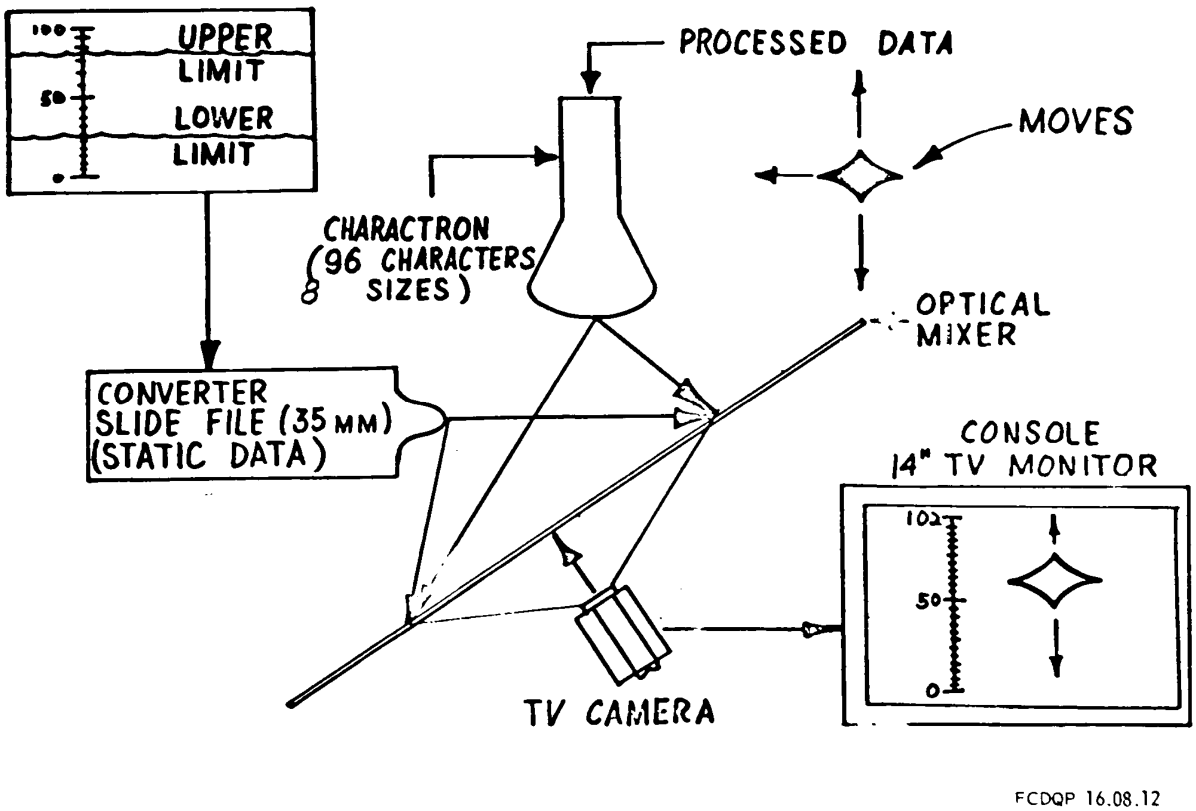

Figure 5: "Optical Interface" (ca. 1965). Source: Manned Spacecraft Center, "MCC-H Consoles and Display Systems: Lesson Plan and Handout, Apollo Network," June 6, 1966, Box 067-13, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

Figure 6: “Mission Control Consoles” (ca. 1965). Source: Manned Spacecraft Center, “MCC-H Consoles and Display Systems: Lesson Plan and Handout, Apollo Network,” June 6, 1966, Box 067-13, Apollo Program Chronological Files, Johnson Space Center History Collection, University of Houston-Clear Lake.

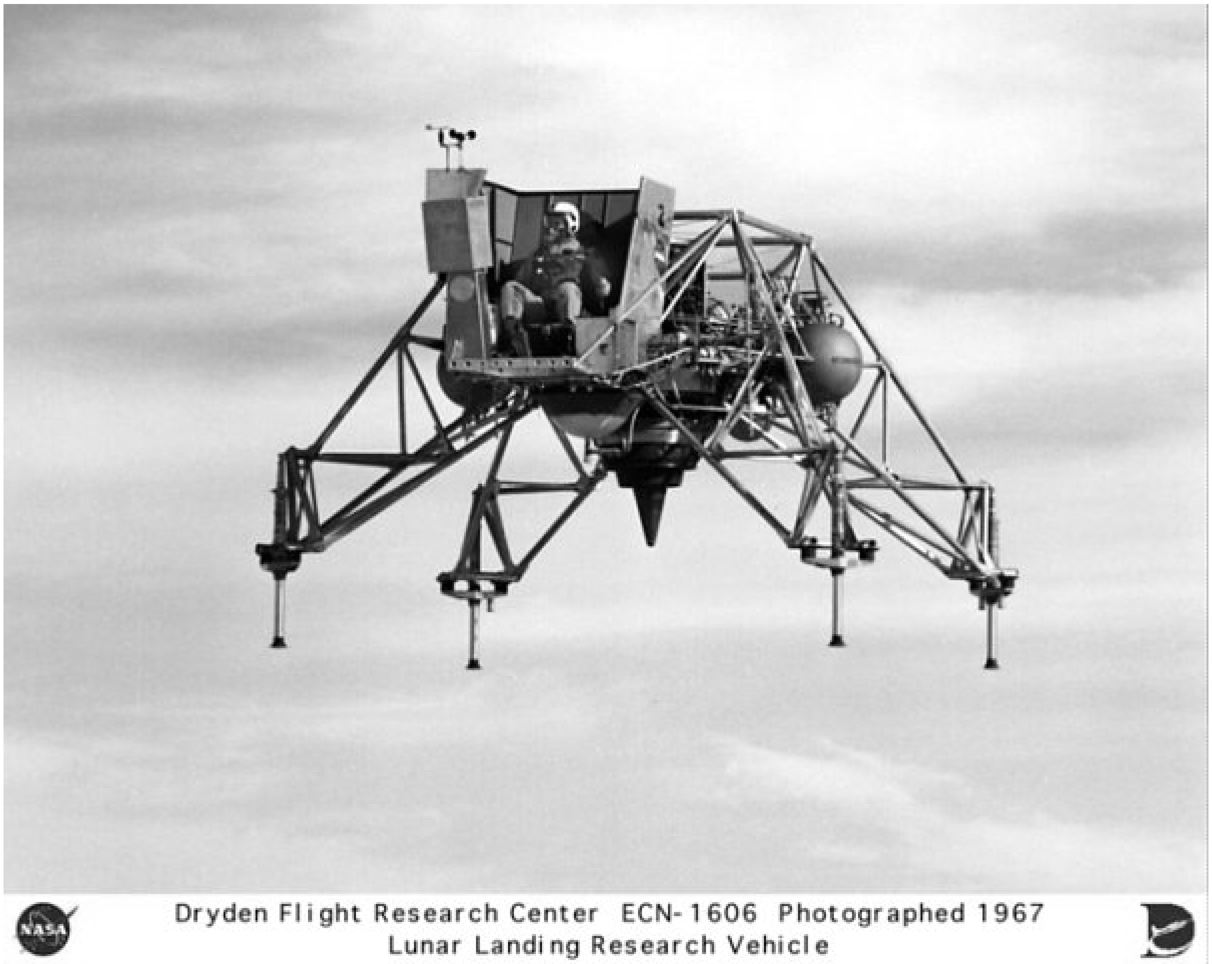

Figure 7: "Lunar Landing Training Vehicle (LLTV)." Source:
http://www.hq.nasa.gov/alsj/a11/a11.lltv1.jpg

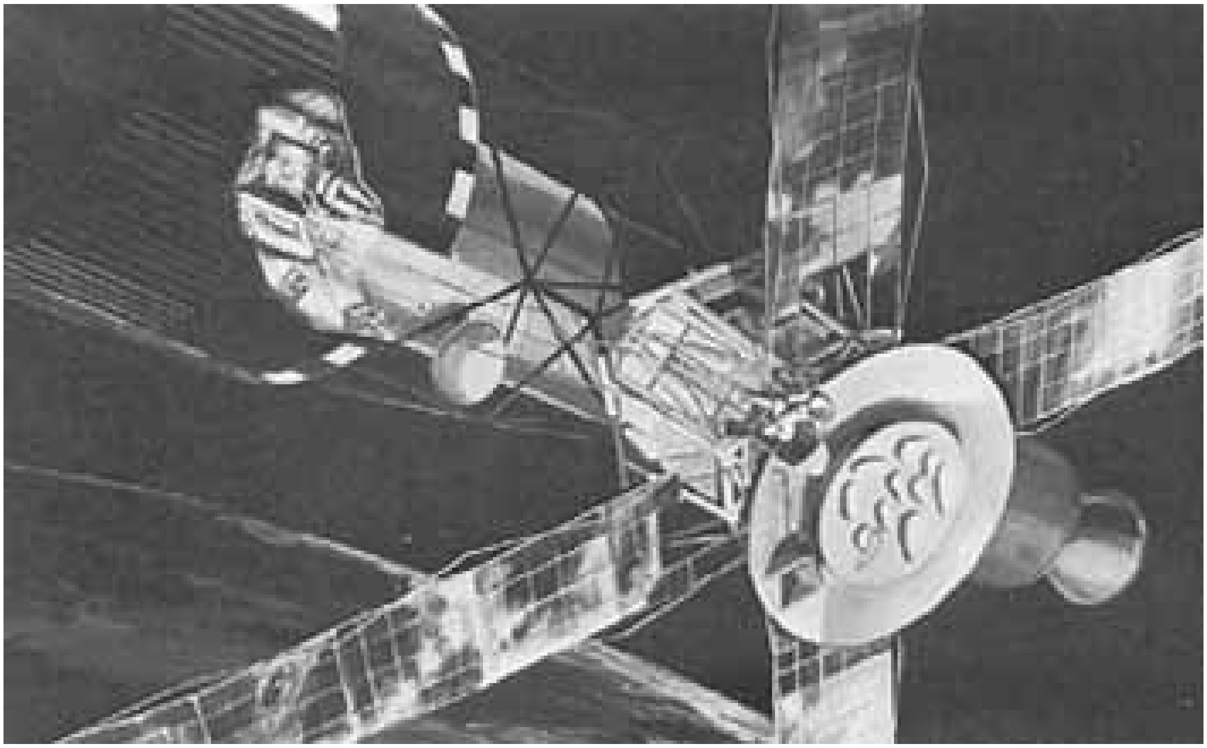

Figure 8: “Apollo Telescope Mount, Showing its solar panel array and the hub containing the instruments.” Source: W. David Compton and Charles D. Benson, *Living and Working in Space: A History of Skylab* (Washington, D.C.: National Aeronautics and Space Administration, 1983), p. 167.