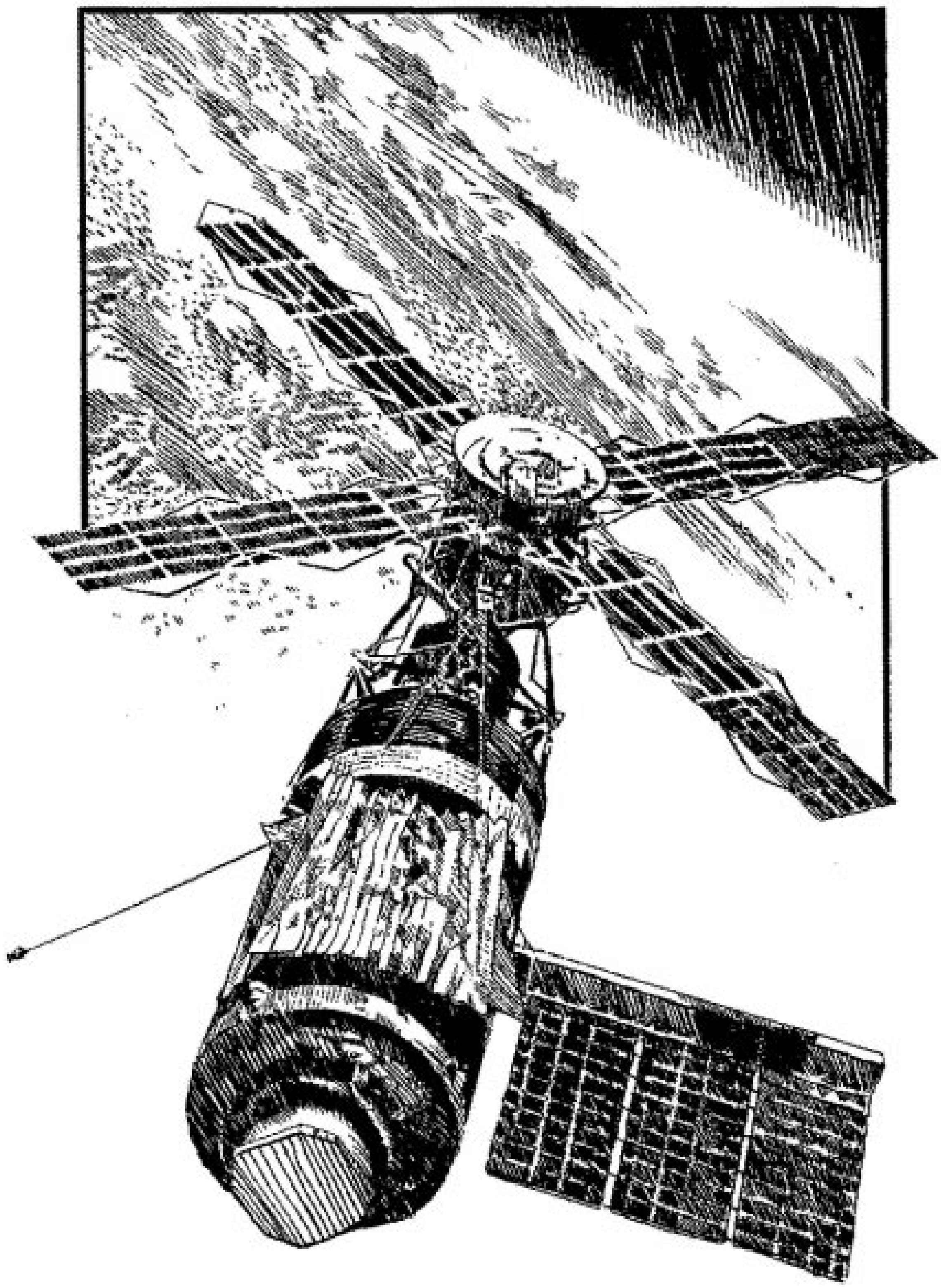


CHAPTER 11: Skylab to Shuttle

"Perhaps the most far-reaching event of the year just passed," Bob Gilruth told MSC personnel in his Christmas message at the close of the first year of the new decade, "may be the clear emergence of the Space Shuttle as the keystone of virtually all future efforts in space." But the past year had been difficult and the future was uncertain. NASA and its contractors were having to adjust to "lowered priorities and shrinking resources."[1]

The center began a transitional phase in the 1970's, shifting from its focus on managing Apollo to the role of managing the design and development of the Space Shuttle, or as it was first officially known, the Space Transportation System (STS). MSC became the lead center for the Space Shuttle Program. Apollo folded into the ensuing Skylab and Apollo/Soyuz programs. The center provided support for the Earth Resources Program intended to extend knowledge of the Earth and its resources from the vantage of space and space technology. The center continued a strong operations role through 1975 with three manned Skylab missions of 28, 59, and 84 days, respectively, in 1973-74, and a joint Russian-American space rendezvous and docking maneuver 2 years later.[2]

The new era required new management approaches and new thought processes. Concerned about the center's situation and role within the changing political and budgetary climate for space, Gilruth commissioned a special internal self-study or situation report. The report recommended "a not so subtle change in internal MSC thinking." Now, more than ever, MSC had to cooperate with other centers and with Headquarters. The old autonomy and independence could no longer be sustained. The center's image (within the NASA community) as being intellectually arrogant had to change. Its technical capabilities had to be sublimated to work more closely in concert with the expertise and strengths of other centers. Future spaceflight goals were expected to be less specific than for Apollo, and the level of funding and public support far less assured. There would be lower budgets and fewer personnel. Budget pressures conflicted with the center's and NASA's traditional engineering philosophy that hardware should be of the best design and best production quality possible irrespective of costs.[3] The center had to develop new thought patterns, reform its internal organization, and create new intercenter and contractor relationships, while preserving its old confidence and high technical standards.

The new era also brought new leadership. In January 1972, Chris Kraft replaced Robert Gilruth as Director, and Sigurd A. Sjoberg became Kraft's Deputy Director. Gilruth went on to a 2-year stint (January 1972 to December 1973) as Director of Key Personnel Development reporting to the Deputy Administrator in Washington, D.C. He was responsible for identifying near-term and long-range potential candidates for key Agency positions. Gilruth retired in December 1973 but continued as a consultant to the Administrator for several more years. At Headquarters, James C. Fletcher, with a doctorate in mathematics and physics and a research and teaching background at Harvard, Princeton and the California Institute of Technology, left the presidency of the University of Utah to replace Thomas O. Paine in May 1971 as NASA Administrator. Rocco Petrone, formerly Director of Launch Operations at Kennedy Space

Center, moved from the Apollo Program Office to replace Homer E. Newell as NASA's Associate Administrator. Dale Myers became Associate Administrator for Manned Space Flight in the Headquarters office. Wernher von Braun stepped down as head of the Marshall Space Flight Center in 1970 and was succeeded by Eberhard Rees, while Kurt Debus turned over the reins of the Kennedy Space Center to Lee R. Scherer in 1974.[4] New leadership and new program requirements produced substantive reorganizations at every level.

As the Apollo lunar missions wound down, MSC began to focus on the Apollo program "extension" —Skylab. Gemini personnel were the first to migrate to the Skylab program. Skylab, in truth, was an interim poor-man's concession to space station planning. It had roots in space station planning, Apollo applications, the Air Force manned orbiting laboratory program, and, more specifically, in studies centering in the Marshall Space Flight Center on how to use the Saturn-IV or S-IVB stage. Skylab could make further use of the Apollo systems. Budgetary constraints and an interest in an immediate and recognizable "payoff" from space operations were direct incentives to Skylab program development. Marshall Space Flight Center engineers and Douglas Aircraft engineers contributed to early Skylab designs, which were among the space station configurations being considered throughout the decade of the 1960's. The orbiting laboratory idea evolved, by 1966, to a "cluster" concept linking an Apollo spacecraft to an "orbital workshop." The concept had the attraction of using "surplus" Saturn IBs and Apollo spacecraft (and a Saturn V to launch the heavier workshop). Workshop experiments in earth sciences held the promise of direct and immediate economic benefits for people on planet Earth. Moreover, Earth-orbit missions cost less than lunar or planetary flights. Lower costs and the promise of immediate returns seemed to be a reasonable response to the public's growing disenchantment with outerspace projects. Even so, as David Compton and Charles Benson explained in their history of Skylab, Congress and the Johnson administration were at best lukewarm in their support of NASA's orbiting workshop plans.[5]

Mechanical failures during the May 14, 1973, launch landed Skylab in orbit overheated and starved for electricity. Astronaut EVAs saved the workshop and proved again the worth of humans in space. Skylab crews set new space endurance records and completed more experiments than originally scheduled, clearing the way for space experiments in the Shuttle era.

MSC, which became involved in the orbital workshop planning only in late 1965, at first opposed any configuration that did not provide a minimum of 0.1 gravity (to be created by spinning the workshop or station on an axis). The real hurdles remained budgetary and political. Finally, in July 1969, NASA received approval for an orbiting workshop and three rendezvous missions to begin in 1972.[6]

Skylab moved rapidly from inception to flight status between 1970 and 1973. The workshop, multiple docking adapter, and propulsion systems were managed by Marshall Space Flight Center, and MSC directed the astronaut training, scientific experiments, and Apollo spacecraft modifications and flight operations. NASA contracted with North American Rockwell for modifications to the Apollo spacecraft, with McDonnell-Douglas for two orbiting workshops, and with Martin Marietta for the docking mechanism. The Air Force contributed astronauts from its canceled orbital laboratory program, provisioning by its food and diet contractor (Whirlpool Corporation), and spacesuits from its contract with the Hamilton Standard Division of United Aircraft.[7]

The MSC Skylab Program Office, managed by Kenneth S. Kleinknecht, directed the necessary center resources (including its contractor and university associates) into the Skylab program, and it was the contact point for all other NASA and government agencies (including the Marshall Space Flight Center and the Kennedy Space Center) involved in any way with Skylab. The Mission Office, Management Operations Office, Engineering Office, Manufacturing and Test Office, Orbital Assembly Project Office and Apollo/Skylab Program Support Offices then interacted with their counterparts in the line and functional divisions of MSC or other NASA centers.[8] Although there were substantive organizational changes within MSC in the early 1970's, the essential elements of effective project management continued to be defining responsibilities and retaining a flow of communications between organizations at every level. The traditional elements of collegial association and doing what was required to get the job done remained intact.

By March 1973, just prior to the launch of the Skylab orbital workshop, the center's organization reflected the configuration indicated in figure 13. As usual, the charts and tables do not represent the actual fluidity of the organization and the interlacing lines of communications between the offices, divisions, and personnel.

To retain business management expertise in the director's office, Chris Kraft named William R. Kelly special assistant for management upon the retirement of General Frank Bogart in early 1972. A 1953 graduate of the Georgia Institute of Technology, Kelly went to work for General Electric following a tour in the U.S. Navy testing the J-79 jet engine. He joined the Mercury Program Office of MSC in 1962, transferred to the Apollo office in 1963, and became the Division Chief for the Institutional Resources and Procurement Division under Phil Whitbeck in 1970. These were difficult times, Kelly (who replaced Whitbeck as Director of Administration in 1981) recalled: "An erosion began in 1970. All of a sudden we had to lay people off. Why, when one was succeeding so well, did one have to begin firing employees? It seemed un-American to win and then lose."[9]

"Our new, young, capable employees took the brunt of the reduction in force (RIF). We lost all of the young people in my division," Kelly recalled. "In 1970-1971 we had about 10,000 contractor employees and 4700 civil service employees at the center. The numbers fell to 6000 contractor employees and 3200 civil service employees within a few years."

Johnson Space Center, 1973

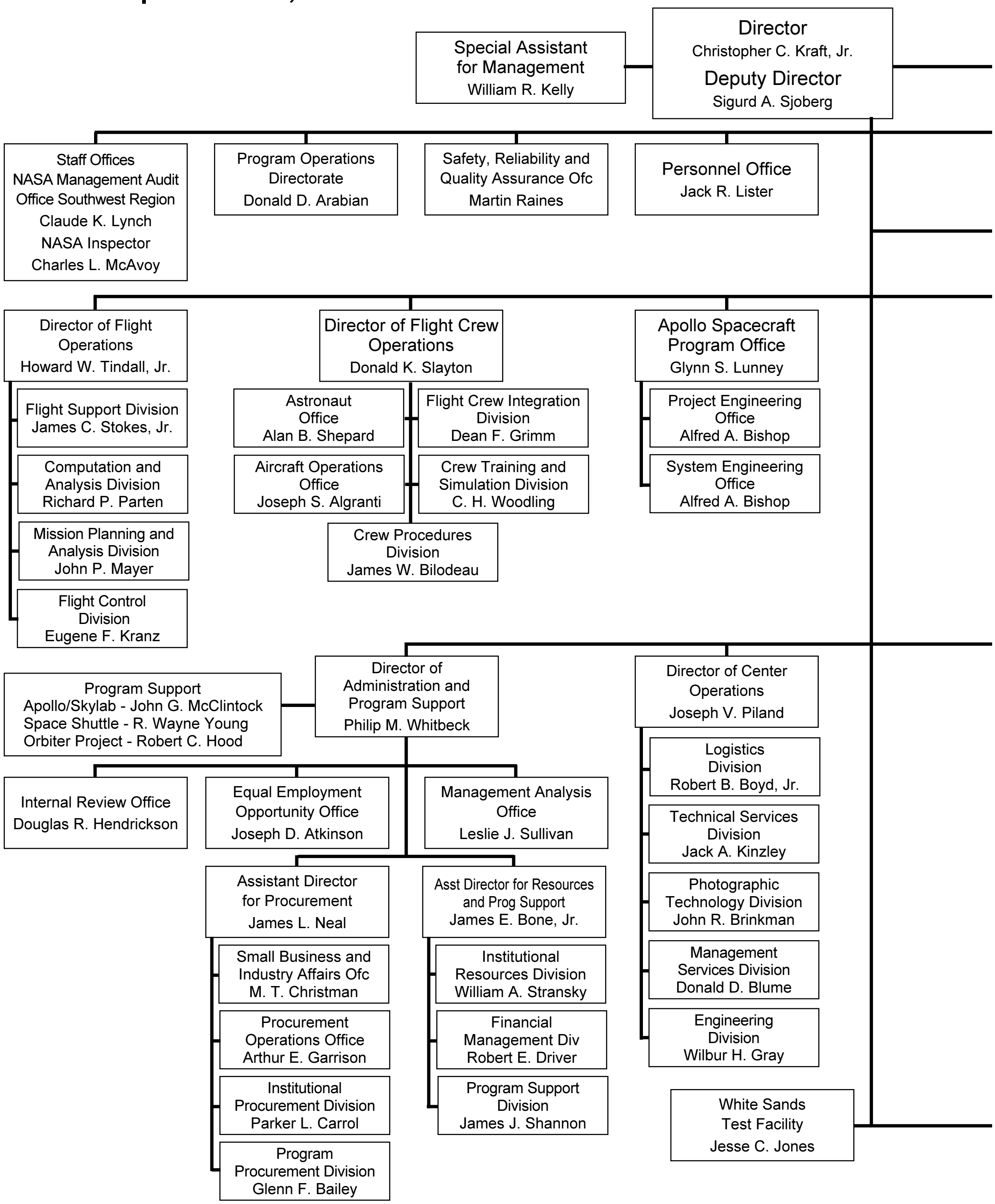
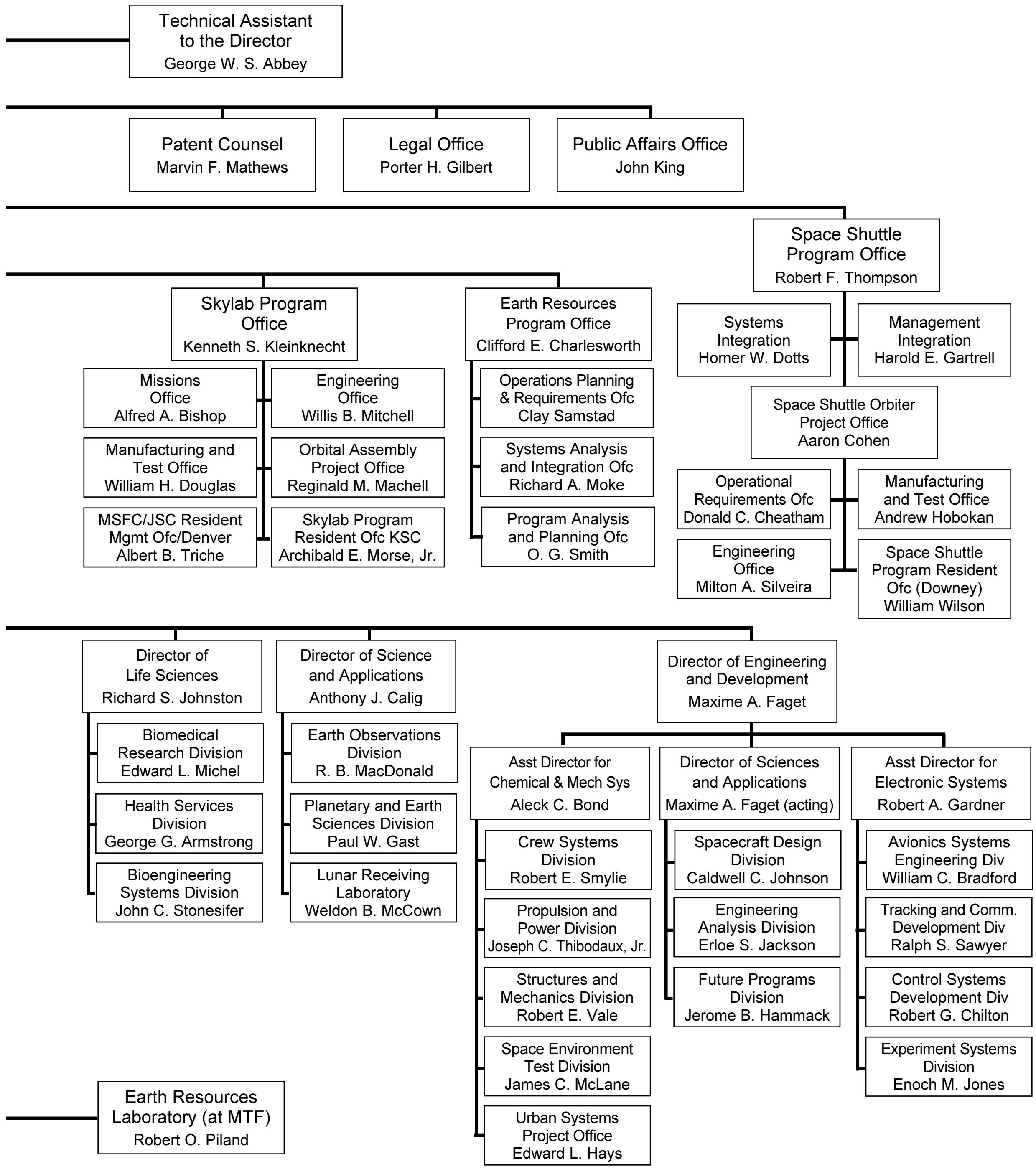


FIGURE 13. Organization as of March 1973


Technical Assistant to the Director
George W. S. Abbey
Patent Counsel
Marvin F. Mathews
Legal Office
Porter H. Gilbert
Public Affairs Office
John King
Space Shuttle Program Office
Robert F. Thompson
Systems Integration
Homer W. Dotts
Management Integration
Harold E. Gartrell
Space Shuttle Orbiter Project Office
Aaron Cohen
Operational Requirements Ofc
Donald C. Cheatham
Manufacturing and Test Office
Andrew Hobokan
Engineering Office
Milton A. Silveira
Space Shuttle Program Resident Ofc (Downey)
William Wilson
Skylab Program Office
Kenneth S. Kleinknecht
Missions Office
Alfred A. Bishop
Engineering Office
Willis B. Mitchell
Manufacturing and Test Office
William H. Douglas
Orbital Assembly Project Office
Reginald M. Machell
MSFC/JSC Resident Mgmt Ofc/Denver
Albert B. Triche
Skylab Program Resident Ofc KSC
Archibald E. Morse, Jr.
Earth Resources Program Office
Clifford E. Charlesworth
Operations Planning & Requirements Ofc
Clay Samstad
Systems Analysis and Integration Ofc
Richard A. Moke
Program Analysis and Planning Ofc
O. G. Smith
Director of Life Sciences
Richard S. Johnston
Biomedical Research Division
Edward L. Michel
Health Services Division
George G. Armstrong
Bioengineering Systems Division
John C. Stonesifer
Director of Science and Applications
Anthony J. Calig
Earth Observations Division
R. B. MacDonald
Planetary and Earth Sciences Division
Paul W. Gast
Lunar Receiving Laboratory
Weldon B. McCown
Director of Engineering and Development
Maxime A. Faget
Asst Director for Chemical & Mech Sys
Aleck C. Bond
Crew Systems Division
Robert E. Smylie
Propulsion and Power Division
Joseph C. Thibodaux, Jr.
Structures and Mechanics Division
Robert E. Vale
Space Environment Test Division
James C. McLane
Urban Systems Project Office
Edward L. Hays
Director of Sciences and Applications
Maxime A. Faget (acting)
Spacecraft Design Division
Caldwell C. Johnson
Engineering Analysis Division
Erloe S. Jackson
Future Programs Division
Jerome B. Hammack
Asst Director for Electronic Systems
Robert A. Gardner
Avionics Systems Engineering Div
William C. Bradford
Tracking and Comm. Development Div
Ralph S. Sawyer
Control Systems Development Div
Robert G. Chilton
Experiment Systems Division
Enoch M. Jones
Earth Resources Laboratory (at MTF)
Robert O. Piland

There were several long-range by-products of the reductions. The center lost its young people and part of its future; it lost much of its "hands-on" learning experience because of the in-house personnel reductions; and the center began relying more on its contractors.[10]

While the center reduced its civil service staff by about 600 persons between 1970 and 1972 through retirements and transfers, contractor employment dropped even more precipitously. Budget guidance from Headquarters indicated that MSC might "be required to achieve a lower employment level for the end of FY1972 than had previously been planned." Kraft announced in February 1972 that although the new ceilings had not been established as firm requirements, the center was required to prepare contingency plans to reduce its personnel beyond the levels previously anticipated before the close of the current fiscal year, make deeper cuts for fiscal year 1973 (to a new ceiling of 3727 employees), and reduce its average GS grade by .05—which meant reductions in pay or no promotions for many employees.[11] The center established an "outplacement center" to help the "riffed" employees find new positions. Many employees elected retirement. This was a sad beginning for a year which brought the highly successful Apollo 16 and 17 lunar explorations.

During this difficult period, the activity level and program responsibilities of MSC were being increased rather than decreased. The last two Apollo lunar missions flew in 1972, the orbital workshop and three manned Skylab missions were all launched in 1973. The Mission Control Center and recovery teams were on constant duty throughout the year, and throughout it all training and preparations were in progress for the 1975 Apollo-Soyuz joint mission. Indicative that the center had embarked upon a new era, but one drawing heavily from its past history and resources, in early 1973 MSC became the Lyndon B. Johnson Space Center.

Former President Lyndon B. Johnson, who had retired to his ranch on the banks of the Pedernales River near his boyhood home at Johnson City, Texas, died on January 22, 1973. "Few men in our time," President Richard M. Nixon said, "have better understood the value of space exploration than Lyndon Johnson. . . . Johnson drew America up closer to the stars, and before he died he saw us reach the Moon—the first great plateau along the way." It was he who helped draft, introduce, and enact the legislation creating NASA. Johnson's senatorial colleague, Lloyd Bentsen, introduced a Senate Resolution to rename MSC for Johnson: "Just as the Houston facility is a physical center of the space program," Johnson was perhaps, "the spiritual center." Bentsen called Johnson the "father of the space program" and NASA Administrator James C. Fletcher described him as the "principal architect of this Nation's space program." MSC personnel were pleased to have NASA's Texas center renamed for Johnson. The name change was effective on February 17, and a formal dedication was held at the center on August 27, 1973.[12]

While dignitaries and Johnson Space Center (JSC) personnel memorialized Lyndon Johnson, the second contingent of Skylab astronauts circled the heavens above in a near-Earth orbit. Skylab made a somewhat faltering start with the launch of the unmanned orbital workshop on May 14. A micrometeorite shield was ripped off during its launch. One solar panel was lost and the other failed to properly deploy, cutting electrical power available to one-half that expected. The loss of the shield also raised the temperature levels within the station to dangerous levels. JSC and Marshall Space Flight Center personnel mobilized for intense collaborative studies of the situation and developed what appeared to be workable solutions within a matter of days. Astronauts Charles Conrad, Jr., Joseph P.

Lady Bird Johnson and Center Director Chris Kraft during JSC dedication ceremonies on August 27, 1973. Just as the Houston facility was thought of as the physical center of the space program, Lyndon Johnson was remembered as "the spiritual center."

Kerwin, and Paul J. Weitz went to the Marshall Space Flight Center in Huntsville, Alabama, for a quick study on repair and restoration of the workshop. On the morning of May 25, they launched from Kennedy and docked with the workshop about 6:00 in the evening. During a number of EVAs, the astronauts erected a parasol of ultraviolet resistant materials "conceived, developed and constructed" by JSC engineers and technicians within one week, cleaned up the debris from the damaged meteoroid shield, and freed the undeployed solar power array. They initiated or completed a large number of experiments and returned to Earth after 28 days in space. The mission passed the Soviet's spaceflight endurance record, and turned a near-disaster into an outstanding success. While the Skylab crew was in orbit, 36 JSC employees retired from federal service as part of the NASA funding cutbacks.[13]

The Skylab 3 crew, including Alan L. Bean (commander), Owen K. Garriott (science pilot), and Jack R. Lousma (pilot), accompanied by two spiders, a swarm of vinegar gnats, a half-dozen mice, and an aquarium of fish, docked with the orbital workshop 8$^1/_2$ hours after lift-off on July 28. Bean had been the fourth man to walk on the Moon. Garriott had a doctorate in electrical engineering from Stanford University, and Lousma held a commission in the U.S. Marine Corps and degrees in aeronautical engineering. The crew encountered stability problems caused by faulty thrusters aboard the command module, had difficulty adjusting to weightlessness, and observed and photographed one of the largest solar flares ever recorded. Fifty-nine days later they returned with a new endurance record and a long list of scientific experiments completed—but the experiments that sought to study the circadian rhythm of pocket mice and gnats failed because of broken circuits providing power to the experimental package.[14]

On October 1, 1973, while astronauts Gerald P. Carr, Edward G. Gibson, and William R. Pogue trained for the final Skylab mission, NASA celebrated its 15th birthday. Skylab 4 launched from Canaveral on November 16, and 8 hours later docked with the workshop. The crew spent a record 84 days, 1 hour, and 16 minutes in space—including Christmas Day, 1973. The astronauts observed that the Earth looked terribly small from space; it was a "tiny blue island in the vast sea of space." Moreover, its populations seemed to be crowded into very small hospitable zones amidst vast areas of desolation. They were also the first humans to observe a comet from space. They photographed the passage of Comet Kohoutek, only recently discovered by Professor Lubos Kohoutek from an observatory in Czechoslovakia.[15] The Skylab crew returned on February 8, 1974. The Skylab office at JSC closed the following month.

A new JSC organizational review concluded that the center could no longer use Apollo-type program or project offices for the multiple programs anticipated in the future. Too many project offices and too many divisions and branches created fragmented responsibilities, scheduling difficulties, and operational inefficiencies. Project offices, it was recommended, should plan, coordinate and direct activities, while the regular line organizations such as administration, engineering, science, medicine, flight, and flight crew should provide technical and administrative support for all programs. Lead personnel from the line offices were to be attached to the program office to coordinate project planning with line office support. Personnel from other centers and "user agencies" needed to collocate with their respective activities offices at JSC. Finally, hardware development at JSC should remain the single responsibility of the Engineering and Development Directorate.[16]

As the Apollo era wound down, personnel recruiting and retention became an increasingly critical problem. Unless the center could, in the face of current personnel freezes and budget cuts, devise means to recruit young administrative and technical personnel, it could "run out of gas." Some economies could be obtained by consolidating support contractor work. For example, thermal and structural analysis and computer programming services were being provided by numerous contractors. Consolidation of service contracts could reduce costs and probably improve service.[17] Shrinking resources, as well as program diversification, mandated center reorganization and operating efficiencies.

While engineers worked to launch and operate Skylab, JSC experienced many consolidations and reorganizations. Thus the old Administrative Directorate became two new offices. The new Administration and Program Support Directorate headed by Philip H. Whitbeck focused on business management in support of the program offices and other center organizations, while a Center Operations Directorate headed by Joseph V. Piland had responsibility for facilities and center support services.[18]

The program offices (Apollo, Skylab, and Shuttle) reported to the Center Director through the Deputy Director. The Administration and Program Support Directorate assigned its own program managers to each program office.[19] Reminiscent of the subsystem managers assigned to contractors, the Administration Directorate's program managers provided greater flexibility in serving the needs of the project offices (figure 14).

The center reorganizations sought to address the seemingly interminable problem of effectively linking permanent center line directorates and support services to the program or project offices. Each of the past programs usually required the unreserved energy of the entire center. But those programs, Mercury, Gemini, Apollo, and Skylab, were relatively short-lived. When each ended, organizational structures had to be realigned to the new program. Long-term programs such as the Shuttle, accompanied by many diverse programs and projects, would require a constant shifting of center resources. A necessary but previously nonexistent mechanism for more responsive and efficient allocation of resources would be to institutionalize advanced planning.

Administration and Program Support Directorate, 1971

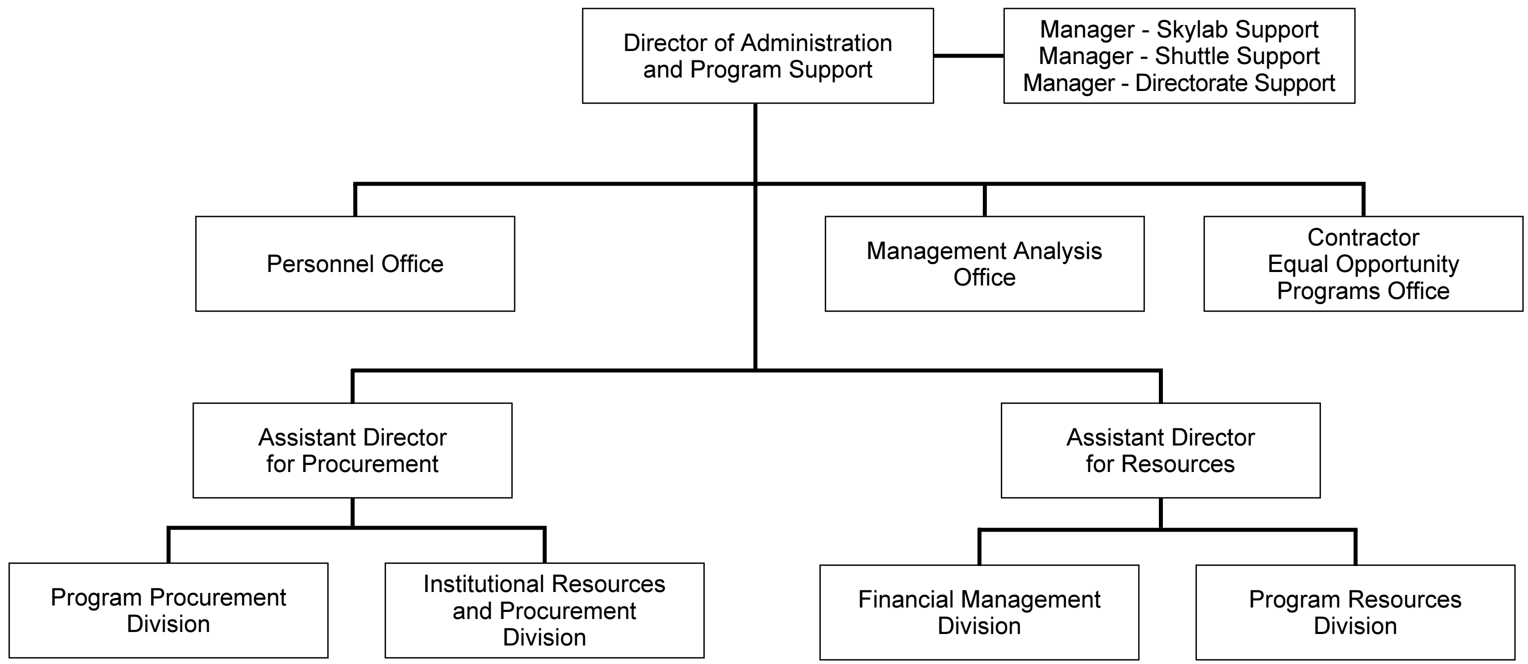


FIGURE 14. Organization as of January 1971

Advanced planning evolved from the ad hoc Apollo Extensions and Apollo Applications study groups to become institutionalized as the Advanced Missions Program Office. That functional office was now transferred to a new Future Programs Division under Jerome B. Hammack (Chief), which reported to Max Faget's Engineering and Development Directorate.[20] The Future Programs Office became the Advanced Programs Office within the Engineering and Development Directorate and much later advanced planning was elevated to the program office level with the creation of a New Initiatives Office reporting to the Center Director.

Other organizational changes came in response to a shift in spaceflight program emphasis. Whereas, at least through Apollo 11, spaceflight programs concentrated on development and operations, later Apollo and then Skylab flights focused on operations, science, and applications. Although a Science and Applications Directorate was established under Wilmot N. Hess in 1967, it held a secondary if not controversial status at the center.[21] A reorganization of the Science and Applications Directorate by the new director, Anthony J. Calio, in 1971 denoted the rising significance of science and applications in spaceflight programs. The Lunar Sample Office supervised the Lunar Receiving Laboratory. A Planetary and Earth Sciences Division included Physics, Geophysics, Geology and Geochemistry Branches, and a separate Earth Observations Aircraft Program Office provided data to correlate with information from space missions (table 7).[22]

A special Earth Resources Experiments Package (EREP) Investigations Office was created in January 1972 to manage the contracting phase of Skylab experiments. The manager of the EREP Investigations Office, O. Glenn Smith, on the staff of the Skylab Program Office, managed the contracting for the Science and Applications Directorate.[23]

As did the Administration Directorate, the Science and Applications Directorate coordinated with the program offices through assigned managers. Thus, Charles K. Williams, assigned to the Engineering Office of the Skylab Program Office, was responsible for the engineering and integration of the EREP being developed by the Science and Applications Directorate into the Skylab systems. He provided a single point of contact for all the program offices, line offices, contractors, and all organizational elements relating to the EREP and its integration into the Skylab program.[24] Through such interfaces, program management became integrated into the line functional divisions of the center consistent with the recommendations of the organizational study completed in 1970.

One of the most fascinating management challenges faced by the JSC and NASA during the post-Apollo initiatives was working with engineering and administrative counterparts in the Soviet Union during the Apollo-Soyuz Test Project. The program began by a direct request of President Nixon that NASA seek to develop significant foreign participation in post-Apollo programs. Nixon was very responsive to a suggestion from Administrator Paine that a joint U.S.-Soviet space project be sought and, with the approbation of the President, in late 1969 Paine sent Mstislav V. Keldysh, President of the Academy of Sciences of the U.S.S.R., copies of reports on long-range American goals in space. He invited the Soviets to join in a cooperative project. Keldysh suggested that a meeting be held by representatives of the two nations to discuss the possibilities. Although a meeting was not scheduled until late the following year, an exchange of correspondence explored the possibilities of a joint docking maneuver by an Apollo and a Soyuz spacecraft.[25]

TABLE 7. Science and Applications Directorate

Office of the Director	A.J. Calio, Director
Lunar Sample Office	J.W. Harris, Manager
Planetary and Earth Sciences	P.W. Gast, Division Chief
Physics Branch	R.J. Kurz, Chief
High Energy Physics	R.J. Kurz, Acting
Astrophysics Section	Y. Kondo, Chief
Geophysics Branch	D.W. Strangway, Chief
Geology Branch	W.C. Phinney, Chief
Geochemistry Branch	P.R. Brett, Chief
Isotope Section	P.W. Gast, Acting Chief
Mineralogy/Petrology	P.R. Brett, Acting Chief
Earth Observations Program Office	A.H. Watkins, Manager
Mission Management Branch	W.A. Eaton, Chief
Engineering and Requirements Branch	B.R. Hand, Acting Chief
Lunar Receiving Laboratory	P.J. Armitage, Manager
Curator	M.B. Duke, Chief
Facilities System Branch	I.E. Campagna, Chief
Laboratory Operations Branch	K.L. Suit, Chief

Source: MSC Announcement 71-54, April 15, 1971, Reference Series, JSC History Office.

In October 1970, Bob Gilruth headed a small NASA delegation for an initial visit to Moscow to discuss a joint venture. Glynn Lunney, who became the center's project manager for the Apollo-Soyuz flight, accompanied Gilruth. The Soviet team was headed by Boris M. Petrov, chairman of the Soviet Intercosmos Council. The representatives agreed to establish "working groups" to study systems for making Soviet and American spacecraft compatible for rendezvous and docking maneuvers. George Low and Mstislav Keldysh then met in January 1971. In April 1972, Low went to Moscow with Glynn Lunney for more intensive discussions. This meeting resulted in a final accord. Subsequently, when President Nixon visited Moscow on May 24, 1972, he and Alexei Kosygin, Chairman of the Soviet Council of Ministers, signed an agreement providing for cooperation and the peaceful use of outer space by the two nations. The leaders specifically approved the Apollo-Soyuz flight being planned and they agreed on a 1975 launch.[26]

While the diplomatic significance of a joint Soviet-American space venture in 1975 was considerable, the engineering aspects of that project faced formidable difficulties. A large delegation of Soviet and American engineers met at JSC in June 1972, and began the very serious work required to make the wholly independently designed and constructed Soyuz and Apollo spacecraft compatible. The two craft would require compatible docking hardware, radio communication modes, rendezvous navigational aids, cabin pressures, and intravehicular communication systems. Moreover, the flights would necessarily require cooperative "live" or real-time management by the launch and flight control teams—one located in the Soviet Union and the other in the United States. Flight teams and ground control teams needed long hours of joint training and simulation. There were marked differences in language, management, and engineering practices that compounded the technical differences. Simple geographical distance made travel and communication difficult. Six technical working groups (including the project directors) with Soviet and American counterparts on each were established to manage the Apollo-Soyuz Test Project.[27]

Glynn S. Lunney took representatives of three of the working groups with him to Moscow in October, accompanied by O.E. Anderson, Jr. from the Headquarters Office of International Affairs, three engineers from North American Rockwell, and secretaries and interpreters. Soviet and American engineers visited and collaborated while cosmonauts and astronauts trained at JSC and the U.S.S.R. Flight control teams in both countries ran simulation exercises. Each control center had direct communications with the other country's spacecraft. The two centers were linked by nine telephone lines, two of them equipped (in 1975) to handle facsimile transfers. Two television links connected the control centers by satellite. During the mission, six Americans and six Soviet mission specialists competent in each other's language and in technical terminology assisted in the other nation's control room.[28]

Three years after its approval, Alexei A. Leonov and Valeriy N. Kubasov were launched aboard Soyuz 19 on July 15, 1975, from Baikonur (Kazakhstan) in the Soviet Union. A few hours after the Soviet launch, Thomas P. Stafford, Vance D. Brand, and Donald K. Slayton were launched from Florida aboard Apollo CSM 111. The two vehicles then "found" each other following a script of very carefully timed and calculated orbital and phasing maneuvers. They began docking maneuvers on July 17 and completed the docking about 12 hours later. When the hatch swung open at 2:17 p.m. Houston time, the television camera showed tangled, spaghetti-like communication cables in the Soviet Soyuz craft. Then the Soyuz commander, Colonel Alexei A. Leonov, a cosmonaut since 1960, and Colonel (soon Brigadier General) Thomas P. Stafford, an astronaut since 1962, greeted each other. "Glad to see you," Leonov said, and the astronauts clasped hands, bridging for a brief time an incredible chasm of space, and the then almost equally insurmountable obstacle of national rivalry and cold war.[29] This is what the world saw and heard. It was an impressive and historic moment. What they did not see was that the moment also reflected the technical as well as political merger of two unlike systems.

The crews, in various combinations, entered each other's compartments, conducted a number of simple scientific experiments, and after 2 days of "joined" operations closed the hatches and undocked. An additional docking maneuver was completed before the final separation on July 19. Soyuz 19 returned to Earth on July 21, and the Apollo crew remained in orbit until splashdown on July 24. During the descent, the astronauts failed to activate two landing switches at the proper time causing nitrogen tetroxide fumes to enter the cabin. The pilot, Brand, lost consciousness and all of the crew became ill. When pure oxygen flooded the cabin, the astronauts recovered and made a safe landing. They were hospitalized for 2 weeks for treatment and observation, before going to Washington D.C., with their families for press conferences.[30]

This July 1975 photograph of the Soviet Soyuz spacecraft, taken from the American Apollo spacecraft, is remarkable not only in documenting the technological feat of the U.S.-Soviet space rendezvous mission, but as evidence of a thaw in the omnipresent cold war that continuously threatened to erupt into open hostilities.

President Gerald Ford, who replaced Nixon in 1974 when the latter resigned under "Watergate" pressure, presented the astronauts Distinguished Service Medals, announced Stafford's promotion to Brigadier General, and had a private luncheon for the astronauts and their families. The crew then met briefly with Congressman Olin Teague, attended a reception hosted by NASA Administrator James Fletcher, and finally got a warm welcome back home in Houston. Then the astronauts were joined by cosmonauts Leonov and Kubasov for a 2-week tour of major American cities followed by a tour of Soviet cities.[31] It was at once a triumphant and eloquent finale for the Apollo program, and an uncertain and disquieting epilogue for the Apollo lunar missions. The brief crack in the Iron Curtain soon closed, and the political and technical dividends of the Apollo-Soyuz mission were left to be determined in some indeterminate future.

A hiatus set in. There would be no more manned spaceflights until the beginning of a new decade. But there was work to do and the promise of a bright future. That future, as Bob Gilruth observed, rested on the development of America's new space transportation shuttle system. The Shuttle, as did Skylab, emerged out of early considerations for establishing a permanently manned orbiting laboratory or space station in orbit about the Earth. The establishment of the Saturn-Apollo program, with its emphasis on large payload capabilities and fewer launches, as opposed to smaller payloads and more frequent launches consistent with a reusable aerospace-type vehicle, actually delayed active development of a space shuttle. Plans for a reusable vehicle "moved downstream by one vehicle generation." The primary rationale for the development of a reusable Earth-to-orbit craft, when it finally came to fruition, had to do with cost reductions.[32]

The Marshall Space Flight Center continued work on the reusable vehicle concept, and in January 1963 developed a statement of work for a fully reusable rocket-powered vehicle. The vehicle was to have low acceleration levels to accommodate non-astronaut passengers, easy access to payload bay areas, and multiple reuse of all stages. Marshall Space Flight Center let independent study contracts to Lockheed Aircraft Company ($428,000) and North

By 1977, the Apollo-Saturn hardware had been retired. This S-1C stage of the Saturn V launch vehicle is being transported by barge for display at JSC.

American Aviation ($342,000). There were other in-house and small contractor analyses. Paraglider studies and contracts for land recovery of Apollo systems related both to reusable vehicle concepts and to reducing space vehicle recovery costs. Conceptual ideas for recovery and reuse of space vehicles and Saturn stages included "air snatches," parachute and retro-rocket recovery, hot-air balloons, and expandable wings.[33]

Early concepts for the reusable space vehicle stressed horizontal take-offs and passenger reliability and safety. Air-breathing propulsion, linked with rocket engines, was believed required for initial flight stages. Configurations for reusable craft ranged from a 10-ton orbiter for passenger transportation, to a 50- to 100-ton space truck cargo carrier. Numerous space shuttle studies completed between 1963 and 1967 established, among other things, a preference for a vertical take-off mode and the elimination of air-breathing engines from incorporation in the propulsion system. Studies also proved the feasibility of a fully reusable two-stage launch vehicle, but indicated that at launch rates of four to eight per year, a reusable lifting vehicle coupled with an expendable launch vehicle would be more economical.[34] A decision on adopting the fully reusable or partly reusable system was not reached until 1971.

By 1967, a consensus developed that a new spacecraft, coupled with an updated Saturn I first stage booster, would be useful for several decades and would produce the most savings that could be expected from reusability. The reusable shuttle studies began to tie in with AAP/post-Apollo planning. Max Akridge, in the Program Development Directorate at the Marshall Space Flight Center, attributes the real inception of the

Shuttle to an Apollo applications conference in Houston on October 27, 1966, attended by A. Daniel Schnyer from Headquarters, Harold S. Becker, C.H. Rutland and Akridge from Marshall, and W.E. (Bill) Stoney, Caldwell Johnson, Ed Olling, Carl Peterson and others from MSC. The meeting resulted in an agreement between Marshall and MSC, with the concurrence of Headquarters, that Marshall and MSC should pursue independent studies of a shuttle system reflecting the parameters of a March 1966 statement of work for a Reusable Ground Launch Vehicle Concept and Development Planning Study (which focused on a nine-person reusable vehicle).[35]

But a conference at Headquarters on January 19, 1967, stressed using the present stable of space vehicles without new launch vehicle development in order to reduce the strain on NASA budgets. And despite a sharpening of the definition of a reusable vehicle, prototypes still varied rather widely from a modified Apollo four- to six-person module, to a new nine-man space ferry being studied by McDonnell Douglas, to a rocket plane strapped onto a Saturn launch vehicle. While technical studies continued on the merits of different systems, "policy" deliberations became increasingly pertinent. George Mueller called a meeting with center representatives and contractors at Headquarters on January 6, 1968, to discuss orbital transportation concepts—and *low cost* operations.[36] Mueller outlined the status of the problem at that time:

> Where we stand now is that feasibility generally has been established for reusability. And we have much data on many concepts. We have an uncertain market demand and operational requirements. The R&D costs for fully reusable systems, including incremental development approaches, appear high. Personnel and cargo spacecraft seem to dominate Earth-to-orbit logistics costs. R&D costs for new logistics systems are in competition with dollars to develop payloads/markets (dollars are scarce).

Participants reviewed with Mueller the studies and conclusions reached thus far by the centers and their contractors relating to a reusable space transportation system. They pondered, "What should we do?"[37]

With the encouragement of the Air Force, which was studying orbiting laboratories and aerospace planes, NASA held a number of work sessions in April and May of 1968 to establish a general agreement of what "we should work toward." The sessions produced 10 variations of a statement of work for a logistics space vehicle, but there was a consensus on guidelines that the emphasis for the shuttle would be for space station logistics missions, the payload range would be from 5000 to 50,000 pounds, and it should be operational by the mid-1970's.[38]

In October, Clarence Brown and Max Akridge from Marshall Space Flight Center flew to MSC to talk with Wayne Corbet, Don Hathaway and others about issuing a joint Phase A (concept definition) study request for proposal. MSC issued the request with proposals to be in by November 29. After an evaluation by teams at Marshall and MSC, the two centers sent a joint TWX to Headquarters requesting approval to award a contract. At Headquarters, Robert Voss resolved some problems involving the request with the two centers, and on December 10, a final letter requesting authority to negotiate and award Phase A shuttle contracts, signed by Marshall and MSC representatives and with the concurrence of Voss, went to NASA Headquarters.[39]

Mueller then called Wernher von Braun asking him to support the shuttle rather than continuing to urge an interim vehicle. Von Braun replied, "If Nixon wants to spend $3 billion, who am I to say no?"[40] But Headquarters approval of the contract negotiations remained on hold while Apollo 8 was readied. That was the flight, it should be recalled, that was advanced to a lunar orbital flight through the collaborative efforts of Marshall and MSC. That successful flight, and the subsequent lunar landing in 1969, strongly advanced the prospects for a post-Apollo shuttle program.

On January 23, 1969, George Mueller approved contract negotiations for the initial shuttle design work and specified that the contract negotiation team would include members from MSC, Marshall Space Flight Center, and Langley Research Center, with the negotiation team to be headed by MSC. It should be noted that this initial arrangement very likely established a precedent for the shuttle "lead center" concept by which MSC was designated the lead center for shuttle developments with other centers to provide independent but supporting roles. To be sure, lead center style operations were a strong part of the NACA tradition, wherein each center specialized in a certain expertise. Another precedent for what became a lead center relationship in the shuttle program came from the early days of NASA when, under Langley Research Center "lead," Ames and Lewis Research Centers played strong supporting roles in developing the Mercury and Apollo program concepts.

Now, in the initial Shuttle contracting phase, Langley Research Center was to manage a contract with McDonnell Douglas, two contracts with Lockheed Missiles and Space and with General Dynamics/Convair were to be directed by Marshall Space Flight Center, and MSC was to manage a contract with North American Rockwell involving configurations for an expendable lower stage and a reusable spacecraft. Each contract was budgeted in the $300,000 range. Other feasibility studies of alternate shuttle designs were being conducted privately by Martin Marietta, and the following year new contracts were awarded to Grumman Aerospace/Boeing, Lockheed Aircraft, and Chrysler Corporation. A review team chaired by Headquarters' A. Daniel Schnyer, Director of Transportation Systems, provided a joint review and reported regularly to a space station coordinating group.[41] What this meant was that the "Shuttle era" began for different reasons than did Mercury or Apollo, and it used different management approaches. It involved NASA-wide integrated management systems with a lead center providing direction and coordination but not necessarily control.

During discussions in Houston of the North American Rockwell study on an expendable low-cost launch vehicle and a reusable spacecraft, MSC personnel (and prominently Ray Bradley, John Hodge, and Caldwell Johnson) disagreed rather strongly with ground rules urged by Engineering and Development Director Max Faget. Daniel Schnyer and Robert Voss from Headquarters were also unhappy. Faget urged cost reductions on the launch vehicle configuration through the use of a solid propellant rocket-powered vehicle, eliminating redundant and expensive launch escape systems. He advised working on only one or two launch vehicle/shuttle configurations.[42]

John Hodge believed that during initial discussions of the shuttle, Gilruth and other administrators at MSC generally were "dead against" the shuttle as it had evolved, while

George Mueller at Headquarters was its primary champion and regarded the shuttle as a necessary program to relieve the inevitable hiatus that would follow the close of the Apollo flights. Although the shuttle was keyed initially to a projected space station (for which Marshall Space Flight Center was to be the designated lead center), an internal MSC study completed under Hodge's auspices recommended that NASA's priority be the shuttle. A space station could be attempted only after the completion of a shuttle.[43] But through at least 1970, NASA anticipated working both on the shuttle and the space station as integral components of Earth resources studies and further planetary exploration.

While differences and discussions between the centers, between the centers and Headquarters, and within the centers over the feasibility and design of a space shuttle continued, Headquarters initiated a joint DoD/NASA study on space transportation. Concurrently, it should be recalled, a special task committee under Milton Rosen and a planning steering committee headed by Homer Newell were preparing recommendations for future programs. Mueller next assembled shuttle task teams from Marshall, MSC, Langley, and Kennedy Space Center to help define the tasks and approach to the planned DoD/NASA study. He also appointed a Headquarters task group including representatives from each of the spaceflight centers to work in Washington, D.C., under Leroy Day until the joint DoD/NASA study was completed. Meanwhile, at each center at the end of April, or during the first few days of May, contractors presented their initial findings and data from Phase A studies. On May 5, 1969, Mueller opened a shuttle review conference by noting he expected to have reports from Day's in-house space task group by mid-May and from the joint DoD/NASA study by mid-June. He added that he and Grant Hanson, formerly a General Dynamics vice president now working with the DoD study group, would present the reports to President Nixon's Space Task Group.[44]

Mueller also outlined the developing configuration of the shuttle, and personally urged the selection of a vehicle with a 50,000-pound payload capability (a container 22-feet in diameter by 60-feet long) and a clam-shell bay door or a swing-nose hatch. In describing the work of such a vehicle, Mueller compared it to a pickup truck, a utility vehicle, or a city shuttle. Max Akridge threw in the word "space" and the "space shuttle" nomenclature became the accepted in-house phrasing for NASA's officially designated space transportation system. The total system included launch capabilities, an integrated launch and reentry vehicle (ILRV), a low-cost Earth-orbit transportation system, and a reusable space vehicle.[45]

During the remainder of 1969, study contracts were revised and extended as new data and resolutions developed. Controversy over design, motives and methods was most often intense. Meetings, most of them in Washington but many at the centers, and review sessions with contractors led finally by December 1969 to the production of a report "Summary Report, Recoverable vs. Expendable Booster, Space Shuttle Studies," that was concurred in by MSC, Kennedy Space Center, and Marshall Space Flight Center. The point of the report, according to Max Akridge, was that by the beginning of the new decade, NASA had exhaustingly explored all possibilities for post-Apollo space vehicles and concluded that the best of the possibilities was a fully reusable system.[46] That, of course, is not what came to be.

Significantly, the Shuttle program was to be one element of the broader space goals outlined by President Nixon's Space Task Group in 1969. But as explained in the previous chapter, the definition of goals failed to equate with worsening budget realities. The

Space Shuttle was to have been one component of a multidimensional program including a permanent space station, unmanned probes to the planets, and manned planetary missions. But a year passed with all eyes still on the Apollo lunar missions and the energies of MSC still devoted almost exclusively to current programs and missions.

The Shuttle got put on the shelf during 1970, while Congress, the Executive branch, and the public agonized over Vietnam and double-digit inflation. President Nixon attempted to "wind down" the war in Vietnam, and announced a plan for the phased withdrawal of American troops. However, in April the administration decided to invade Cambodia in order to destroy enemy bases and supplies thus, in theory, improving the ability of South Vietnamese forces to sustain the war without American involvement and shortening American participation in the war. Many Americans, however, saw this simply as an extension of the war in southeast Asia and public protests rose precipitously. The violent deaths of student protesters at Kent State in a confrontation with National Guard troops created deepening public tensions and controversies. While the public was fast losing interest in Apollo lunar landings and was seemingly uninspired by the announced Skylab or projected Apollo-Soyuz programs, plans for a future program such as the Space Shuttle or a space station were even more remote from the public mind.

Only in 1971 did the President approve program development of the Space Shuttle, and although the related programs were not literally abandoned, in reality what remained in place after 1972 was an emasculated Shuttle program without a space station. There were plans for unmanned planetary scientific probes, orbital and suborbital physics and astronomical projects, life and bioscience experiments, basic scientific and aerospace research, and the promise of continuing study on space stations and planetary missions.[47] But for relatively small attention spans during the Skylab and Apollo-Soyuz missions, space for the American public was passing out of sight and out of mind. Gilruth was quite right when he said in December 1970 that the Shuttle would be the keystone of all future efforts in space, but he was unaware that the Shuttle would be for a time the only manned space program under development.

To be sure, the dwindling contractor and civil service personnel at the center had a very full plate from 1970 through 1975, with the conclusion of the Apollo lunar flights, the development and operation of Skylab, and the Apollo-Soyuz mission. As time passed, MSC began devoting more of its resources to shuttle development and management.

Despite the inactivity on the Shuttle front in 1970, there were some important management changes bearing directly on the Shuttle program in that year. At Headquarters, George Mueller resigned as Associate Administrator for Manned Space Flight on December 10, 1969, to accept a position as vice president of General Dynamics Corporation. Controversies within NASA over the Shuttle program, budgetary uncertainties, and personnel changes at higher and lower levels within NASA undoubtedly contributed to Mueller's departure. Dale D. Myers, a vice president and general manager for the Space Shuttle program at North American Rockwell, replaced Mueller. Myers became involved in North American's space-related programs in the 1950's, and was the company's Apollo program manager in 1964, and a vice president and general manager of the command and service module work in 1968. He was tremendously knowledgeable about NASA and its space programs and had a strong record in production and management discipline.[48] He also had a long and effective working relationship with MSC.

Myers assumed his new position keenly aware of the "watershed" situation in which NASA found itself. In May 1969, prior to the lunar landing, Myers expressed concern that a lunar landing might be followed by a tremendous emotional letdown in the aerospace industry. North American employment peaked long before. Company employment was already down by one-half and still falling. He sensed an apparent lack of interest in Congress and a propensity in the public mind to solve budget problems by cutting NASA expenditures. A lot of people, he said, seemed to think that a lunar landing, when it came, was going to be just one big trick. People, he said, have got to develop a much longer view of space.[49] He prepared for what became an inordinately long Shuttle development and production program.

Myers established the Shuttle Program Office under the Office of Manned Space Flight and appointed Charles J. Donlan (an original member of the Space Task Group who had remained at Langley as associate director when the new MSC was located in Houston) program manager. Myers also created a new Shuttle Program Task Group under Donlan's direction to reexamine the technical and management aspects of the Shuttle program. Donlan urged a restructuring of the management system to provide greater coordination and integration among the centers on the Shuttle project, but to establish one center, MSC (Johnson Space Center), as a lead center. He recognized, as did Gilruth, that the Shuttle was intrinsic to future efforts in space and was most closely related to the technical expertise possessed by MSC. Low supported Donlan in the "lead center" concept.[50]

He regarded the lead center management style as a way to preclude some of the conflicts between Headquarters and the field centers that plagued the Apollo program. Low and Myers wanted to hold Headquarters staffing to a minimum. NASA personnel cuts from the 1968 peak averaged one-third by 1973, with heavier cuts being made at Headquarters and Marshall Space Flight Center than at other centers. Thus the lead center concept was appealing as a device to most efficiently use NASA's dwindling resources.[51]

Although he had some reservations, Myers announced in June 1971 that MSC would have "program management responsibility for program control, overall systems engineering and system integration, and overall responsibility and authority for definition of those elements of the total system which interact with other elements . . . (a Level II responsibility)." The center also received primary development responsibility for the orbiter stage of the Shuttle, while Marshall would manage the booster stage and main engine for the Shuttle, and Kennedy Space Center would design and direct launch and recovery facilities. Headquarters (Level I), Myers announced, was to manage the overall program and have primary responsibility for the assignment of duties, basic performance requirements, allocation of funds to the centers, and control of major milestones.[52]

Shuttle project integration, it was felt, could be accomplished with Apollo-type Integration Panels. The panels included members from Kennedy, Marshall and MSC with Marshall and MSC co-chairing the panels. Under the lead center system, integration panels reported to a Systems Integration Office at MSC which in turn reported to a Policy Review Control Board chaired by NASA Headquarters.[53]

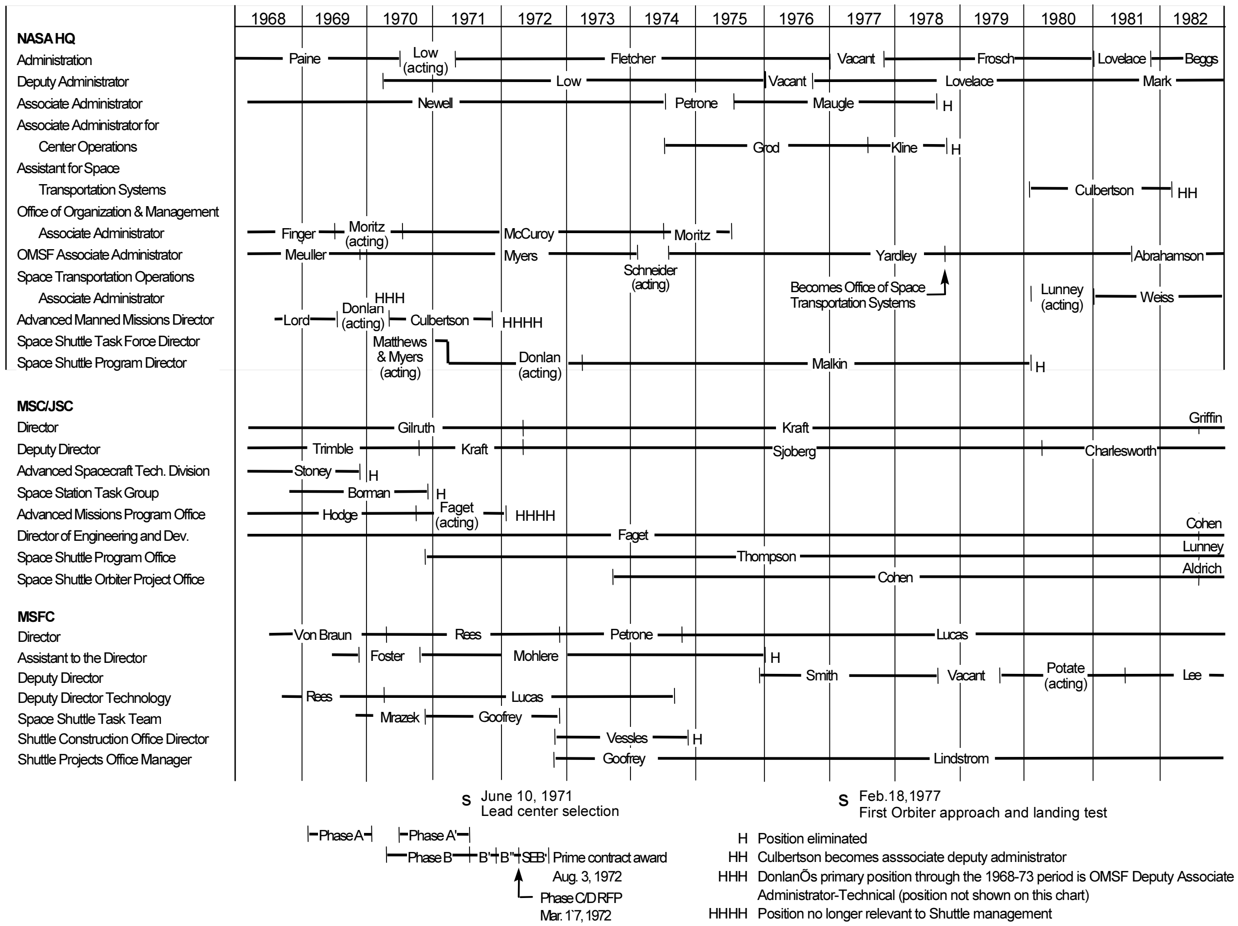


FIGURE 15. Shuttle Management Timeline, 1968-1982. This chart portrays the development and administrative history of the Space Shuttle from its conceptual stage in 1968 through the first flight in 1981.

Space Shuttle responsibilities at MSC rested on Robert F. Thompson, whom Gilruth appointed Space Shuttle program manager in April 1970. Another of the original Space Task Group personnel from Langley Research Center, Thompson headed the MSC Landing and Recovery Division during the Mercury, Gemini, and early Apollo years; and in 1966 became manager of the Apollo Applications Program Office and then Skylab. As manager of the Apollo Applications Program Office, Thompson "grew up" with the Shuttle. As the lead center program management office, Thompson's office provided a day-by-day integration and overview of all aspects of Shuttle design and development. Thompson said that his office was "concerned about everything happening across the total program."[54] Despite the fact that the Shuttle management system was in place by the end of 1971, the Shuttle remained in a very tenuous and uncertain status.

When NASA Administrator James C. Fletcher replaced Paine in April 1971, he became convinced that a fully reusable Shuttle such as that recommended in the NASA "Summary Report" of December 1969, and which bore a tentative price tag of $10.5 billion, would literally "not fly"—especially with Congress. He initiated a "rigorous restudy and redesign." The redesign study, focusing on the use of an expendable launch stage (which had long been considered a viable alternative to a fully reusable shuttle) lowered costs by about one-half.[55]

Fortified with this new data, on January 5, 1972, George Low and Jim Fletcher met with President Nixon and John Erlichman, his staff assistant, for a review of the Shuttle program. Nixon wanted the Shuttle program to stress civilian applications, but not to exclude military applications. Moreover, he wanted the public informed of any military applications. Nixon was pleased that ordinary people could fly in the proposed Shuttle. He was concerned that the skills of people in the aerospace industry be preserved. He said NASA should stress the fact that the Shuttle was not a "$7 billion toy," but a good investment. Even if it were not a good investment, Nixon continued, "we would have to do it anyway, because spaceflight is here to stay." He did ask that NASA stress international cooperation and participation for all nations. When the meeting ended, Nixon approved the Shuttle program and asked Erlichman to mention to Secretary of State Henry Kissinger the international aspects of the Shuttle and the planned U.S.-Soviet docking maneuver for 1975.[56]

The MSC Shuttle Program Office began "gearing up" for the center's lead role. Thompson added a few personnel to his small program office, and began making arrangements for key personnel from other participating centers to sit on his staff in Houston. Since much of the actual Shuttle design and development would come from the Engineering and Development Directorate, Milton A. Silveira became the representative from that directorate on Thompson's program staff.[57] Under the new organization scheme, program offices would avoid duplicating any technical or functional operations available within the center or at other NASA installations. Duplication and competition between program offices and line offices, such as had occurred under the Gemini and Apollo programs, were to be avoided by preserving the *program* management and administrative integrity of the program office.

For example, traditional administrative tasks not directly program related were performed by the MSC Administrative and Program Support Directorate. R. Wayne Young from the Administrative Directorate was assigned to the Shuttle Program Office to manage contracts and procurement through the directorate. When it became appropriate, the Flight Crew Operations Directorate and the Medical Research and Operations Directorate assigned representatives to the program office.[58] Thus the system sought to preserve the integrity of the line offices, prevent duplication, reduce expenses, and promote overall operating efficiency. The management style was actually not so new. It really reflected a more disciplined subsystem management approach in reverse, that is the subsystem managers (or their representatives) were assigned to the program office. Wesley Hjornevik, it should be remembered, placed contracting and procurement personnel in program and functional offices, and with contractors when it seemed advisable, to expedite and improve program development.

With 6 or 8 years of tumult, confusion and controversy behind it, the Shuttle now began to move from the conceptual stage to the design and production phases. Rocketdyne was selected to design and build Shuttle engines under Marshall Space Flight Center management. MSC awarded separate contracts for developing and testing ceramic insulating materials for Shuttle reentry to McDonnell Douglas, General Electric, and Lockheed. The center also requested proposals for the development of a low-density ablative material and a design study for an orbital maneuvering system (OMS). NASA invited proposals for the development of the Shuttle in March, and in May received proposals from North American Rockwell, McDonnell Douglas, Grumman, and Lockheed. An interim letter contract was approved with North American Rockwell in August 1972, and the final contract was approved in April 1973. North American Rockwell (which became Rockwell International) subcontracted with Fairchild Industries for the vertical tail section of the Shuttle, with Grumman for the delta wings, with Convair Aerospace Division of General Dynamics for the mid-fuselage, and with McDonnell Douglas for the OMS. In early 1974, JSC contracted with IBM for computer software designs for Shuttle support systems. A full-scale center/contractor design review was held in early 1975, and a test model (comparable to the boilerplate Apollo mockups) was completed in 1976. Despite the intensive work on the Shuttle, flight was still 5 years away.[59]

Much of the work on the Shuttle had to do with the design and construction of laboratory and testing equipment at JSC that could handle the intricate electronics and flight simulation tests required for the Shuttle. Most of the existing laboratory and testing facilities, such as the thermal and materials test laboratories, continued in full service. The more sophisticated design of the Shuttle required considerably more advanced test facilities. Computer hardware and software programs, communications, electronics, and even materials used in Mercury, Gemini and Apollo command modules were primitive compared to the degree of sophistication of Shuttle orbiter systems. Space had so advanced the frontiers of aerospace and related technology that earlier systems and the tools used to build and test them were becoming obsolete. The Shuttle Avionics Integration Laboratory (SAIL) coupled with a new Shuttle mission simulator became the primary test and training devices for the development and operation of Shuttle systems.[60]

New technology, or the application of new knowledge in engineering, medicine and the sciences, had much to do with creating tools and laboratories that could manage that knowledge effectively. Much of the post-Apollo work of NASA and of JSC had to do on the one hand with harnessing the existing knowledge in such a way as to advance humankind's explorations in space either by increments or by leaps and bounds, and on the other hand to understand and apply the new knowledge obtained from space both to further the frontiers of space and to improve the welfare of people in the United States and on Earth.

Paradoxically, trauma followed the triumphs of the Apollo program for NASA and MSC. Skylab, the Apollo-Soyuz mission, and even the Space Shuttle with its emphasis on economies were products of the changing political and budgetary environment for space programs, as were the new organizational structures and management approaches.