

## CHAPTER 12: *Lead Center*

Johnson Space Center personnel began work on the Space Shuttle under the cloud of reductions in force, tightening budgets, growing public apathy or outright criticism, and unclear and changing program directives. In the 1970's, JSC evaluated its new status, responsibilities, and capabilities; retooled to provide the engineering expertise demanded by the Shuttle; helped NASA and American society assimilate the lessons learned from Apollo; and recruited and trained astronauts for missions scheduled for the 1970's, but actually flown in the next decade. Between 1970 and 1974, JSC lost one-fourth of its employees, Marshall Space Flight Center lost one-half, and NASA Headquarters accepted the largest proportion of required "RIF" or reductions in force in order to help preserve field operations. Budgetary constraints contributed to the decision to establish a lead center management approach for the Shuttle and affected program development.<sup>1</sup>

The Space Shuttle developed in a markedly different social and technical environment than had the Mercury, Gemini, and Apollo programs. Cost pressures had a direct bearing on its conceptual design and configuration. Costs affected the contract awards, production schedules, and mission planning. Costs affected the style and structure of Shuttle management. Based on budget guidelines for fiscal years 1972 through 1974, NASA Administrator James C. Fletcher described the program as "austere but meaningful."<sup>2</sup> The Sputnik crisis environment of the 1960's became a business-management-cost-effectiveness environment for the 1970's.

A NASA management document called the *Catalog of Center Roles*, issued in April 1976 and revised in December, explained the overall role of NASA as "the conduct of a broad program of research and development aimed at achieving the Nation's goals in aeronautics and space." The NASA field centers possessed distinctive capabilities, technical excellence, and the facilities necessary to accomplish the overall program. JSC's principal role had to do with the development and operation of manned space vehicles and the required support technology and systems.<sup>3</sup>

Headquarters assigned JSC responsibility for the development of the orbiter, that is, the manned shuttle vehicle, and designated it lead center for the management of the entire Shuttle system. This meant that while Headquarters was responsible for planning and policy decisions (Level I), JSC had responsibility for Level II program management relating to systems engineering and integration, configuration, and design and development. Level III project offices such as the orbiter manager at JSC, the booster manager at Marshall Space Flight Center, and the launch and recovery operations manager at Kennedy Space Center had responsibility for their specific projects and reported to and were coordinated and integrated by the Program Manager at JSC. Under the lead center management system, Headquarters effectively delegated engineering and development management to JSC while allocating resources among the centers and among tasks and exercising overall program direction. The Shuttle Program Office exercised cost controls within the funding parameters established by NASA.<sup>4</sup>

The lead center system facilitated the integration of technical capabilities with program management. The Shuttle Program Manager, Robert F. Thompson, came through the NACA ranks into NASA. He earned a degree in aeronautical engineering at Virginia Polytechnic Institute in 1944 and served a 2-year stint as a naval officer before joining NACA in 1947. An original member of the Space Task Group, he later headed the MSC Landing and Recovery Division before becoming manager of the Apollo Applications Program (and Skylab). Now, as Shuttle Program Manager, Thompson had overall responsibility for the development of the Shuttle.<sup>5</sup> Other centers provided support roles and services for the Shuttle program and worked through the JSC Shuttle Program Office.

Thus, Marshall Space Flight Center's project units having responsibility for the design, development, production, and delivery of the Space Shuttle main engine, the rocket boosters, and the external hydrogen-oxygen propellant tanks reported to the JSC Shuttle Program Office. Langley Research Center examined Shuttle payloads and conducted aerodynamic and aerothermal testing. Ames Research Center focused on Shuttle passenger selection criteria, astronomical observation systems, aerothermal dynamic analysis, and materials development. Goddard Space Flight Center provided tracking, data acquisition, and network planning support for Shuttle flights. Dryden Flight Research Center gave direct support to JSC for approach and landing tests of the Shuttle orbiter. Personnel from Marshall Space Flight Center, Kennedy Space Center, and JSC were collocated in certain functional areas at the centers under the authority of the Space Shuttle Program Manager.<sup>6</sup>

The program manager had overall technical responsibility and management authority. He directed, scheduled and planned all elements of design and production, and imposed cost controls on all elements of the program. The office responded directly to Headquarters on matters relating to the Shuttle, and communicated directly with Shuttle project offices at Marshall Space Flight Center, Kennedy Space Center, and JSC.<sup>7</sup>

The Orbiter Project Office at JSC managed the design, development, testing, and production of the orbiter (or manned spacecraft vehicle which is today considered the Shuttle). Aaron Cohen, the Project Office Manager, and a native Texan from Corsicana, completed undergraduate work in mechanical engineering at Texas A&M University, and pursued advanced studies in mathematics and mathematical physics at Stevens Institute of Technology, New York University, and the University of California-Los Angeles before joining MSC in 1962. He became Chief of the System Integration Branch of the Systems Engineering Division, Apollo Command and Service Module Manager (1969-1972), and headed the Shuttle Orbiter Project Office from 1972 to 1982. In 1986, Cohen became Director of JSC.<sup>8</sup>

He organized the orbiter office under a deputy manager with four functional branches each headed by a manager and attached a resident manager to the primary orbiter contractor, North American Rockwell at Downey, California (figure 16). The orbiter project branch managers were in effect special divisions of the center's line directorates collocated in the orbiter office exclusively for work on the Shuttle.<sup>9</sup>

Cohen's orbiter team constantly encountered technical difficulties in the design and construction of the wholly new flying machine. Orbiter management required close and almost constant technical liaison with the line divisions of JSC and other centers. One of the first construction problems on the Shuttle came with the discovery that the contractor used

## Orbiter Project Office

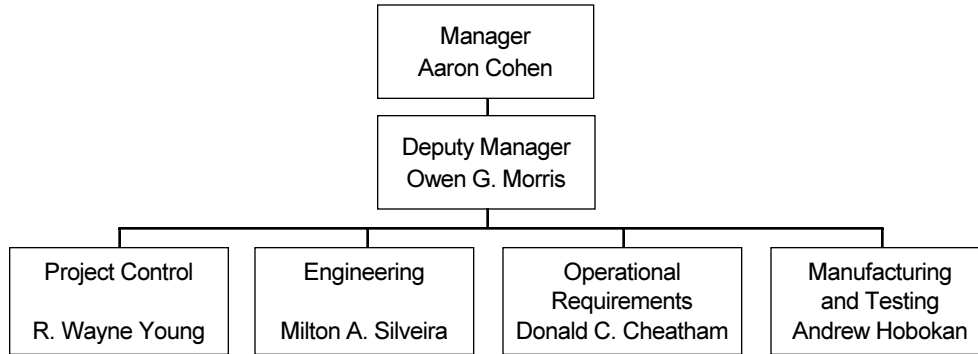


FIGURE 16. Organization as of 1973

soft rivets in the fabrication of the forward fuselage. “Why, in this high-technology spacecraft, should we use something so mundane as soft rivets?” Cohen wondered.<sup>10</sup>

The Shuttle and its components required constant testing, adjustment, and frequent redesign or reconstruction. Since the Shuttle was to be the first spacecraft launched on its maiden flight with people aboard, testing, redundancy, and man-rating the systems became more imperative. Testing was a more critical development tool for the Shuttle than had been true in previous programs where unmanned flight testing had been the rule. The Shuttle differed from previous spacecraft, not only in being a more complex flying machine, but in the manner of management and in the greater reliance and emphasis upon ground-testing its components.

Financial resources, always important of course, exercised much greater influence on decisionmaking in the Shuttle program than in previous programs. Thompson spent much of his time as program director attempting to reconcile budgets with elements of risk in the technical development of the Shuttle. Headquarters spent most of its time trying to convince Congress, the Executive branch, and the Office of Management and Budget (OMB) of the essential nature of each technical component of the Shuttle, and of the overall validity of America’s space program. Moreover, declining or fixed budgets were being further undermined in the 1970’s by the declining buying power of the dollar. Chris Kraft recalls vividly, for example, that when the OMB funded NASA’s 1972 budget which had been appropriated with 1971 dollar values in mind, the funding represented a serious budget cut for NASA because inflation had reduced the buying power of the dollar by almost 10 percent.<sup>11</sup>

President Richard M. Nixon justified proceeding with the space transportation system in January 1972, because it would, he said, “take the astronomical costs out of astronautics.” But critics in Congress were unconvinced. Senator William Proxmire (D-Wisconsin) said it was a “great mistake and an outrageous distortion of budgetary priorities.” Senator Edmund S. Muskie (D-Maine) thought it was extravagant, Senator Vance Hartke (D-Indiana) labeled the Shuttle decision an example of “pork barrel politics,” and Senator Walter Mondale (D-Minnesota) called it a ridiculous project.<sup>12</sup>

Shuttle defenders argued that reusable space vehicles could bring operating costs down to one-tenth that of Apollo vehicles. The promise of economies in space operations helped sell the Shuttle program to Congress and to the American people. But the subsequent failure of the Shuttle to achieve those economies became the “original sin” of the Shuttle program. Costs projected on the basis of as many as 50 Shuttle flights each year proved totally unrealistic. Although firm data is elusive because of many different methods for counting costs, Shuttle cost and performance comparisons are indicated in table 8. Generally, the cost of space transportation, as a percentage of the NASA budget, dropped from 56 percent of the budget during the development of the Saturn and Atlas Centaur launch vehicles to about 45 percent of the budget when the Shuttle became the primary launch vehicle (table 9).

Cost considerations affected the configuration of the proposed Shuttle and booster systems. Funding limitations during the start-up years that caused scheduling delays contributed to increasing costs of completion. NASA selected a parallel burn rather than a

*TABLE 8. Launch Capability,  
Launch Vehicle Cost and Performance Comparison*

Launch Vehicle	Payload to 160nm due East	Cost per Flight*	Failure Record	Reliability	Cost per Pound**
Delta II	10100	40	6 of 122	0.95	3960
Atlas IIAS	18100	110	6 of 48	0.875	6077
Titan III	27000	130	7 of 115	0.939	4815
Titan IV	44400	180	0 of 2	1.000	4054
Ariane 4	21000	110	5 of 36	0.86	5238
Long March 2e	15200	40	2 of 21	0.905	1645
H-II	22400	70	No flts to date		3125
Proton	38000	75	12 of 120	0.9	1974
Zenit	28000	70	0 of 23	1.000	2500
Shuttle	50000	295	1 of 35	0.971	5900
Saturn V	270000	1145	—	1.000	4241
Energia	250000	634	—	—	2533









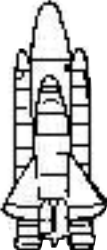
- Notes:
1. All vehicles' performance normalized to due east launch from the customary launch site.
  2. Cost per flight is derived from various sources as a function of the particular vehicle. Cost of launch has a fixed minimum, but may increase significantly depending on negotiated price of interfaces and services.
  3. Shuttle costs are the operating budget 1989 through 1994 for all the flights manifested allocated to 10 percent less flights.
  4. Shuttle cost per pound is all allocated to payload—none to the orbiter and crew.
  5. Saturn V and INT 21 at two per year. Hardware costs were 495 M. The balance is KSC processing.

\* Millions of dollars

\*\* Thousands of dollars

Source: Papers of Joseph P. Loftus, Assistant Director (Plans), JSC.

TABLE 9. National Launch Vehicles

	Pegasus	Taurus	Titan II (Castor IVA)	Delta II <sup>a</sup>	Atlas II <sup>a</sup>	Atlas II AS	Commercial Titan III	Titan IV (SRMU) <sup>b</sup>	STS
									
Responsible agency	DARPA	DARPA	USAF	USAF	USAF	COMSAT	COMSAT	USAF	NASA
Performance, lb. Low Earth polar	600	3000	4200 (10,000) <sup>c</sup>	--	--	16,200	--	32,000 (40,200) <sup>d</sup>	--
Low Earth due east	700	3600	--	11,100	14,300	20,000	31,000	39,000 (49,500) <sup>d</sup>	51,000
Reliability	0.98	0.975	0.96	0.96	0.94	0.94	0.96	0.96 - 0.93 <sup>e</sup>	0.98
Cost, \$ million	12	25	50	54	62	65	120	150	250
<sup>a</sup> Commercial version in production									
<sup>b</sup> Solid rocket motor upgrade									
			<sup>c</sup> Castor IVA performance			<sup>e</sup> With upper stage			
			<sup>d</sup> SRMU performance						

These vehicles will constitute the national space launch resources for the 1990's. The Air Force Atlas II, Delta II, and Titan II will handle lighter payloads, and the Titan IV with Inertial Upper Stage or Centaur upper stage will handle heavy, high-altitude satellites. The Air Force plans to phase out use of the Space Transportation System (STS) for most primary DoD payloads by 1993 and will use the Shuttle to fly secondary experiments thereafter. The commercial Atlas, Delta, and Titan are used by the commercial satellite (COMSAT) industry. The Pegasus and Taurus are representative of small launch vehicles being developed by the Air Force, the Defense Advanced Research Projects Agency (DARPA), and the commercial launch industry for a potential new class of lightweight satellites and quick-response tactical space support scenarios.

series burn for the solid rocket motor (SRM), in part because of lower cost and less technical risk. NASA selected a single contractor to provide engineering and integration for the Shuttle (Rockwell), and another for the booster (Thiokol) because of cost and management efficiencies. The decision to substitute a partially reusable for a fully reusable Shuttle system resulted in part from the need to reduce initial development costs at the expense of somewhat higher operating costs in the future. The decision to drop the external propellant tanks into the ocean after a suborbital staging, rather than boosting the tanks into orbit and having them deorbit by a solid rocket motor was shown by calculation “cost-effective” and a tradeoff for larger payloads. Although certainly costs always entered into NASA decisions, the Shuttle differed significantly from Gemini and Apollo experiences in that the “fiscal and political environment influenced detail engineering design decisions on a month-to-month, and at times a day-to-day, basis.”<sup>13</sup>

Budget reductions often translated into program delays and slippages, which in turn drove total Shuttle development costs higher. In August 1972, Dale D. Myers (Associate Administrator for Manned Space Flight) reported to NASA Administrator James C. Fletcher that Skylab funding was dangerously low and recommended reducing Shuttle funding, if necessary, to preserve Skylab. Caspar Weinberger, Director of the OMB, advised Fletcher that the administration wanted NASA programs to be sustained, but with fewer dollars. Weinberger did anticipate some budgetary improvements in fiscal years 1973 and 1974, but that was an uncertain future. On two occasions, in October and December 1972, Myers recommended canceling the Shuttle program if cost cuts recommended by OMB were approved. The DoD helped rescue the Shuttle program, but recommended payload and reentry and landing configurations that greatly increased development costs. Langley Research Center considered canceling its Shuttle payload studies because of budget cuts.<sup>14</sup> The financial duress continued throughout 1972 and 1973 and beyond.

JSC Director Christopher C. Kraft informed Dale Myers in October, 1973, that proposed budget cuts for 1973 and 1974 would have “negative effects” and constitute “unsound planning.”<sup>15</sup> Budget cuts directly affected the planned performance capability of the Shuttle, and resulted in slippages or deferrals in development. In March 1974, Administrator Fletcher explained that the \$100 million increase in the NASA budget scheduled for 1975 was less than the amount required simply to sustain existing levels of operation because of inflation and other adjustments. He announced another slip in the flight of the Shuttle from late 1978 to mid-1979.<sup>16</sup>

Fletcher retired on May 1, 1976. Alan M. Lovelace became acting administrator. In the presidential elections in November, Jimmy Carter defeated President Gerald Ford and became President in January 1977. Despite President Carter’s favorable statements about America’s space programs, money remained short and Congress continued its budget cutting. On May 23, President Carter appointed Dr. Robert A. Frosch, a former assistant secretary general of the United Nations (1973-1975), assistant secretary of the Navy (1966-1973), and associate director of the Woods Hole Oceanographic Institute, to head NASA.<sup>17</sup>

Lovelace and Frosch fought desperately to try to keep the Shuttle from being destroyed by Congress and the administration. NASA’s relations with Congress and the administration were either passive or reactive and defensive throughout the 1970’s. Chris

Kraft recalled a meeting at Goddard Space Flight Center in early 1977 where he exclaimed, “When are we going to expose the fact that we don’t have enough money to do this [the Shuttle]?” Shortly thereafter Kraft became Director of JSC, and Frosh, when briefing President Carter on the Shuttle program alluded to the fact that NASA would likely again slip the Shuttle flight schedule. “What do you mean?” Carter responded. The fact was, Kraft said, Carter’s SALT (Strategic Arms Limitation Treaty) talks with the Soviet Union presumed early completion of the Shuttle by the United States. Since the Shuttle comprised a considerable part of the United States’ leverage behind the arms limitation talks, President Carter began to move to help get Shuttle budgets and the development schedule back on track.<sup>18</sup> There were still 4 difficult years before the first Space Shuttle flew.

One by-product of the budget difficulties was something of a reconciliation or liaison between NASA and the scientific community, which had been highly critical of Shuttle expenditures on the grounds that they reduced budgets for scientific Earth and unmanned planetary missions. NASA accepted a greater role for the Shuttle as a research vehicle in order to win the support of the scientific community.<sup>19</sup>

At the same time, NASA did receive more support from the DoD, which had become concerned that the Shuttle’s demise would adversely affect national security. Deputy Secretary of Defense Kenneth Rush outlined a plan for DoD participation in the Shuttle program, which recognized that “it is essential that DoD continue to support the Shuttle program and that we vigorously plan to utilize the Shuttle’s advantages.” A special “Air Force User Committee” began studying Shuttle applications and DoD cooperation.<sup>20</sup> With the program under serious fire, NASA welcomed all allies, however disparate. Broadening the Shuttle support base and participation, however, affected configuration, payload planning, and costs. Science and defense received greater priority in mission planning.

Despite the fact that the science, defense, aerospace contractor, and NASA communities became less divisive and more collaborative in their support of the Shuttle, congressional expenditures for the Shuttle and for space, scientific, and nuclear programs remained very lean. Although it is somewhat misleading to compare the first 8 years of Apollo funding with the first 8 years of Shuttle funding, the figures do indicate that Shuttle development costs were considerably less than those for Apollo. It should also be noted that Shuttle dollars, particularly after 1973, had a constantly declining buying power or value as compared to Apollo dollars of the 1960’s era.

Not only did the Shuttle emerge in a very hostile budgetary environment, but it offered some new and difficult technological problems. The Shuttle was to be a considerably more complex machine than previous Apollo-Saturn systems. The main rocket engine had to be a high-performance engine capable of being throttled, turned off, and reignited. No space engine had yet been built to do that. No vehicle had yet been built that could be piloted both within and outside of the Earth’s atmosphere. The Shuttle was a launch vehicle, spacecraft, and glider. The thermal protection system, main engine, and avionics system were “outside the existing state of the art.” Moreover, “a 200,000-pound glider with a very low lift-to-drag ratio at the end of a landing strip many miles from its normal operating base presents some interesting logistics problems.” Finally, because it was designed for piloted landings, there could be no unmanned test flights as there had been for all previous space vehicles.<sup>21</sup>



*TABLE 10. Requested and Authorized Apollo and Shuttle Budgets for First 10 Program Years (millions \$)*

Apollo Requested/Programmed <sup>1</sup>			Shuttle Requested/Programmed		
1962	160	75.6	1970	9	12.5
1963	617.2	1,184.0	1971	110	78.5
1964	1,207.4	1,147.4	1972	100	100.0
1965	2,677.5	2,614.6	1973	200	198.6
1966	2,997.4	2,941.0	1974	475	475.0
1967	2,974.2	2,922.6	1975	800	797.5
1968	2,606.5	2,556.3	1976	1,527	1,206.0
1969	2,038.8	2,025.0	1977	1,288.1	1,413.1
1970	1,691.1	1,684.4	1978	1,349.2	1,349.2
1971	956.5	913.7	1979		

<sup>1</sup>Programmed funds are the amounts actually allocated for expenditure after congressional appropriations.  
 Note: Apollo program funding ceased after a 1973 program allocation of \$56.7 million.  
 Source: Linda Neuman Ezell, NASA Historical Data Book, II, p. 128; III, pp. 69, 71.

Previous spaceflight experiences, however, provided technological precedents that helped solve Shuttle problems. There was now a much higher experience base in the government/industry complex. Research airplanes (X series), Dyna-Soar and Gemini Earth landing studies contributed to Shuttle design. Tremendous advances in electronics and computer design facilitated the development of guidance and control systems and reliable pilot-controlled avionics systems. Both solid and liquid rocket engine history contributed to the design of the sophisticated engines. Silica-fiber based tiles protected with a boro-silicate material were chosen to cover the orbiter’s bottom and sides and thus help resolve the thermal protection problem which existing metals could not solve at acceptable weight levels. The leading edges of the Shuttle wings and body were covered with heat-resistant “carbon-carbon” developed from a rayon material. There were historical precedents (with flying model and wind tunnel verification) for piggyback transport of Shuttles on the Boeing 747, but whether the method of transporting would work remained unproven until it actually happened.<sup>22</sup> While the Shuttle system was something new and different, development could now draw upon a reservoir of aerospace technology which was virtually nonexistent even a decade earlier.

A considerable part of that technology was located at JSC in the form of the expertise of its personnel and its laboratory and testing facilities. Building a space vehicle, or perhaps any engineered machine, involved conceptualizing the final product and each component of that machine, designing the parts, testing the parts (sometimes redesigning them), then assembling the parts and testing the whole (and sometimes redesigning the parts or the whole). Often the design or even conceptualization of a device could not proceed until sufficient testing had occurred to indicate how one might proceed. For example, a Langley Research Center-designed Manned, Upper stage, Reusable Payload (MURP) craft described

as a “lifting body fuselage with variable geometry wings in a horizontal recovery, land landing vehicle” influenced the design of the Space Shuttle. MURP experimental vehicles of the early 1960’s provided the first real experiences with hypersonic and supersonic flight and ablative heat shields. Wind tunnel tests, simulated reentry trajectories and, finally in 1966 and 1967, the firing of model reentry vehicles called the ASSET and PRIME (34 and 55 inches in length, respectively) from high suborbital trajectories into the atmosphere, produced real reentry test results for bodies and wings that would have the configuration of the Space Shuttle.<sup>23</sup>

A part of the built-in system of redundancy in spacecraft had to do with the thorough testing of all materials, parts, and systems. Much of what JSC was and is has to do with its laboratory and testing facilities. Engineers could neither manage nor be engineers without such facilities. Those unique attributes which JSC contributed to Shuttle development included its past experiences, but most significantly its unique Mission Control Center and operations expertise, and its special laboratories that were not replicated anywhere else.

Those laboratories included the vibration and acoustics facilities, the Shuttle Avionics Integration Laboratory, the atmospheric reentry materials and structures laboratory, the thermal-vacuum laboratories, the electronic system test laboratory, the space environment simulation laboratory, the life sciences laboratory, and the Shuttle mission simulator. Less unique, but still reflecting the state of the art in those fields, were the radiation instruments laboratory, geology and geochemistry laboratory, photographic technology laboratory, geophysics and applied physics laboratories, a meteoroid simulation laboratory, thermochemical test areas, optical labs, and antenna and anechoic chambers. Instruments included magnetometers, spectrometers, a Van de Graaff facility to calibrate radiation detectors, radiometric counting equipment, and vacuum chambers—among other devices. Universities, laboratories, or other public and private agencies might have had some of the specialized laboratory equipment, but its assemblage and concentration at JSC was in itself unique. The center possessed the most advanced electronic, radio, and radar equipment available, and created some that was previously nonexistent.<sup>24</sup> The center provided the engineer a veritable cornucopia of testing and laboratory equipment, all with very serious and ineluctable purposes.



*Development of spacecraft such as Apollo and the Shuttle required unusual and “unworldly” laboratories such as this anechoic chamber at JSC. The chamber replicates space by absorbing radio and radiation emissions.*

### **Engineering Facilities at JSC**

*Comment by Henry O. Pohl, Director, Engineering*

To understand JSC and its facilities, it is necessary to understand the background of the men and women who moved from Langley Field to Houston. They came from a research background and were accustomed to operating with very small budgets. They did only what they themselves could accomplish to expand the envelope of flight. It is interesting to note that they never designed an airplane, yet every airplane of that era flew with Langley wings. They wrote the criteria and developed the formulas used by the various aircraft companies to design every wing. They often worked in crummy offices but had very fine laboratories.

They understood the value of good, accurate data. They understood the necessity to test their theories. They understood the absolute requirement for each engineer to understand his or her discipline and to understand firsthand the limitations and accuracy of the data. As flight speeds increased and missiles entered the scene, wind tunnels were no longer capable of providing the velocities, temperatures and pressures required to validate their theories. As a result, they turned their attention to placing models on top of rockets designed to place the model at the desired velocity and altitude. These models were precision devices and fairly expensive. Unlike models used in wind tunnels, these could be used only once. Therefore, it was essential that good, accurate data be obtained from each test. As a result, reliability also became important.

It was this experience base that the MSC personnel, charged with landing a man on the Moon within 8 years, brought with them from Langley Research Center. They realized they would have to train several thousand new employees in the exacting science of spaceflight. They realized that in a very few years they would have to depend upon these engineers and scientists to provide good, accurate data, and that many new theories would have to be validated. They realized that if they were to accurately supervise the multitude of contractors and systems, these new employees would have to develop confidence in themselves. The only way they knew to do this was to provide the facilities necessary to give employees the opportunity to verify their theories. This attitude was reflected by Hugh Dryden in an article published in *NASA Activities* (August 1976): “. . . each employee at NASA should be a doer of things, not just a watcher.”

Therefore, when they laid out MSC facilities in a cow pasture south of Houston, they took into account all the disciplines required to build and operate manned spaceships. These were the finest laboratories money could buy. The facilities were built, not because they could afford it, but because they knew they could not afford to be without. It was no accident that MSC contained facilities that specialized in the health and well-being of humans as well as operations in life support, materials, metallurgy, structural dynamics, acoustics, guidance, control, communications, tracking, propulsion, power, explosives, data acquisition, data reduction,

fabrication shops, machine shops, and large computers. One should remember that at the time MSC was designed, computers were mostly thought of as humans with Gerber Scales, slide rules, and mechanical calculators converting squiggly lines from oscillograph traces and strip charts to engineering units. Yet they knew that much more computing power would be an absolute necessity.

Moreover, the Mission Control Center was no accident. Langley/MSC engineers knew from their experience in flying models that it would be essential that they keep track of the status of the spacecraft and be able to reprogram the course of the missions if problems developed. Apollo 13 is a good example of where this forethought paid off. Similar examples can be cited in every discipline. Through the use of these facilities many of our current employees became true international experts in their disciplines.

This expertise, developed during the Apollo era, saw the Shuttle program through its developmental phase. Over the years, some of these facilities have changed very little. Much of the original equipment still functions and is in use. Some facilities are unique. Perhaps the greatest change in the facilities has been in the use of computers. We spend vast sums on new computing equipment and software each year—yet we no longer have state-of-the-art computers for spaceflight.

Another area in which NASA/JSC pioneered was in materials and metallurgy. Through better materials processes, stronger, lighter, and more consistent materials have been obtained. By thoroughly understanding the behavior of materials, it became possible to tailor materials for a specific application, resulting in lighter, more reliable systems. These processes have largely been adopted by the aircraft and auto industries.

There are over 70 laboratories and facilities listed in the Engineering Directorate Technical Facilities Catalog. These laboratories are located in 18 buildings, not including other laboratories used in Life Sciences and Operations. Sixty-four percent of the facilities were built in the 1960's, 10 percent during the 1970's, and 26 percent in the 1980's. During the 1980's facilities were added to accommodate robotics, microwaves, communications, data management, avionics integrations, and additional computer facilities. The replacement cost of test and evaluation facilities put in service during the 1960's would exceed \$390 million. Replacement costs for those added during the 1970's is estimated at about \$15 million, if the Shuttle Avionics Integration Laboratory (SAIL) were excluded. The \$630 million SAIL facility was put in place to design and verify the hardware and software used in the electronic flight control system on the Space Shuttle. Construction costs for additional facilities built in the 1980's was about \$16 million. In total, JSC technical and engineering facilities are among the most advanced and distinctive anywhere in the world and are central to the completion of the center's mission.

## Johnson Space Center, 1977

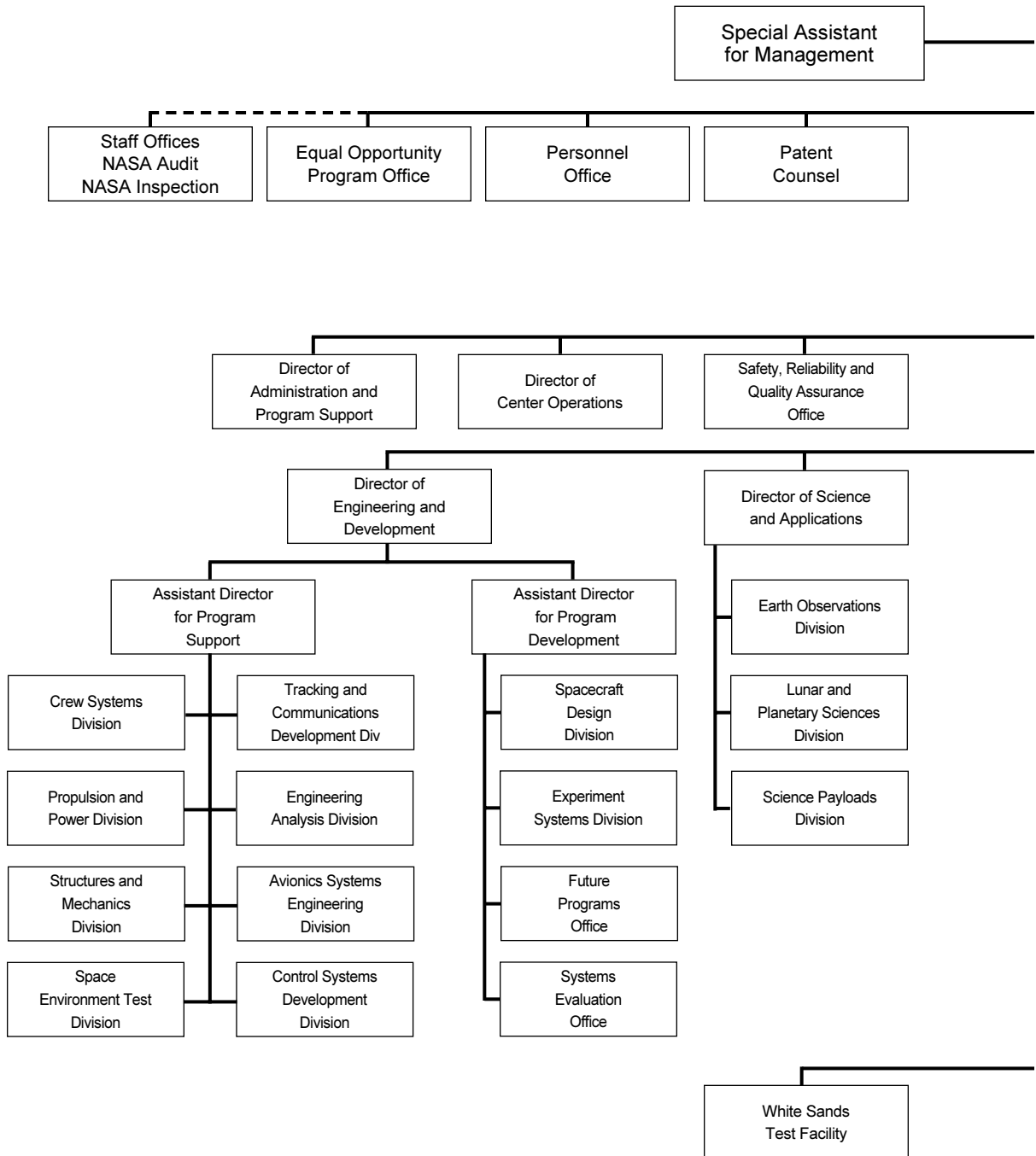
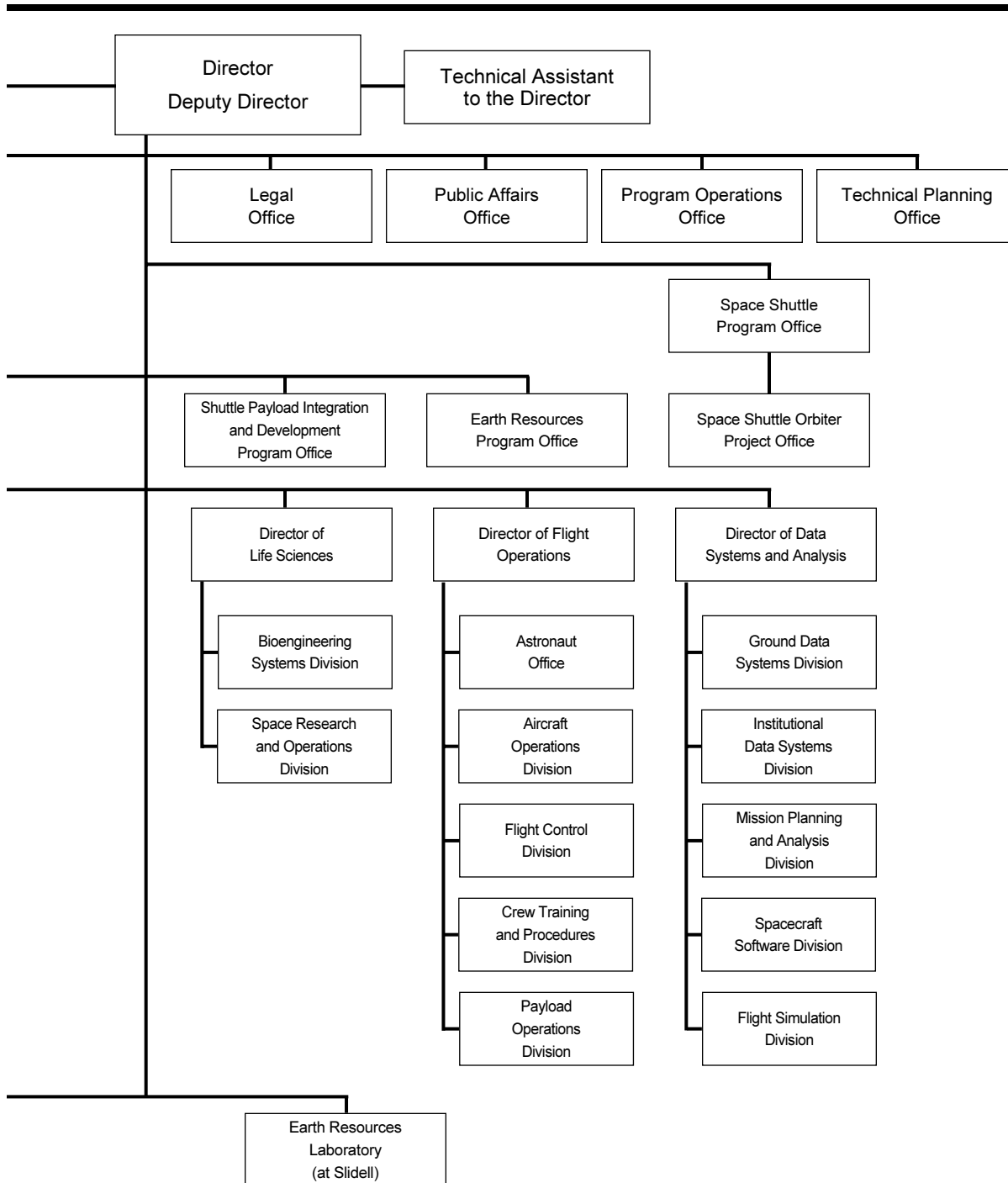


FIGURE 17. Organization as of January 1977



The history and culture of JSC is tied inextricably to its laboratories and tradition of hands-on engineering, but because much of its work could not be verified in Earth laboratories, JSC engineers relied heavily on analytical and computational methods of engineering. The culture of JSC engineers is described in the comment on engineering facilities at JSC by Henry Pohl who succeeded Aaron Cohen as head of Engineering and Development. Pohl began his career as a “rocket engineer” with the Army Ballistic Missile Agency in Huntsville, Alabama, in 1957. He transferred to MSC in 1962 as the senior propulsion engineer and became Chief of the Propulsion and Power Division in 1980 before being named Director of Engineering and Development in 1986.<sup>25</sup>

Within the testing and laboratory facilities at JSC, unseen and much of it literally underground, resided the heartbeat of the center. The laboratories operated within the Engineering and Development Directorate under a division chief and branch or section heads (figure 17). The Advanced Spacecraft Technology Division which became the Space Environment Test Division in the Shuttle era, managed the radiation and fields laboratories and test facilities. The Lunar Surface Technology Branch became part of the Science and Applications Directorate and managed the geology, geochemistry, cartographic, and geophysics laboratories. The old Meteoroid Technology and Optics Branch of Engineering, which directed the meteoroid simulation, and the applied physics (conducting optical experiments to determine methods of making space measurements which cannot be made from the Earth’s surface) and planetary atmosphere laboratories became elements of Science and Applications Directorate, Earth Observations Division and Science Payloads Division.<sup>26</sup> Although the division (and laboratory designations) changed over time, figure 17 indicates the divisions within the JSC directorates, most of which operated laboratories and test facilities.

The Crew Systems Division, responsible for “establishing and validating the physiological design parameters for manned spaceflight,” designed and tested everything having to do with life support systems. Food, spacesuits, water, waste, and health care fell under the division’s supervision. A space environment could complicate the most innocuous human function. Pre-Shuttle toilet facilities, for example, comprised essentially strapped-on tubes, bags, and diapers. Perfecting a workable toilet in a zero-gravity environment proved difficult but “do-able.”

A 20-foot and 8-foot diameter altitude chamber could simulate altitudes to 150,000 feet. A liquid nitrogen cold-trap tests heat exchangers and thermal characteristics. An envirotron chamber replicates a full range of vacuums, temperatures, and pressures. There are materials labs, chemistry and instrumentation laboratories, a waste management and microbiology laboratory, and a crew performance laboratory associated with the altitude chambers. The latter crew performance laboratory examines crew behavior under varying simulated extraterrestrial and flight conditions. An impact test facility determines what would happen to pieces of equipment such as gauges, lights, or cameras when subjected to shock. The flight acceleration facility, or centrifuge, was used to train crews and test their equipment through the Apollo era, but then was closed in the mid-1970’s, and the building became a Weightless Environment Test Facility.<sup>27</sup>

The world of computers changed markedly and rapidly during the first three decades of NASA’s existence. Generally, computer technology evolved from the massive

corporate-owned IBM-style 7090 computers using vacuum tubes into the new-generation microchip mainframe computers such as the IBM 7044/7094. Subsequently, these mainframe units became more sophisticated, but also less costly, as microchip and printed circuitry evolved. The IBM 360s and 370s characterized this second phase of the computer industry. At this point, new corporations and new products began to challenge IBM dominance. In the 1980's, Amdahl, Packard, and Texas Instruments, among others, became formidable contestants in the rapidly expanding computer market.

Personal computers became popular in the late 1970's and became indispensable in the 1980's. Initially, engineers regarded personal computers as toys or for typing. Not only were the PCs unsuitable for running the engineer's FORTRAN programs, but they tended to be beneath the dignity of the professional engineer. In time this changed, but some tension continued to exist between the advocates of mainframe computer systems and personal computers, and often between administrators who opted for less costly and often less current computer equipment. In this, JSC compared to most large organizations caught in the throes of rapidly changing computer technology.

Digital Electronics Corporation introduced its powerful and affordable VAX computers that brought forth a new generation of division and department-owned computers that could be directed to specific uses. Meanwhile, personal computers became more powerful. Networking and individual workstations began to blur the old lines between mainframe and personal computing. Once essentially a "corporate" operation, computing for NASA engineers (and engineers everywhere) increasingly became a personal operation despite the later introduction of yet another generation of "super" mainframe computers in the 1980's. JSC's "computer" culture tends to reflect this overall pattern of development.

The branches of the Engineering (previously Computation) and Analysis Division at JSC specialized in work on engineering analysis, flight mechanics and applications, data processing, programming, and data systems development. Major computers in use during the 1960's and 1970's included an IBM 7044/7094, two IBM 7094s, A Univac 1108, two Control Data Corporation (CDC) 3600s, several hybrid systems, and a number of lesser units. An idea of what this means is suggested by the fact that an IBM 7094 could calculate in 5 seconds what would otherwise involve 86 person-years of labor and the UNIVAC 1108 was three times faster than the IBM 7094.<sup>28</sup> Even these systems were outmoded almost as soon as they were in place. Both computer hardware (the equipment) and software (the program) are constantly upgraded.

VAX 11/785 computers began to handle such engineering design graphics packages (not available in the 1960's and 1970's) as PLAID and TEMPUS, which can give multidimensional views of design models. The pencil became almost obsolete in engineering design. Even the Apple Macintosh and other desktop computers offered state-of-the-art graphics packages in the 1980's that greatly advanced the frontiers of engineering design. NASA's first new-generation supercomputer, a Cray 2 located at Ames Research Center, can do a quarter of a billion computations per second. At the heart of JSC Mission Control Center in the 1980's were five IBM 308X class computers. JSC completed installation of its own supercomputer, an "Engineering Computation Facility (ECF) Class VI," using Cray and Amdahl data processors in 1990. The Space



Shuttle itself housed five interconnected (modified IBM AP101) computers, each about the size of a breadbox, which surpassed NASA's total computer capability of the Apollo era (but which by today's standards are slow). A special testing device, built specifically for the Shuttle, used 32 computers (primarily Perkin-Elmer 8/32 computers) which are tied together through two "host" UNIVAC 1100/44 computers.<sup>29</sup> These are the brains of the Shuttle mission simulator (SMS).

The SMS, which became operational in 1978 and has been updated periodically, marked a significant enhancement of the Apollo simulation laboratory complex. Managed by the Flight Simulation Division, SMS became the primary training device for Shuttle crews and for the Mission Control Center with which the systems are integrated. Built by Singer Company's Link Division, the major components of the simulator are a fixed base crew station, a network simulation system, and a motion base crew station. The device provides real-time mission simulation: prelaunch, ascent, orbit operations, deorbit, entry, approach and landing. The crew's orbital operations, visual scenes, and aural cues are "rigorously" simulated. In the motion base crew station, displays, control responses, and inputs are indistinguishable from those aboard the actual Shuttle. An instructor at a remote station can initiate over 3800 malfunction situations requiring crew responses. A network simulation system simulates the ground spaceflight tracking and data network which provides telemetry, tracking and communications with the actual Shuttle that is tied to the Mission Control Center through the Goddard Space Flight Center.<sup>30</sup> By the time astronauts complete their mission training on the SMS, they think they have already flown the mission—many times over.

Testing applies not only to machines and spaceflight equipment, but to the men and women who would fly those machines and use that equipment. A new-generation space vehicle, the Shuttle would be manned by new generation astronauts. NASA had last recruited astronauts in 1966 and 1967. The class of 1966 comprised 19 pilot astronauts, and in 1967, 11 scientist astronauts were selected for the lunar science missions. In 1978, both pilot astronauts and astronaut mission specialists were recruited. From over 8000 qualified applicants, NASA chose 15 pilot astronauts and 20 mission specialists. Pilot astronauts needed a minimum B.S. or B.A. degree in engineering, biological, or physical sciences with an advanced degree preferred and a minimum of 1000 hours of high performance jet aircraft experience. Mission specialists (and payload specialists) did not need flight time or pilot experience and were subjected to a less rigorous physical examination than the Class I flight physical, but academic credentials and psychological testing weighed heavily in the selections.<sup>31</sup> Reflecting the growing national concerns about opportunities for minorities, affirmative action, and civil rights, NASA's first Shuttle class included six women and four minority candidates.

The Shuttle astronauts, once admitted to candidacy, completed 12 months of rigorous training and testing before a final review and full acceptance into the program. Studies included guidance and navigation, astronomy, meteorology, math, physics, and computer programming. They spent a lot of time in the SMS. Astronaut Robert Crippen told Henry S.F. Cooper, author of *Before Lift-Off*, that "if it weren't for the mission simulators, flying in space at all would probably be impossible." A spacecraft crew flies only once, and when it does, it must be a crew in all that the term implies. The crew is created by the simulator.<sup>32</sup>

*Astronauts Class of 1978*<sup>33</sup>

Bluford, Guion S.	Brandenstein, Daniel C.*	Buchli, James F.
Coats, Michael L.*	Covey, Richard O.*	Creighton, John O.
Fabian, John M.	Fisher, Anna L.	Gardner, Dale A.
Gibson, Robert L.*	Gregory, Frederick D.*	Griggs, David S.*
Hart, Terry J.	Hauck, Frederick H.*	Hawley, Steven A.
Hoffman, Jeffrey A.	Lucid, Shannon W.	McBride, Jon A.*
McNair, Ronald E.	Mullane, Richard M.	Nagel, Steven R.*
Nelson, George D.	Onizuka, Ellison S.	Resnik, Judith A.
Ride, Sally K.	Scobee, Francis R.*	Seddon, M. Rhea
Shaw, Brewster H., Jr.*	Shriver, Loren J.*	Stewart, Robert L.
Sullivan, Kathryn D.	Thagard, Norman E.	Van Hoften, James D. A.
Walker, David M.*	Williams, Donald E.*	

\*Pilot astronauts

After their first flight, astronauts reported that the Shuttle simulations were so accurate that they felt they had indeed flown the mission many times. Mission specialists and payload specialists also trained with the remote manipulator system (RMS), which loaded or off-loaded cargo from the Shuttle bay during orbital missions. Built at the SPAR Aerospace Plant in Toronto, Canada, the RMS recalled perhaps a much earlier Anglo-Canadian contribution to the American space program—the 25 or so AVRO aerospace engineers who joined NASA and the original Space Task Group shortly after they were first formed. Crew specialization “sharply reduced training resources required (equipment, personnel, money) per mission.”<sup>34</sup> Specialization eased the training problem, but not the overall task or the essential development of teamwork and trained responses.

By the time the Shuttle astronauts began training, the old centrifuge at JSC, which had whirled astronauts around at often unbearable speeds to simulate gravitational forces equivalent to launch pressures, was no longer needed. Whereas Apollo flights subjected astronauts to forces 15 times the pull of gravity, the Shuttle only subjected them to forces 3 times the pull of gravity. The centrifuge was replaced with a device designed to simulate zero gravity. A gravity-free environment cannot be achieved on Earth, but the conditions can be closely approximated by immersing the suited astronaut into as much as 25 feet of water. A Weightless Environment Training Facility (WETF), actually a large swimming pool 76-foot long, 35-foot wide, and 25-foot deep, approximated some aspects of a weightless environment. Astronauts trained intensively to do those tasks which required EVAs while submerged in the WETF. They also, as did the Apollo astronauts before them, got a momentary sense of weightlessness as passengers aboard a KC-135 (comparable to a large commercial jet) during flight over a parabolic curve.<sup>35</sup>

Astronauts began their Shuttle pilot training in a substantially modified Gulfstream II aircraft adapted to mimic the flight characteristics and instrumentation of the Shuttle. When Al Pacynski, who was stationed at JSC’s White Sands Test Facility for radar and propulsion



*Astronauts trained to work in the weightless environment of space in JSC's WETF. Here, astronauts George D. Nelson and James D. van Hoften, STS 41-C mission specialists, go through a drill preparing them to repair the damaged Solar Maximum Satellite in orbit about Earth.*

tests, heard that the astronauts needed a practice landing strip, he suggested the relatively unused 10,000-foot Northrup Strip located on the test facility grounds. Originally a part of the Army's White Sands Missile Range before being transferred to NASA in 1962 to test the Apollo command module and lunar descent engines, the Northrup Strip was used by Northrup Aviation to land target drones. (A typographical error in an early press release transformed Northrup to

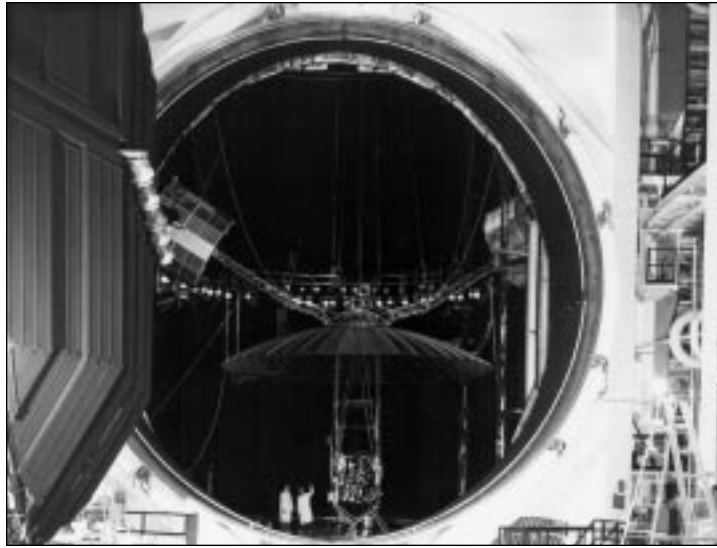
Northrup—and the latter stuck.) JSC reactivated the field in the summer of 1976, built a second runway in 1978, and expanded both runways to 35,000 feet in 1979, establishing the "White Sands Space Harbor" as both a training field and an alternative landing site for future Shuttle flights.<sup>36</sup>

The 60,000-acre White Sands Test Facility continued to operate propulsion and materials testing laboratories in the Shuttle era as it had for Apollo. Engine test stands at the laboratories include altitude chambers that simulate the vacuum of space during engine firings. Materials test laboratories are constantly adapted to simulate unique space conditions and to examine such things as space debris impact, the performance of high pressure pumps and valves, and metals flammability. Originally staffed largely by Grumman and North American contractor personnel, the White Sands Test Facility has been staffed in the Shuttle era by approximately 60 JSC (civil service) personnel and 500 or more Lockheed Engineering and Sciences Company personnel and staff. Although used only on one occasion, in March 1982, as an alternate shuttle landing field (for STS-3), the Space Harbor and laboratories of the White Sands Test Facility are an important adjunct of JSC's training, testing, and recovery capabilities.<sup>37</sup> Although they never flew, the SMS and its complementary SAIL located at JSC in Houston provided an almost real-time flight simulation experience.

The SAIL developed by the Avionics Systems Engineering Division (formerly the Instrumentation and Electronic Systems Division) after 1974, examined physical and electronic components and their integration into the Shuttle systems.<sup>38</sup> The whole concept of applying electronics to aviation, and the word avionics, evolved in the post-Sputnik aerospace industry. The SMS, and more especially the Shuttle orbiter itself, represented as

of the 1970's and 1980's the leading edge in aerospace and computer electronics. NASA space programs, through the contractor affiliates, facilitated the diffusion of an advanced state of electronic, engineering, medical and geophysical technology throughout the socioeconomic system.

Changes within what might be considered the more traditional areas of engineering were no less startling than in the areas considered new and innovative. Thus the Propulsion and Power Division of the Engineering



*Although manned lunar flights ended with Apollo 17, new applications of space technology were already enriching human knowledge. Here a test is conducted on an Applications Technology Satellite's 30-foot umbrella-shaped antenna in Chamber A of the SESL at JSC.*

and Development Directorate was primarily concerned with thermochemical and pyrotechnic tests. The Structures and Mechanics (or Engineering Analysis Division) laboratories examined spacecraft materials, gaseous helium and liquid nitrogen systems. The Space Environment Simulation Laboratory (SESL), completed in 1965 and 1966, included two vacuum chambers. Chambers A (65-foot diameter and 120-foot height) and B (35-foot diameter and 43-foot height) were built to provide simulated space and lunar surface environments for Apollo training. Thermal vacuums are to space systems what aerodynamics is to aircraft; that is, the vacuum pressures, internal pressures, and heat create the stress on the structure. Temperature control in the chambers ranged from 80 to 400 degrees K. The Apollo lunar science experiments, Skylab, and Shuttle missions all relied heavily on data from the SESL tests. Built at a cost of \$35 million, SESL was one of the most unique of all JSC laboratories, a machine tool designed to do things that otherwise could not be done on Earth.<sup>39</sup>

Although the technology of structures and mechanics, thermochemical reactions, electronics and computers often skirted the mainstream of American interests, Moon rocks, and environmental issues did attract considerable public interest as the lessons learned from Apollo began to unfold. Those lessons evolved from the work completed in the Lunar and Planetary Sciences and Earth Observations Division laboratories of the Science and Applications Directorate. The division began with the establishment of the Lunar Receiving Laboratory in 1968. The laboratory is equipped with two-way biological safeguards to provide a sterile environment and protect the lunar samples and Earth from mutual contamination. It contains instruments for physical, chemical, petrographic, and mineral analysis—and radiation detection. The laboratory not only conducted its own

investigations, but also distributed samples and information throughout the United States and to foreign countries.<sup>40</sup>

JSC made significant contributions to scientific knowledge about the heavens and the Earth. “Along with technology, national confidence, and human spirit,” Jack Schmitt, the scientist astronaut aboard Apollo 17 recalled at a public review of Apollo science programs during the 20th Anniversary celebrations of the Apollo 11 lunar landing, “science benefited permanently from our exploits. Remembering just how little we knew about the Moon before Apollo serves to emphasize both how far we have come and how far we now may go.”<sup>41</sup>

John Wood, with the Smithsonian Institute’s Astrophysical Laboratory put it more succinctly: “What we thought we knew about the Moon before Apollo was wrong.” People thought of the Moon as a “strange, weird, scary place.” The Lunar Receiving Laboratory, Wood commented, was built to quarantine astronauts coming from the Moon as much as it was to analyze Moon rocks or data. What we found out was that there were no unknown pathogenic organisms on the Moon, and it was not, in fact, a strange, weird, scary place. As a result, people began to think of other planets as not so scary after all.<sup>42</sup> For a time, during the Apollo era, the Moon became one of those very special NASA laboratories.

William David Compton’s study of the Apollo lunar exploration missions examines “how scientists interested in the Moon and engineers interested in landing people on the Moon worked out their differences and conducted a program that was a major contribution to science as well as a stunning engineering accomplishment.” Although the analysis of lunar and planetary data is still in progress and conclusions are still tentative, one of the most important results of Apollo science and explorations was to change our understanding and knowledge of the Earth.<sup>43</sup>

Dr. Wendell Mendell, with the Solar System Exploration Division of JSC, commented that Apollo changed the American mind-set from the idea that space was difficult and expensive to the understanding that it is real and possible. We need to think of space as an evolving sector of the Earth’s and the United States’ economy and society. And the Moon, Mendell thought, had some real opportunities in terms of scientific research, resource utilization, and colonization.<sup>44</sup>

For Americans and the world, one of the indelible memories of Apollo included the photographs and videotapes of the lunar surface. Accepting the rubric that a picture is worth a thousand words, the photographs brought back from the Moon by the astronauts dispelled the old mysteries of the Moon. But the Apollo lunar voyages actually taught humans more about themselves than about the Earth, the Moon or the planets. There was a new awareness of Earth, of Earth resources, and of the total human environment. It was this new awareness of Earth and Earth people that in time became the central thrust of the Space Shuttle program as scientific experimental planning for Shuttle missions began to focus on Earth resources and the environment. Greater public support for the Shuttle emerged from the decision to begin to apply Shuttle capabilities to the more immediate and direct benefit of humankind on planet Earth.

Nevertheless, although the Shuttle staggered through a prolonged and agonizing developmental phase, it remained in the minds of NASA planners as one component of a broader space program, a facilitator for the construction of a permanent space station

circling Earth, and subsequently a Space Shuttle to ferry passengers and cargo to the station and to waiting interplanetary vehicles. The development of the Shuttle helped make that rather ancient and distant dream become very real and, in the construct of human history, imminent.

By 1977 the complex elements of the Space Shuttle began to mesh. The four basic elements of the Shuttle system include two massive solid rocket boosters (SRBs) (each generating 2.65 million pounds of thrust at lift-off), an external fuel tank, and the manned Shuttle or orbiter. The three main engines fire in rapid sequence. Then the twin SRBs ignite and the Shuttle lifts off. When the SRBs burn out, they separate and parachute into the Atlantic for retrieval and reuse. The main engines continue to burn, using fuel from the external tank, until just before orbital insertion. After main engine cutoff, the external tank detaches and the orbiter moves away through short burns of its reaction control system thrusters. The tank is the only expendable element of the Shuttle stack—it tumbles and disintegrates during reentry. The Shuttle orbiter completes orbital insertion by using its two orbital maneuvering system engines. Usually one burn puts it into orbit; a second burn puts it into a stable circular orbit. Reentry into the atmosphere begins with a deorbit engine burn after which the Shuttle engines are shut off and the space vehicle glides to a landing at Edwards Air Force Base, Kennedy Space Center, or one of the alternative landing areas such as White Sands, New Mexico. The Shuttle, if it landed elsewhere than Kennedy, was then returned to its launch site at Cape Canaveral piggyback aboard a Boeing 747.<sup>45</sup>

The first test of the external fuel tank was completed by Marshall Space Flight Center in January, and a solid rocket booster engine was first fired in July 1977. Rockwell International Corporation, the orbiter prime contractor, rolled the first orbiter *Enterprise* (sans engines) from its plant in Downey, California, on January 30, 1977, for a year of testing. An unmanned *Enterprise* flew piggyback aboard a 747 in February and March, while control and guidance systems were being installed. The first manned unpowered flight of the Shuttle was made on June 18. NASA scheduled its first free flight with a separation from the 747 for August. Five free flights were made during the year. Shuttle main engines, rocket booster engines, and Shuttle orbital engines were being tested. The shuttle main engines misfired on occasion, causing NASA reviews and a National Academy of Science inquiry in 1978. The 31,000 shuttle tiles, each individually crafted and glued to the orbiter's bottom and sides, required an estimated 335 person-years of labor to install on the orbiter *Columbia*, which would be the first of the orbiters to fly.<sup>46</sup> Development was slow but sure—and costly.

In 1977, the *Enterprise* neared completion at a cost of \$500 million; the *Columbia* was expected to cost somewhat more. Three additional Shuttles scheduled for production were now being estimated at \$550 to \$600 million each. NASA estimated that a 2-year funding delay for the construction of additional Shuttles might elevate costs as high as \$1 billion each. Before the decade was out, Congress had authorized construction of five completed orbiters or shuttles: *Enterprise*, *Columbia*, *Challenger*, *Discovery*, and *Atlantis*. By 1981, the first shuttle was ready to fly—2 years behind schedule and \$1 billion over costs anticipated in 1975.<sup>47</sup>

JSC worked on the Shuttle, but also developed a greater social consciousness in these years as it began to apply and to teach others the lessons learned from Apollo and

from work on the Shuttle. Astronaut Charles M. Duke, Jr., left NASA in 1978 and later became a lay minister, while James B. Irwin (the eighth man to walk on the Moon) founded a religious organization after his retirement in 1972. Many engineers founded consulting companies. Others joined space-related corporations. Eugene Horton left JSC and became involved in industry and environmental programs. Horton, formerly the center's education officer, organized the Earth Awareness Foundation dedicated to uniting the industrialist and the environmentalist in their common cause. Each year the center hosted a week-long lunar and planetary science conference in cooperation with the neighboring Lunar and Planetary Institute of Houston. The Lunar Receiving Laboratory developed national and international associations. In 1977 the center hosted a junior and senior high school symposium for 2000 Texas students—including tours, lectures and visits with astronauts, scientists and engineers.<sup>48</sup>

Its outreach program extended to far distant west Texas. The center established an Emergency Medical Communications Console at Odessa, Texas, designed to provide emergency medical care for the sparsely populated but vast distances of the Texas Permian Basin area. The facility represented a direct application of Apollo and Shuttle technology to a present, on-Earth problem. Through the network, physicians and nurses could consult paramedics in the field, doctors could receive electrocardiograms on the telephone lines (now common), telephones and radios could be interconnected, and physicians and hospital staff members within a 17-county area could be paged directly through the central console.<sup>49</sup> Texans began to think of Texas not just as a traditional cotton, oil, and cattle kingdom, but as a center for new opportunities derived from the application of space technology and research.

The decade of the seventies began with the triumphs of the successful Apollo lunar landings, the construction and launch of Skylab with three long-duration manned flights, and the Apollo-Soyuz docking between a Soviet and an American spacecraft. During these years, the Shuttle program, officially designated the Space Transportation System, struggled for survival. Funding was short. NASA and contractor personnel declined precipitously. There were unanticipated technical difficulties. By 1975, the time of glory, what Gerald Griffin had earlier referred to as the “scarf in the wind” era of spaceflight, had ended. The last 5 years of the decade, during which time JSC and its personnel devoted most effort to the Shuttle program and the development and testing of the orbiter, were difficult years requiring hard work and perseverance. NASA learned how to do more with less, and discovered sometimes hidden costs. JSC people learned a lot during these years about aerospace engineering and lunar science, about people in general, and about themselves in particular.

When the Boeing 747 carrying the Shuttle *Enterprise* landed in March 1978 at Ellington Field near Houston and JSC, the center released its usual press release announcing the event. What happened was an overwhelming show of curiosity and support of the center and the space program as 240,000 people came out to view the Shuttle. A tour guide perhaps explained the situation better than the most enlightened engineer or scientist: “What I think is that this is different than Apollo and going to the Moon. I think the Shuttle is coming closer to the people. It is something they can relate to. They wanted to know when they can go on it.”<sup>50</sup>

Although its primary role as a lead center for the Shuttle would continue through the 1970's and 1980's, JSC had developed a subordinate role as a research and development center leading Texas and the Southwest into a new era of economic and industrial development.