History of Rocketry and Astronautics

Proceedings of the Forty-Ninth History Symposium of the International Academy of Astronautics

Jerusalem, Israel, 2015

Tal Inbar, Volume Editor

Rick W. Sturdevant, Series Editor

AAS History Series, Volume 47

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 35

AAS Publications Office
P.O. Box 28130
San Diego, California 92198

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 2017

ISSN 0730-3564

ISBN 978-0-87703-639-5 (Hard Cover)
ISBN 978-0-87703-640-1 (Soft Cover)

Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198
Web Site: http://www.univelt.com

Printed and Bound in the U.S.A.

Chapter 5

Project Gemini—
An Engineering and Managerial Assessment: What Yesterday Teaches about Tomorrow*

Benjamin G. Davis†

Abstract

To fully understand an object, questions must be asked and answered. The reporter asks "who, what, when, and where." The philosopher adds "why." The engineer adds "how." These are crucial questions, to be certain, but until the "so what" question has been asked and answered, one has a partial understanding of an issue at best. This chapter addresses the "so what" question for Project Gemini, the second manned space program of the United States. Elsewhere there exist technical and historical accounts of Project Gemini, but an assessment of the true importance of Project Gemini for future space programs has been sorely needed.

Tsiolkovsky famously said that "earth is the cradle of man." This being the case, in terms of human spaceflight Project Mercury served as the kindergarten and Project Apollo was the doctoral program. It was Project Gemini, however, that took spaceflight through the elementary school, high school, baccalaureate, and Master's degree levels, all in in just five years, yet the implications of Project Gemini and its relevance for tomorrow's space programs are little understood. This chapter addresses this gap.

---

* Presented at the Forty-Ninth History Symposium of the International Academy of Astronautics, 12–16 October, 2015, Jerusalem, Israel. Paper IAC-15-E4.2.3.

† Ph.D., LL.M., President of Dulles University, Vienna, Virginia, United States.

Projects Mercury and Apollo were planned from the outset by NASA, with Project Apollo landing man on the Moon "sometime in the 1970s." Once the length of the time gap between the final Mercury flight and the first Apollo flight was realized, and given President Kennedy's challenge to reach the Moon within the 1960s, it became obvious that something heretofore unique would be necessary, hence Project Gemini.

Project Mercury, as important as it was, took America into space, but it was "Spam in a can," as the astronauts themselves said. The astronauts had essentially no control over the space capsule, only able to alter its attitude. To be able to rendezvous, dock, precisely re-enter, and be assured that man could truly live and work in space, a program based on new engineering and managerial approaches was required. The management systems that later made Project Apollo such a success, were developed under Gemini. The engineering methods that created the then-world's most complicated system were developed, tested, and implemented in Gemini. And the key questions facing the success of Project Apollo were identified and addressed by Gemini. This chapter documents the engineering and managerial approaches that were implemented in Project Gemini and lays out the lessons learned from the critical tasks and their accomplishment for future space programs.

I. Introduction and Project Gemini Goals

In family planning terms, the United States space program was to have two children, Mercury and Apollo. According to NASA's Ten Year Plan of 1959, Project Mercury was to get the United States into space and the Apollo Project was to take the United States to the Moon sometime in the 1970s. This plan was overtaken by events when the Soviet Union launched Yuri Gagarin into orbit in 1961. Even before President Kennedy's now famous lunar challenge later that year, however, it became obvious to NASA management that an intermediate step would be required if only to keep the United States in space in the years between the ending of Project Mercury and the first flight of the Apollo Project.

What was something of an afterthought to the many early space planners was anything but that to a select few, and solid thinking was given to what the next steps in the United States should be. First designated as "Mercury Mark II," the outcome of that thinking was Project Gemini.

In school terms, Project Mercury can be likened to kindergarten. The astronauts themselves referred to their flights as "Spam in a can" and said that flying in it was flying in "chimp mode," referring to the automated sequencing that was used when chimpanzees occupied the pilot's seat. The duties of the pilot were few, so few that if the engineers had had their way there would have been no window in the capsule. Calling it "kindergarten" is in no way meant to denigrate Project Mercury and what the engineers, managers, and astronauts accomplished. It is in kindergarten, after all, that we learn our A-B-Cs and how to count from one to ten—or backwards from ten to one in the case of space.

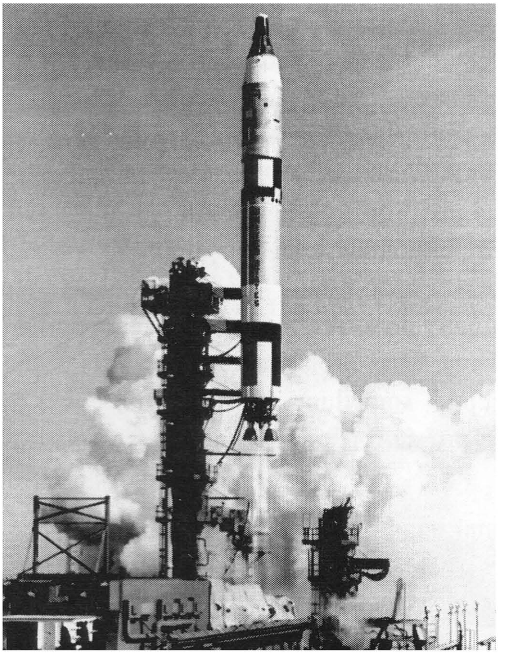

Figure 5–1: Gemini 5 launches onboard a Titan launch vehicle. (NASA photo).

Project Apollo served as the Ph.D. with astronauts landing, walking, driving, and doing useful scientific work on the lunar surface. It was Project Gemini that bridged the gap between Mercury and Apollo and served as elementary school, high school, the Bachelor's degree as well as the Master's degree. As Martin Caidin wrote in 1962, "The three-man Apollo spaceship program was already on its way nearly two years before Gemini became officially authorized as a specific NASA effort. Gemini, one might say, is a product directly of the demonstrated needs of research in space and, as such, it is being regarded as an ambitious undertaking with tailor-made plans in mind."[1] Without the work of Project Gemini, there would have been no lunar landing in the 1960s.

Project Gemini was born out of necessity. As John Logsdon writes, "There was a confluence of political will and technical competence toward a common and well-understood goal. Reaching the Moon before the end of 1969 was important, and whatever needed to be done to achieve this goal was worth the cost." He adds by way of warning, "Even as this is said, however, there *were* calls for an end to the 'space race' in order that resources could be directed elsewhere."[2]

The broad goals of Project Gemini were twofold. The first goal was to fill the gap that would exist between Projects Mercury and Apollo, years in which Soviet accomplishments would have gone unchallenged. Project Mercury was scheduled to end in early 1963 and the first uncrewed Project Apollo flight was optimistically scheduled to be launched in 1967, leaving a major gap. As it turned out, the Soviet space program had its own difficulties and launched no cosmonauts during the entire Gemini manned flight program; nonetheless the concern based on earlier Soviet successes was very real.

The second broad goal for Project Gemini was the result of the lunar landing decision that NASA ultimately made. The options available were direct ascent, Earth orbit rendezvous, and lunar orbit rendezvous. Wernher von Braun, perhaps naturally, originally preferred the direct ascent approach, but when direct ascent was eliminated and lunar orbit rendezvous was selected, rendezvous and docking would be required, something for which there was no precedent in the US or any other space program. Gemini would accomplish this for the United States.

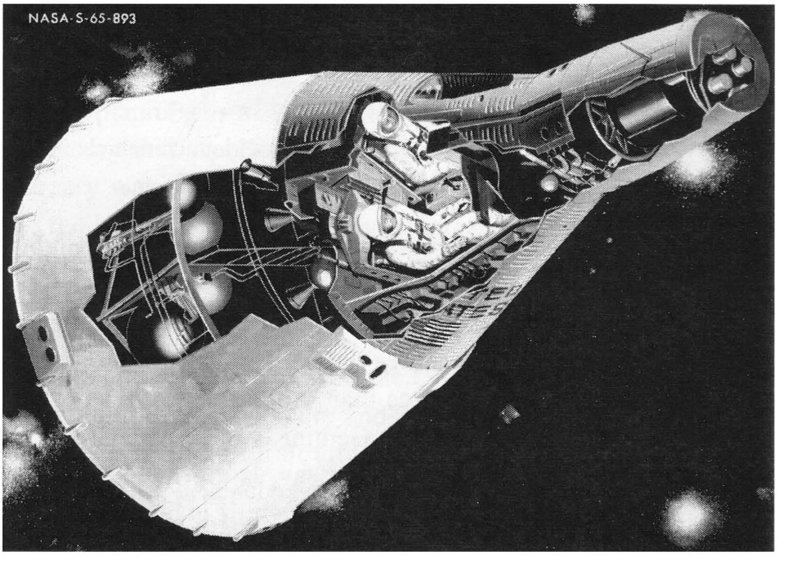

Figure 5–2: Gemini spacecraft illustration. (NASA photo).

It is impossible to find a single, definitive list of the official goals for Project Gemini, but the best amalgamation is:

1. To subject two men and their supporting equipment to long duration flights of up to two weeks in space.
2. To achieve rendezvous and docking with another orbiting vehicle and to develop efficient and reliable rendezvous techniques. The ability to dock on first revolution was highly desired.
3. Using the target vehicle propulsion system, to maneuver the spacecraft in space after docking.
4. To perform extravehicular activities requiring one of the flight crew to climb out of the spacecraft for short periods of time while in orbit and to develop the capability and techniques for extravehicular operations in free space.
5. To provide a controlled reentry whereby the spacecraft is brought to a specific landing site. The initial goal was a land landing using a paraglider, or "Rogallo wing." This portion of the goal was cancelled in 1964 and the landings all took place at sea.[3]
6. To provide training for the flight crew members who would fly in the Apollo program.
7. To perform appropriate engineering and scientific experiments in support of the national space program.

The goal was to pave the way for the Apollo lunar landing. As Chris Kraft and Sigurd Sjoberg, then Assistant Director and Deputy Assistant Director for Flight Operations, respectively, stated at the time, "Before the Gemini program is concluded ... many of the flight systems and operational problems associated with the Apollo lunar-landing mission will have been explored and solved."[4]

In addition to the official goals of the project, there was one goal that was implicit in all of the planning and operations of the program. The major unofficial but clearly understood goal was to overtake and surpass the Soviet Union in space accomplishments.

When the Gemini project concluded, all of the official and unofficial goals had been met.

II. Who, When, and Where?

The first questions to be addressed in understanding the unique engineering and managerial aspects of Project Gemini are who, when, and where.[5]

Who Were the Key Actors?

It has been estimated that 400,000 people were involved in one way or another with the Gemini Project. A number of individuals played key roles and certainly deserve recognition, however for this chapter we will focus on just two, James Chamberlin and Robert Gilruth.

James Chamberlin

James Chamberlin was responsible for all engineering in Mercury and Gemini. He had served as Chief of Technical Design for the highly advanced Avro CF-105 Arrow which, fortuitously for the United States, was cancelled by the Canadian government in 1959.

Along with 25 colleagues, Chamberlin joined the staff of the fledgling NASA first as head of engineering for the Mercury Project, next as Chief Designer and first Project Manager for Project Gemini, and later as a technical advisor to the Apollo Project. For Gemini, then known as Mercury Mark II, Chamberlin believed that a complete reworking of the Mercury capsule would be required.

He also pushed for the use of the Gemini spacecraft as part of a lunar lander well in advance of what would have been possible with Apollo. As Hacker and Grimwood state, "Much of the ultimate success of the [Gemini] project had its roots in Chamberlin's brilliance as a designer and skill as an engineer, but so did some of the [then] current harvest of troubles. The talented engineer can always see new ways to improve his machines, but the successful manager must keep his eyes on costs and schedules, even if that sometimes means settling for something good enough instead of better."[6] As the saying goes, "the best is the enemy of the good enough."

Chamberlin was replaced as project director on March 19, 1963, by Charles Matthews. Robert Gilruth made that decision. James Chamberlin proved to be the reverse of Wernher von Braun, the US chief designer on the Apollo Project, and Sergei Korolev, the Russian chief designer—he was a better engineer than he was a manager.

Robert Gilruth

Robert Gilruth began his career in aerospace immediately after completing his Master of Science degree at the University of Minnesota. He joined the National Advisory Committee for Aeronautics (NACA), the precursor agency to NASA. Gilruth's early work involved the development of the first guidelines for aircraft testing including the use of instruments as a means of supplementing the pilot's experience in the cockpit. When NASA was created by President Eisenhower, Gilruth was appointed to be head of the Space Task Group. He later served as head of the Manned Spacecraft Center (now the Johnson Space Center) in Houston from the Mercury-Redstone 3, better known as Freedom 7 flight, Alan Shepard's first step into space for the United States, through Apollo 15, the first long-duration, scientific, lunar landing and the first lunar mission to use the Lunar Roving Vehicle.

As recounted in *Suddenly, Tomorrow Came: A History of the Johnson Space Center,* "Mr. Gilruth gathered a group of fewer than 10 engineers and, working night and day, came up with all the basic principles of what would become Project Mercury, the first American human spaceflight program, begun in 1959. These included the design of the Mercury capsule, the choice of rockets and decisions on astronaut qualifications and mission control procedures."[7] Robert Gilruth had the managerial skills necessary to make the United States preeminent in space.

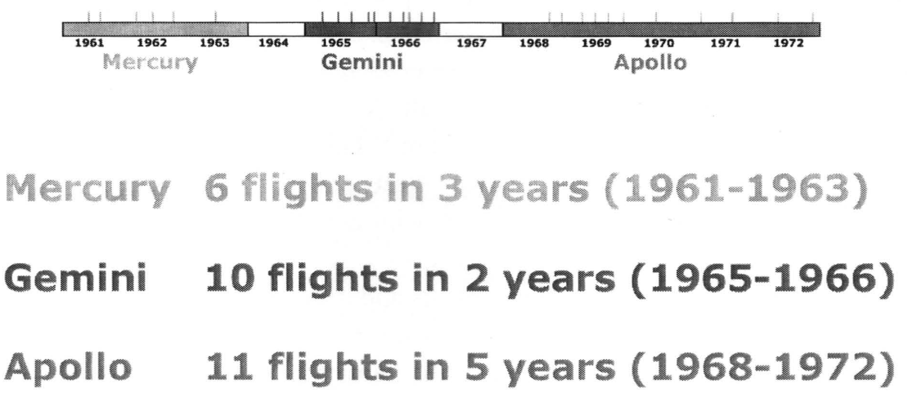

Figure 5–3: Timelines of the Mercury, Gemini, and Apollo programs.

When Did the Program Take Place?

Project Gemini ran from December 7, 1961, to February 2, 1967. There certainly were a number of key dates, but in addition to the flights themselves, as noted in the What Was Accomplished? section of this chapter, only a few will be identified here:

- Project start date as Mercury Mark II—December 7, 1961
- Named Project Gemini—January 3, 1962
- All major Gemini systems under contract—March 1962
- James Chamberlin replaced as Project Manager by Charles Matthews—March 19, 1963
- First uncrewed flight—April 8, 1964

- First manned flight—March 23, 1965
- Mid-program conference—February 23–24, 1966
- Last manned flight—November 11–15, 1966
- Concluding conference and closing of the Gemini Project Office—February 1–2, 1967.

It is worth noting that the lengthy gap between the first uncrewed flight and the first manned flight was due primarily to weather conditions at the launch site in Florida, not because of technical or managerial issues.

Where Was the Program Performed?

Truly, the entire nation participated in the Gemini Project. There were 58 major contractors with billings of over $100,000 ($750,000 in 2015 dollars) and 116 subcontractors, and vendors with contracts totaling $100,000. These firms were located in 22 states and one Canadian province. All of NASA's locations participated at one level or another, in particular NASA Headquarters in Washington, DC; the Goddard Space Flight Center in Maryland; the Kennedy Space Center in Florida; and the Manned Spacecraft Center in Texas. The Department of the US Air Force, which operated the Titan II launch vehicle, and the US Navy, which operated the rescue and recovery fleets played major roles as well. Finally, NASA's worldwide tracking network with facilities from Ascension in the South Atlantic to Kano in northern Nigeria to Tananarive in the Indian Ocean was able to provide real-time data for analysis and decision making.

All launches took place at Cape Kennedy in Florida. Launch Complex 19 was used for the Titan II launch vehicle and Launch Complex 14 was used for the Agena rendezvous and docking target.

III. Why Did the Program Exist?

The specific goals for Project Gemini were identified above, but in summary:

- Two-man flight
- Precision reentry and landing
- Long-duration flight, solving living, dietary, and hygiene issues
- Extravehicular activity
- Rendezvous and docking, including docking on the first revolution
- Performance of docked-vehicle maneuvers
- Integration of fuel cells as the power source.

The key reasons for the existence of Gemini were to learn for the Apollo Project, for which three barriers existed that had to be overcome for the lunar landing:

1. Long-duration flight
2. Rendezvous and docking
3. Precision landing.

In addition, there were three unofficial goals that were equally as important:

1. To fill the two-year gap between the close of the Mercury Program and the first flight of the Apollo program.
2. To match and surpass any Russian accomplishments in space. On October 12, 1965, for example, the Soviet Union launched Voskhod I with three cosmonauts aboard. That the Voskhod was little more than a stripped-down, one-man Vostok capsule was not known until much later.
3. To bolster national prestige around the world, in particular with the unaligned nations.

IV. What Was Accomplished?

Perhaps the most fitting statement that describes the Gemini Project came in another context from US football coach Vince Lombardi: "We shall strive for perfection, knowing that we shall never achieve it. But along the way, we will achieve excellence." The Gemini Project did just that.

Flights

Project Gemini had 12 successful flights, 10 of which were crewed. With the exception of the first all-up systems test flight, 11 flights were successfully completed in less than a two-year period. The launcher chosen for the effort was the US Air Force Titan II, a craft that used storable hypergolic propellants. The flights, the crew members' names, the length, the key accomplishments, and the closeness of the landing to the target point are shown below. The launcher was to rendezvous with an Atlas Agena target vehicle, and despite delays in the development of this vehicle, four successful dockings were achieved.

Vehicle	Date	Details
Gemini I	4/8/64	Uncrewed Systems tests 3 orbits
Gemini II	1/19/65	Uncrewed Reentry systems tests Suborbital Landing—14 mile miss
Gemini III	3/23/65	Grissom, Young First crewed flight Conduct orbital maneuvers 3 orbits Landing—60 mile miss
Gemini IV	6/3-7/65	McDivitt, White First EVA 4 days Landing—44 mile miss
Gemini V	8/21-28/65	Cooper, Conrad First use of fuel cell for power 8 days Landing—91 mile miss
Gemini VII	12/4-18/65	Borman, Lovell Long duration, rendezvous target for Gemini VIA 14 days Landing—6.4 mile miss
Gemini VIA	12/15-16/65	Schirra, Stafford Rendezvous, station-keeping with Gemini VII 1 day Landing—7 mile miss
Gemini VIII	3/16/66	Armstrong, Scott Rendezvous, docking, emergency reentry 11 hours Landing—1.4 mile miss
Gemini IX	6/3-6/66	Stafford, Cernan Rendezvous, EVA 4 days Landing—0.38 mile miss
Gemini X	7/18-21/66	Young, Collins Rendezvous, docking, EVA 3 days Landing—3.4 mile miss
Gemini XI	9/12-15/66	Conrad, Gordon Rendezvous, first orbit docking, EVA 3 days Landing—2.65 mile miss
Gemini XII	11/11-15/66	Lovell, Aldrin Rendezvous, docking, EVA with work completed 4 days Landing—2.6 mile miss

Table 5–1

Achievements

- Two-man flight—10 successful flights accomplished.
- Precision reentry and landing—to within 0.38 miles of target.
- Long-duration flight—14-day mission—by astronauts including eating, sleeping, waste disposal, and productive work.
- Extravehicular activity—activities on five flights with one major success.
- First astronaut-controlled orbital changes using the Orbit Attitude and Maneuvering System (OAMS).
- Use of an onboard digital computer, a purpose-built IBM computer with a 4,000-word memory for guidance and control operations.
- Rendezvous and docking, including docking on first revolution. Ten rendezvous exercises were accomplished using seven different rendezvous modes. Nine docking operations were accomplished.
- Perform docked-vehicle manoeuvers—raised the spacecraft to a 1,370 km apogee.
- The integration of fuel cells as the power source. The astronauts were not able to use the byproduct (water) for drinking, but the Gemini experiments made it possible in the Apollo program.
- Establishment of a project management board that was the model for the Apollo Project.
- Completion of 111 experiment missions, assessing everything from sea urchin growth to human otolith function to star occultation in navigation.[8]

V. How Was It Possible?

Exogenous Factors

The United States and the Soviet Union were at the height of the Cold War where national survival was believed to be at stake. (Today the concern is about terrorism, local attacks on specific targets; then the concern was about a nuclear fusillade.)

The challenge of the Apollo schedule and requirements was to land a man on the Moon during the 1960s.

The availability of a group of exceptionally talented engineers who had served on the cancelled Avro Arrow project in Canada.

The increased outflow of new engineers from US colleges after the launch of Sputnik—there were 28.9 percent more engineering graduates in 1963–64 than in 1956–57 immediately prior to Sputnik.

The United States pursued miniaturization in space resulting from the development of solid state electronics, which in turn resulted from the US ability to shrink the size and weight of nuclear weapons. Physicists von Neumann and Teller predicted in 1953 that "The United States would be able to build a hydrogen bomb that would weigh less than a ton but would explode with the force of a megaton, i.e., eighty times the power of the simple atomic or fission bomb that had blown away Hiroshima."[9] Combined with the development of solid state electronics, this gave the United States a major advantage. By contrast, and this may be a generalization, the Soviet Union valued size and strength and so built larger launchers, which reduced the need to push technological development in miniaturization for space. It is perhaps significant to note that a substantial portion of the beginning training for Soviet cosmonauts was physical strength training, a much greater emphasis than in the US astronaut program, which focused more on academic issues.

Another exogenous factor that pushed the Gemini Project was Soviet Premier Nikita Khrushchev's need for spectaculars. Leonov's spacewalk and the three man Voskhod spacecraft (with no launch escape system and shortened training program) were rushed as missions in an effort to undercut Project Gemini's forthcoming two man missions.[10]

Although Russia never exactly called it a rendezvous, the close approach of the Vostok 3 and 4 spacecraft led Western analysts to assume that orbital maneuvers and essentially a docking had taken place. They had not, but the assumption gave added impetus to the US Gemini Program.

Common Factors

Common sense rather than the rule of law was followed. As an example, "Insofar as possible, excessively repaired components will not be used on Gemini"[11] was the operating standard.

"One of the most valuable lessons of the Gemini launch program has been that success is dependent upon the early establishment of managerial and technical disciplines throughout all phases of the program, with vigorous support of these disciplines by all echelons of management."[12]

NASA had a willingness to accept risk.

Engineering and Technical Factors

Reliable systems design—certainly always the goal, but in Gemini systems were developed as independent units so operational defects would not be masked by complex inter-systems operations. This was a plus for testing, check-out, and replacement.

Further regarding systems independence, as opposed to Project Mercury key systems were located outside the pressure vessel. These systems were accessible through easily removable panels. Connectors were located at the equipment so wiring bundles could be left untouched during system check-out and replacement. This approach allowed multiple systems to be accessed at the same time and work to be done in parallel as opposed to Mercury where systems were placed inside the capsule and could be reached only one at a time. Independent systems testing reduced the need for integrated systems checking. Last-minute changes could be introduced without causing a major rescheduling of a launch.

Redundant systems or "sufficient inherent reliability" were used in all Titan II component systems including flight control, electrical, and hydraulic systems, and the addition of a malfunction detection system to provide pilot warning.

Titan II used as the launcher for Gemini was primarily a weapon. It had to be man-rated, and the US Air Force worked with NASA to accomplish this and to remove all instances of POGO that would have made manned flight impossible.

Because Titan II used hypergolics, which were slower burning, ejection seats could be used rather than an escape tower, saving weight. This required larger hatches that opened outwardly, building in greater safety and facilitating EVA.

There was an intentional focus on future program requirements, in particular, those of Project Apollo with its lunar landing, in particular the development of operating principles that could be carried forward.

Delivery of operationally ready vehicles and equipment from the manufacturer decreasing the required disassembly and testing at the launch site.

Critical path method (CPM), developed in the late 1950s, was applied to manufacturing.

All-up testing so lauded in the Apollo program was actually begun with Project Gemini.[13]

Systems testing was done at the manufacturer's facility and flight-ready components were then shipped to NASA for assembly. "Once a subsystem had been tested, it would take its proper place in the spacecraft and stay there. No longer was the spacecraft to taken apart after it reached the Cape, tested, and put together again. Systems were to be rechecked, of course, but only as part of the complete spacecraft, not as individual pieces."[14] Because the spacecraft design was modular, systems could be installed, serviced, and replaced as individual components, and multiple components could be serviced in parallel. Test points were built into the components to remove the need to disconnect wiring and so the components did not have to be removed from the spacecraft for testing.

Computers were utilized for spacecraft operations and for real data processing and analysis for the first time. Through computers NASA was able to collect massive amounts of data. The problem was that there was too much data to print out and far too much to analyze effectively. "Computers can look at volumes of data in seconds, but they require many hours to print data in a usable form."[15] Data had to be turned around and analyzed in very short order in order to provide information for the next Gemini flight, which was only two months away from splashdown of the previous one.

Data analysis was key particularly with the rapid turnaround between missions. Computers were able to process massive amounts of data. The limitations were printing capability and analyst time. Data analysis techniques had to be invented. Much of this seems obvious today, but it must be remembered that this was 50 years ago. NASA did not use the term, but followed a "dashboard" approach for data processing and analysis: (1) Select important data elements and key time periods in the mission. (2) Do discrepancy analysis—look for anomalous data that fall outside pre-established limits. (3) Do data analysis by the personnel who were responsible for the design, testing, and operation of the systems since they were the most knowledgeable about what systems performance should have been and hence when an anomaly occurred.

The entire NASA program has the attitude that Gene Kranz made famous later with regard to the Apollo XIII emergency, "*Failure is not an option.*"

Managerial and Personal Factors

In addition to automated systems, the Gemini spacecraft used manual sequencing systems. The human as a participating element was built into the design of Gemini. This utilized the human capabilities to diagnose and correct anomalies such as was the case with the false start of Gemini VIA.

Astronauts, those whose lives would depend on the systems, were involved in the design, development, manufacturing, and testing of systems and components. This approach allowed potential problems to be identified and corrected in advance as well and providing the astronauts with complete familiarity with the make-up of the systems. The involvement of astronauts who in the 1960s were as special as rock stars are today, at the manufacturing sites with personnel involved in the design and manufacturing teams helped make all people working on the project to feel important.

There was a strong emphasis on the motivation of all personnel including contractors. Good communications among all parties was the norm. Those involved at different levels in the project held direct discussions rather than functioning in the more typical military chain-of-command. The program was blessed that it grew so rapidly that there was no time to put a bureaucracy in place. Some of the tools used were the measurement of results, accountability, astronaut involvement, incentive contracts based on schedule and systems performance, and recognition and awards. The project approach was like that involved with textbook instructions on effective delegation: know what is wanted, assign the task to the appropriate person or group, establish expectations and schedules, confirm understanding, gain commitment, and hold accountable for results. In their concluding remarks at the Gemini Midprogram Conference, Mitchell and Hammack stated that, "It is axiomatic that no organization will function well, no matter how carefully devised are the organization charts nor how well documented are the authorities and responsibilities, unless it is manned with well-motivated and dedicated people who work cooperatively toward the objective."[16] That spirit was very much evident during the Gemini Project.

The Gemini Project Office "enjoyed a degree of autonomy that permitted [project director] Chamberlin to deal directly with McDonnell and Air Force Space Systems Division. He reported only to MSC Director Gilruth, and that was chiefly a matter of keeping Gilruth informed on the status of the project."[17] The ability of the project director to contact any staff member or contractor involved on the project to manage the many engineering changes that came about on a daily basis.

The relationship between the government agencies and the contractors was based on a high level of cooperation and trust, so much so that when very preliminary thinking was first given to the follow-on spacecraft for Project Mercury, the McDonnell Corp. went ahead and invested its own money on a potential design. "Where others refused to move without money in hand, McDonnell focused on the task and relied on the good faith of its customer to make up the cost." McDonnell had not felt obliged to wait until its contract was amended to provide the extra funds. "The company spent its own money," which generated "a good deal of respect in NASA circles."[18] McDonnell's risk-taking was rewarded with a contract for the Gemini capsule.

There was a strong focus on planning—pre-mission planning, carefully sequenced growth in mission objectives, in-mission flexibility, and rapid post-mission data and mission analysis by the persons most directly involved.

- The launch site team participated in the checkout and testing of components at the manufacturers' sites.
- The Gemini Launch Vehicle Coordinating Group was established to cut through red tape and to facilitate communications. This working group was the model used for the Apollo Project.
- The focus was on outputs, not on process; it was results that mattered.

- There was great attention to detail and a high degree of personal responsibility. The attitude of all staff members, as reported by one of the scientists who worked on the Gemini Project, was "this won't fail because of me."
- There was a high reward for problem solving and systems thinking. Intelligence was rewarded.
- Astronaut training had a high emphasis on academics—568 hours (14 weeks) were dedicated to academic subjects with only one hour per day for physical exercise. The Russian program had a major emphasis on physical training.
- Systems management was practiced. CPM and PERT project management tools were implemented. There was a complete focus on outcomes; innovation was valued; failures and mistakes were allowed—on the way, not at the end.
- The program had specific goals, tight deadlines, and almost enough money to do the job.
- Finally, a critical data component in flight assessment was the post-flight crew briefing, again showing the integration of the human factor in mission planning and operations.

Summary

Before Gemini there were serious questions about whether or not man could survive and do useful work in space and whether it was possible for space-craft to rendezvous and dock. After, there were no questions.

VI. So What?

What can be learned from the engineering and managerial features that is relevant to current and future space missions? Common sense was the rule.

- Cooperation at all levels and among organizations was expected and occurred.
- There was a common, clearly stated, publicly known purpose.
- There was a specific and inflexible schedule and goal.
- In today's parlance, the program used "stretch goals."

Attention to the individual worker (as in the Hawthorne and other similar experiments) should have made this obvious to all of industry. In this project workers were trained, certified, and retrained; they met with astronauts; and they had a voice in how systems evolved. Motivation was a key factor.

The Gemini launch vehicle coordinating group that allowed for continuous monitoring and management was implemented.

There were almost enough resources to do the job. The original estimate of total program cost $347.8 million. The final, actual program cost was $1.3 billion. Project Gemini faced recurring budget crises, particularly in 1963. While NASA's budget problems occasionally threatened Project Gemini itself, sufficient resources were ultimately made available, but the pot of money was not bottomless. Nonetheless, while NASA was wrestling with Congress about its overall budget, lower-level scientists and engineers had the equipment they needed to do their work and keep the project moving forward.[19]

"The continued high level of concern evidenced for the human factor in this program is probably the most significant effort required for the success of Gemini."[20]

The paraglider, or Rogallo wing, for landing while not used in the Gemini program has been proposed as the landing system for the forthcoming Mars mission.

VII. Epilogue—Earning the Ph.D.

On January 27, 1967, just prior to the Gemini Summary Conference, the interior of the Apollo 1 capsule was engulfed in fire during a plugs-out test on the launch pad and the lives of Gus Grissom, Ed White, and Roger Chaffee were lost. The design of the Apollo capsule (Block I) was begun before that of the Gemini capsule and did not have an outward-opening hatch as did Gemini (and Mercury). It also had a maze of wires and connectors that were exposed.

When the redesigned Block II capsule became available, the Apollo program leapt forward. In December 1968, Apollo 8 completed a circumlunar flight during which the astronauts read the creation story from the Bible, "In the beginning God," which must have had a bit of as sting in it for the "Godless communists," as they were often called.

Seven months later in July 1969, Apollo 11, with Neil Armstrong, Buzz Aldrin, and Michael Collins, successfully completed the lunar landing mission that had been the goal of the space program since 1961.

Less than four months later, the United States returned to the Moon with Apollo 12 and, drawing on lessons learned in Gemini, landed within walking distance—200 meters—of its target, the Surveyor 3 spacecraft that had soft landed on the lunar surface two years earlier.

References and Notes

[1] Caidin, Martin. (1962). *Rendezvous in Space: The Story of Projects Mercury, Gemini, Dyna-Soar, and Apollo*. New York: E.P. Dutton & Co. pp. 228–230.

[2] Logsdon, John M. (1970). *The Decision to Go to the Moon: Project Apollo and the National Interest*. Cambridge, MA: The MIT Press.

[3] The initial goal was for Gemini to land on hard ground rather than water for both safety reasons (the memory of Mercury Redstone IV's loss was still fresh) and for cost reasons. For Gemini IV, for example, 10,384 personnel, 134 aircraft, and 26 ships were a part of the recovery team. See *Gemini Summary Conference*, p. 193.

[4] Christopher Kraft and Sigurd Sjoberg. (1966). "Gemini Mission Support Development," p. 153, in NASA. (1966). *Gemini Midprogram Conference* report.

[5] For a more complete discussion of the "Who," "Where," and "When" questions, see the forthcoming book by the author, *Gemini: The Project that Won the Space Race.*

[6] Grimwood, James M. and Hacker, Barton C., with Vorzimmer, Peter J. (1969). *Project Gemini Technology and Operations: A Chronology*. Washington, DC: Scientific and Technical Information Division, Office of Technology Utilization, National Aeronautics and Space Administration. p. 129.

[7] Dethloff, Henry C. (1993). *Suddenly Tomorrow Came...A History of the Johnson Space Center.* The NASA History Series. Houston, TX: Johnson Space Center.

[8] For a complete list of experiments, see *Gemini Summary Conference*, pp. 225–226 and 291–317.

[9] Sheehan, Neil. (2009). *A Fiery Peace in a Cold War: Bernard Schriever and the Ultimate Weapon*. New York: Vantage Books. p. 178.

[10] See Siddiqi, Asif A. (2000). *Sputnik and the Soviet Space Challenge*. Gainesville, FL: University Press of Florida. pp. 423, 424.

[11] Robert E. Goebel. (1966). "Product Assurance." Mid program. p. 142, in NASA *Gemini Midprogram Conference* report.

[12] Richard C. Dineen. (1966). "Development of the Gemini launch Vehicle," p. 149, in NASA. (1966). *Gemini Midprogram Conference* report.

[13] Bilstein, Roger. (1980). *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles*. Washington, DC: Scientific and Technical Information Branch, National Aeronautics and Space Administration. p. 348.

[14] Hacker, Barton C. and Grimwood, James M. (1977). *On the Shoulders of Titans: A History of Project Gemini*. Washington, DC: Scientific and Technical Information Office, National Aeronautics and Space Administration. p. 191.

[15] Simpkinson, Neshyba, and St. Clair. (1966). "Data Analysis and Reporting," p. 265, in NASA. (1966). *Gemini Midprogram Conference* report.

[16] Mitchell and Hammack. "Launch Vehicle Management," p. 106 in NASA. (1966). *Gemini Midprogram Conference Including Experiment Results*. Logsdon, John M. (1970). *The Decision to Go to the Moon: Project Apollo and the National Interest*. Cambridge, MA: The MIT Press.

[17] Hacker, Barton C. and Grimwood, James M. *op. cit.* p. 81.

[18] Hacker, Barton C. and Grimwood, James M. (1977). *On the Shoulders of Titans: A History of Project Gemini*. Washington, DC: Scientific and Technical Information Office, National Aeronautics and Space Administration. pp. 33–45, 49.

[19] One then-Second Lieutenant chemist in his first year out of college stated to the author that he had his own electron microscope with which to do his analyses.

[20] E. Douglas Ward. (1966). "Propulsion System." p. 131 in *Gemini Midprogram Conference* report.

Selected Bibliography

Bilstein, Roger. (1980). *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles*. Washington, DC: Scientific and Technical Information Branch, National Aeronautics and Space Administration.

Bisney, John, and Pickering, J. L. (2015). *Spaceshots and Snapshots of Projects Mercury and Gemini*. Albuquerque, NM: University of New Mexico Press.

Caidin, Martin. (1962). *Rendezvous in Space: The Story of Projects Mercury, Gemini, Dyna-Soar, and Apollo*. New York: E.P. Dutton & Co.

Chamberlin, James and Meyer, Andre. (1963). "Project Gemini Design Philosophy." *Astronautics and Aerospace Engineering*. February 1963.

Chamberlin, James and Rose, James. (1963). "Gemini Program and Mission." *Proceedings of the 2nd Manned Space Flight Meeting*, Dallas, Texas. April 22–24, 1963. pp. 23–32.

Chamberlin, James and Rose, James. (1964). "Gemini Rendezvous Program." *Journal of Spacecraft*. January 1964.

Dethloff, Henry C. (1993). *Suddenly Tomorrow Came . . . A History of the Johnson Space Center*. The NASA History Series. Houston, TX: Johnson Space Center.

Gainor, Chris. (2001). *Arrows to the Moon: Avro's Engineers and the Space Race*. Burlington, Ontario, Canada: Apogee Books.

Gemini 3—The NASA Mission Reports; also the same for *Gemini 6*, *Gemini 7*, and *Gemini 12*, all by Apogee Books (Burlington, Ontario, Canada). Supposedly *Gemini 4* is available but I have yet to find a copy.

Gemini Program. (1965). Fact Sheet #291. Houston: Manned Spacecraft Center, NASA.

Grimwood, James M. and Ertel, Ivan D. (1967). "Notes and Documents: Project Gemini." *The Southwestern Historical Quarterly*. Vol. 71, No. 3 (Jan 1968). pp. 393–418.

Grimwood, James M. and Hacker, Barton C., with Vorzimmer, Peter J. (1969). *Project Gemini Technology and Operations: A Chronology*. Washington, DC: Scientific and Technical Information Division, Office of Technology Utilization, National Aeronautics and Space Administration.

Hacker, Barton C. and Grimwood, James M. (1977) *On the Shoulders of Titans: A History of Project Gemini*. Washington, DC: Scientific and Technical Information Office, National Aeronautics and Space Administration.

Hardesty, Von, and Eisman, Gene. (2007). *Epic Rivalry: The Inside Story of the Soviet and American Space Race*. Washington, DC: National Geographic.

Harland, David. (2010). *How NASA Learned to Fly in Space*. Burlington, Ontario, Canada: Apogee Books.

Johnson, Stephen B. (2002). *The Secret of Apollo: Systems Management in American and European Space Programs*. Baltimore: The Johns Hopkins University Press.

Levine, Sol. (1963). *Appointment in the Sky: The Story of Project Gemini.* New York: Walker and Company. Levine served as Deputy Technical Director of the Gemini Program for the Martin Company in Baltimore. The book includes a forward by President Lyndon Johnson(!).

Logsdon, John M. (1970). *The Decision to Go to the Moon: Project Apollo and the National Interest*. Cambridge, MA: The MIT Press. Describes the atmosphere in which Project Gemini existed. Interestingly, however, while Project Mercury is discussed along with Project Apollo, there is *no* mention of Project Gemini.

Logsdon, John M. with Launius, Roger D. (2008). *Exploring the Unknown, Volume VII: Human Spaceflight—Projects Mercury, Gemini, and Apollo*. Washington, DC: Office of External Relations, National Aeronautics and Space Administration. NASA SP-2008-4407.

Mayfield, Mark. (2010). *The Spaceflight Vault: A History of NASA's Manned Missions*. Atlanta, GA: Whitman Publishing LLC.

McDivitt, James A. and Armstrong, Neil A. (1965). "Gemini Manned Flight Program to Date." *Society of Experimental Test Pilots Proceedings—1965*. pp. 134–156.

NASA. (1966). *Gemini Midprogram Conference Including Experiment Results*. Washington, DC: Scientific and Technical Information Division, National Aeronautics and Space Administration.

NASA. (1967). *Gemini Summary Conference*. Washington, DC: Scientific and Technical Information Division, National Aeronautics and Space Administration.

NASA Project Gemini Familiarization Manual. (1965) McDonnell Aircraft Corporation. Released by Periscope Film, LLC, in 2011.

Selected documents in the history of the US civil space program.

Shaler, David J. (2001). *Gemini: Steps to the Moon*. Chichester, England, UK: Springer-Praxis Publishing.

Shankle, Ralph O. (1964). *The Twins of Space: The Story of the Gemini Project*. Philadelphia: J.B. Lippincott Company.

Sheehan, Neil. (2009). *A Fiery Peace in a Cold War: Bernard Schriever and the Ultimate Weapon*. New York: Vantage Books.

Siddiqi, Asif A. (2000). *Sputnik and the Soviet Space Challenge*. Gainesville, FL: University Press of Florida.

Teitel, Amy Shira. (2011). Designing a Bridge to the Moon. Available at http://amyshirateitel.com/2011/02/19/designing-a-bridge- to-the-moon/

Whitfield, Steve, (compiler). (2014). *Gemini 3: The First Manned Gemini Flight—The NASA Mission Reports*. Burlington, Ontario, Canada: Apogee Books.

Woods, Davis and Harland, David M. (2015). *NASA Gemini 1965-1966 (all missions, all models)—Owner's Workshop Manual*. Somerset, England, UK: Haynes Publishing. (Similar to the Haynes repair manual people used for their 1966 Chevrolets).