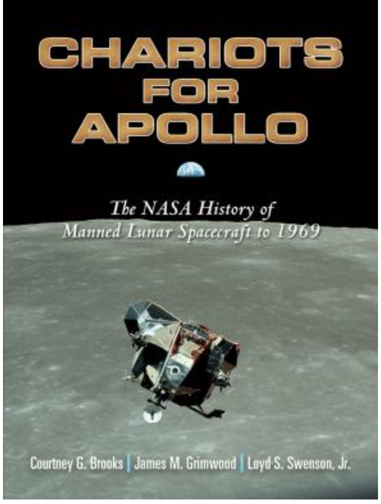

CHARIOTS
FOR
APOLLO
The NASA History of
Manned Lunar Spacecraft to 1969
Courtney G. Brooks
James M. Grimwood
Loyd S. Swenson, Jr.

... I believed that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth.

25 May 1961

... July 1969 A.D. We came in peace for all mankind.

Frontispiece:

Astronaut Edwin Aldrin walks on the surface of the moon near a leg of the lunar module after the 20 July 1969 Apollo 11 *landing. He was photographed by fellow crewman Neil Armstrong.*

Chariots for Apollo

The NASA History of
Manned Lunar Spacecraft to 1969

Courtney G. Brooks
James M. Grimwood
Loyd S. Swenson, Jr.

Introduction to the Dover edition by
Paul Dickson

DOVER PUBLICATIONS, INC.
Mineola, New York

Copyright

Bibliographical Note

This Dover edition, first published in 2009, is an unabridged and slightly corrected republication of the work first published in 1979 in the NASA History Series as NASA SP-4205 under the title Chariots for Apollo: A History of Manned Lunar Spacecraft. A new Introduction by Paul Dickson has been added to this edition.

International Standard Book Number

9780486140933

Manufactured in the United States of America
Dover Publications, Inc., 31 East 2nd Street, Mineola, N.Y. 11501

Table of Contents

Introduction to the Dover Edition

Of all humankind's achievements in the twentieth century—and all our gargantuan peccadillos as well, for that matter—the one event that will dominate the history books a half a millennium from now will be our escape from our earthly environment and landing on the moon.

—WALTER CRONKITE, *A Reporter's Life,* 1996.

CHARIOTS FOR APOLLO: A HISTORY OF MANNED LUNAR SPACECRAFT is the definitive NASA account of the Apollo program first published in 1979. This new Dover edition, reprinted on the 40th anniversary of the lunar landing and the 30th anniversary of the original publication of *Chariots for Apollo,* gives an account that still has freshness and suspense worthy of best works of narrative nonfiction. We all know how the story will end, but even so, as the program runs into difficult moments we are not entirely sure. This volume skillfully tells the story of the Apollo program, focusing on the development and deployment of the three elements of the Apollo spacecraft—the Chariots alluded to in the title. They are the Command Module, which served as the crew's quarters and flight control section; the Service Module, which contained propulsion and spacecraft support systems; and the Lunar Module, which served to take two crewmen to the lunar surface, supporting them on the Moon, and returning them to the Command and Service modules in lunar orbit. Taken together the Apollo spacecraft was, as the narrator for the Turner television documentary *Moonshot* put it, "... probably the most complex thing ever put together by humans. As much technology as a nuclear submarine crammed into a package the size of a minivan. The electrical system alone had thirty miles of wire."

Chronologically, the epic narrative begins with the creation of NASA itself and with the definition of a manned space flight program to follow the Mercury program. It proceeds through the intermediary Gemini missions and tells the story of Apollo from its tragic opening, when the crew of *Apollo 1* (Virgil "Gus" Grissom, Ed White, and Roger B. Chaffee), preparing for what was to have been the first manned launch of the Apollo program one month later—died in a matter of seconds. The Apollo tragedy set the Moon mission back about eighteen months, during which, among other things, NASA redesigned the ventilation system of the Apollo capsule. After six unmanned test flights the space program was back on track with Walter M. Schirra, Donn F. Eisele, and R. Walter Cunningham, who made the first manned flight of Apollo on Oct. 11, 1968. That flight, *Apollo* 7, had been preceded by six unmanned test flights. Then came the bold decision that the *Apollo 8* team would orbit the Moon. It launched on Dec. 21, 1968, carrying Frank Borman, James A. Lovell, and William A. Anders, and featured the famous reading from Genesis as the astronauts circled the Moon on Christmas Eve.

Apollo 9 tested the lunar module by flying it while in Earth orbit. Then *Apollo* 10 orbited the Moon and tested its lander close to the Moon's surface. The testing phase was now over.

The narrative ends with *Apollo 11,* when America attained its goal of the 1960s, landing the first men on the Moon and returning them safely to Earth. On July 16, 1969, with Neil Armstrong, Buzz Aldrin, and Michael Collins atop the massive *Saturn* V rocket, *Apollo 11* blasted off from Launch Pad 39. At 4:17 in the afternoon of July 20, Washington time, Armstrong radioed back: “The Eagle has landed.” Just about four minutes before 11:00 pm EDT, he became the first human to step on the Moon, bringing the narrative to a close.

It would be hard to find a work in the NASA History Series that more fully underscores the importance of using independent scholars to paint a relatively quick and accurate portrait of a program while there are still participants willing to give personal accounts. Some 341 oral histories were compiled in the creation of this book, and many were willing to share what the authors termed their “desk archives.” The list of persons interviewed at the end of the book is a veritable Who’s Who of the leadership of the Apollo program from both NASA and its contractors.

The technical side of the story is told with a clarity and vividness that makes it exciting and accessible to any interested reader. At the core of the technical side of the story is the intense religion of “quality control,” which got us to the Moon and back. It was born of the belief that the three most important variables, in descending order, were reliability, schedule, and cost. What is fascinating here is the fact that both NASA and its contractors were working in areas that often had huge unknown factors, such as the Lunar Module, which had to be built to land on an unknown surface.

But the human side of the story is front and center with personal accounts and insights left out of the more formal mission reports. There are heroic moments as well as those that are trivial but telling. For example, an aside in the discussion of *Apollo* 10 addresses the food and the difficulty of reconstituting it with gas-laden water: “Poor water quality may have affected their appetites, for the astronauts on this flight were not big eaters. On occasion, they skipped meals. Stafford estimated they had enough food to last for thirty days. Not all the blame could be laid on the water, however; the food was still no epicurean delight. Back on Earth in early May, Donald D. Arabian, chief of the Apollo Test Division, had tried a four-day supply of their rations. Arabian claimed to be ‘somewhat of a human garbage can,’ but even he lost his desire for food on this diet. The sausage patties, for example, tasted like granulated rubber and left an unpleasant taste.”

Chariots for Apollo is not just a book for those with an enduring fascination with space exploration, but for anyone looking for an insight into how America was able to assemble a team of 400,000 individuals and accomplish a mighty goal. As the twenty-first century rolls on, the Apollo experience becomes an even more important prime example of what America can do when it puts its mind to it, a point made time and again by Barack Obama in his race for the presidency.

PAUL DICKSON

Foreword

The story of Apollo is a remarkable chapter in the history of mankind. How remarkable will be determined by future generations as they attempt to assess and understand the relationship and significance of the Apollo achievements to the development of mankind. We hope that this book will contribute to their assessments and assist in their judgments.

Writing the history of Apollo has been a tremendous undertaking. There is so much to tell; there are so many facets. The story of Apollo is filled with facts and figures about complex machines, computers, and facilities, and intricate maneuvers—these are the things with which the Apollo objectives were achieved. But a great effort has also been made to tell the real story of Apollo, to identify and describe the decisions and actions of men and women that led to the creation and operation of those complex machines.

The flights of Apollo were the focus of worldwide reporting and attention. The success of these flights is directly attributable to the less well reported and less visible work of nearly 400 000 people in hundreds of different organizations. That the efforts of so many could be organized and coordinated so effectively is a tribute to American ingenuity and management abilities. Moreover, only those who were directly involved can fully appreciate the dedication, competence, courage, teamwork, and hard work of those people.

It is not possible to single out any one or even a few of the many people and the countless decisions, actions, and key events in the program as being more critical or important than the others in determining its ultimate success. Nor is it appropriate to do so since that success could not have been achieved without having first succeeded in building effective teamwork in an environment where every task, no matter how seemingly insignificant at the time, in some way affected the ultimate outcome of the program.

It was a rare personal privilege for me to serve in the Apollo program. The greatest reward was the opportunity to work with the many people in government, industry, and other organizations in this country and around the world who played a part in this tremendous undertaking. Words cannot adequately describe the extraordinary ingenuity and selfless devotion that were so often displayed by so many in surmounting the multitude of problems and obstacles that developed along the way. This program surely demonstrated what our great country can accomplish when the national will and leadership steadfastly support a competent and dedicated group of people who are unwaveringly committed to attaining a seemingly unattainable objective.

I hope that this book will not only serve future generations as they view the Apollo story in a historical perspective, but will also bring the satisfaction of a job well done to all those who served in the Apollo program.

December 1978 SAMUEL C. PHILLIPS

General, USAF (Ret.)

Preface

A pollo was America's program to land men on the moon and get them safely back to the earth. In May 1961 President Kennedy gave the signal for planning and developing the machines to take men to that body. This decision, although bold and startling at the time, was not made at random—nor did it lack a sound engineering base. Subcommittees of the National Advisory Committee for Aeronautics (NACA), predecessor of the National Aeronautics and Space Administration (NASA), had regularly surveyed aeronautical needs and pointed out problems for immediate resolution and specific areas for advanced research. After NASA's creation in October 1958, its leaders (many of them former NACA officials) continued to operate in this fashion and, less than a year later, set up a group to study what the agency should do in near-earth and deep-space exploration. Among the items listed by that group was a lunar landing, a proposal also discussed in circles outside NASA as a means for achieving and demonstrating technological supremacy in space. From the time Russia launched its first Sputnik in October 1957, many Americans had viewed the moon as a logical goal. A two-nation space race subsequently made that destination America's national objective for the 1960s.

America had a program—Project Mercury—to put man in low-earth orbit and recover him safely. In July 1960 NASA anounced plans to follow Mercury with a program, later named Apollo, to fly men around the moon. Soon thereafter, several industrial firms were awarded contracts to study the feasibility of such an enterprise. The companies had scarcely finished this task when the Russians scored again, orbiting the first space traveler, Cosmonaut Yuri CGagarin, on 12 April 1961. Three weeks later the Americans succeeded in launching Astronaut Alan Shepard into a suborbital arc. These events—and other pressures to "get America moving"—provided the popular, political, and technological foundations upon which President Kennedy could base his appeal for support from the Congress and the American people for the Apollo program.

Because of its accelerated pace, high technology, and need for reliability, Apollo's costs were high (expected to be $20 billion to $40 billion as early as mid-1961), but the program lasted longer (albeit with aliases) than either Mercury or Gemini. (Gemini began in December 1961 to bridge some technological gaps and to keep America in space between the simpler Mercury flights and the more ambitious Apollo missions.) Requiring seven years of development and test before men could fly its machines, Apollo craft carried men into space from October 1968 through July 1975. The Apollo program itself recorded its final return from the moon on flight 17 in December 1972, after a dozen men had made six successful explorations on the lunar surface. Shortly thereafter Skylab, using the basic Saturn launch vehicle and Apollo spacecraft hardware, sailed into earth orbit, supporting crews on research missions up to 84 days in length during 1973 and 1974. Apollo passed from public view in July 1975, following the Apollo-Soyuz Test Project flight, flown by American astronauts and Russian cosmonauts to make the first international space rendezvous.

The Apollo story has many pieces: How and why did it start? What made it work? What did it accomplish? What did it mean? Some of its visible (and some not so visible) parts—the launch vehicles, special facilities, administration, Skylab program, Apollo-Soyuz Test Project, as examples-have been recorded by the NASA History Office and some have not. A single volume treating all aspects of Apollo, whatever they were, must await the passage of time to permit a fair perspective. At that later date, this manuscript may seem narrow in scope—and perhaps it is. But among present readers—particularly those who were Apollo program participants—there are some who argue that the text is too broad and that their specialties receive short shrift. Moreover, some top NASA leaders during Apollo's times contend, perhaps rightly, that the authors were not familiar with all the nuances of some of the accounts set down here.

Chariots for Apollo: A History of Manned Lunar Spacecraft begins with the creation of NASA itself and with the definition of a manned space flight program to follow Mercury. It ends with *Apollo 11*, when America attained its goal of the 1960s, landing the first men on the moon and returning them to the earth. The focal points of this story are the spacecraft—the command and service modules and the lunar module.

The 14 chapters cover three phases of spacecraft evolution: defining and designing the vehicles needed to do the job, developing and qualifying (or certifying) them for the task, and operating them to achieve the objective. Like most large-scale research and development projects, Apollo began haltingly. NASA, with few resources and a program not yet approved, started slowly. Ad hoc committees and the field centers studied, tested, reported, and suggested, looking for the best way to make the voyage. Many aerospace industrial firms followed the same line, submitting the results of their findings to NASA and hoping to get their bids in early for a piece of the program.

When lunar landing became the Apollo objective in May 1961, the United States had only 15 minutes of manned flight experience in space and a tentative plan for a spacecraft that might be able to circumnavigate the moon. No rocket launch vehicle was available for a lunar voyage and no route (mode) agreed on for placing any kind of spacecraft safely on the lunar surface and getting it back to the earth. Nor was there agreement within NASA itself on how it should be done. But the luxury of time for committees to debate, thrash out, and reconcile differences vanished all too quickly—although NASA still had too few people and resources with which to do anything else. The agency awarded contracts for development of the systems—command module, guidance and navigation, and launch facilities—that were likely to change least when subsequent decisions were finally made. The first two chapters are devoted to these discussions.

Resolving the mode question was perhaps the most difficult decision of the entire program. The debate occupied NASA (and touched off arguments from other governmental agencies and from industry) for 18 months. General agreement on this pivotal part of the Apollo mission was essential for the selection and development of both the Saturn V launch vehicle and the lunar module that completed the Apollo hardware “stack.” Passions among the participants in the mode battle appeared violent, even divisive; but when the lunar orbit rendezvous mode was eventually selected, in July

1962, the centers and Headquarters groups closed ranks behind the decision. Chapter 4 concludes the difficult definition phase of the program.

Apollo's middle years are covered in Chapters 5 through 9. When the development and qualification phase began, the lunar module was a year behind the command module, even though there were two versions of the CM: "Block I," limited to earth-orbital operations, and "Block II," equipped for lunar-orbital rendezvous. At the same time, NASA was staffing and organizing to manage the complex program and drafting detailed specifications, from the smallest component to the largest subsystem. Spacecraft development took two years, lasting much longer and meeting more difficulties than expected, and caused manufacturing delays. By 1965, Apollo managers were able to spell out the tests and reviews needed to qualify the spacecraft and get it to the launch site. All this time, the managers were fighting the extra kilograms that engineering improvements were adding to the two machines. Toward the end of the year and throughout 1966, Apollo moved ahead, with Gemini and NASA's unmanned lunar reconnaissance programs supplying some answers to Apollo planners, especially about astronauts living and working in space, the ability to rendezvous, and the composition of the lunar surface. Just when mission planning and launch schedules had assumed some firmness, a spacecraft fire on the launch pad during a routine test killed three astronauts and caused a wrenching reappraisal of Apollo program plans and much rework of the space vehicles.

Many deficiencies in the early model of the Apollo command module were eliminated as work on the advanced version progressed. When the command module was ready for its first trial flights, the lunar module was still a year behind because of propulsion, corrosion, wiring, and weight problems. NASA flight-tested both the lunar module, with all its problems, and the Saturn V, which had developed unwanted “pogo-stick” oscillations, and then decided that neither could yet be trusted to carry men into space. While solving these problems, NASA pushed ahead to qualify the command module, launching it into earth orbit (with the first Apollo crew aboard) on the smaller Saturn IB in October 1968. A daring circumlunar voyage in December not only qualified the command module for its ultimate mission but demonstrated that the Saturn V was at last trustworthy. Only the lunar module still lagged. But early 1969, the last year allowed by Kennedy’s challenge, brought two flights in quick succession—one in earth orbit and the other in lunar orbit—employing all the lunar-oriented vehicles and certifying that Apollo was ready to land men on the moon. The world then watched—via television—as its first representatives walked on the surface of the moon in July 1969. These dramatic missions are discussed in Chapters 10 through 14.

This book is the work of three authors: Courtney Brooks, James Grimwood, and Loyd Swerison.[a] Brooks focused on the history of the lunar module, the mode issue, the search for an adequate launch vehicle, and the selection and training of astronauts (including spacesuits and training devices). Swenson examined the command module story, guidance and navigation, the command module fire, and scientific concerns. Grimwood wrote the five chapters on the Apollo missions and revised the drafts.

Sally D. Gates, Johnson Space Center History Office Editor-Archivist, served indispensably in many capacities in preparing this history: research assistant, editor, coordinator of the comment draft, compiler of the appendixes, typist, proofreader, and critic. Contributions en route were made by Billie D. Rowell, Corinne L. Morris, and Ivan D. Ertel, all former members of this office. Rowell and Morris worked on the archives, and Ertel selected the illustrations. Verne L. Jacks, an employee of the University of Houston, transcribed some of the taped oral history interviews and typed several trial draft chapters.

As may be seen in the source notes, the text rests on primary Apollo program documentation on the spacecraft. The archival base (about 25 cabinets of documents) was extensive, and the authors owe the program participants a great debt for heeding the admonition, “Don’t throw away history!” Melba S. Henderson provided the Apollo Spacecraft Program Office reading files, which contained the day-to-day record of the worries and joys of managers and engineers as Apollo progressed. A host of others-most of whose names are in the notes—gave up treasured desk archives and illustrations. More than 300 of these participants agreed to taped oral history interviews.

Although this book was written under the auspices of the NASA history program, partially through a contract with the University of Houston, the contents are the judgments of its authors and in no way represent a consensus of NASA management—if such a thing were possible—about any of the topics, programs, actions, or conclusions. Like many who write contemporary history, the present chroniclers found far more advantages than hazards in having the counsel of the participants in weighing the mass of evidence and clearing the technical points. This assistance proved invaluable, though many who provided aid would not agree with the authors' selections and presentations—and some have said as much. Special mention should also be made of the help received from the NASA History Office—Monte D. Wright, Frank W. Anderson, Jr., Lee D. Saegesser, Carrie E. Karegeannes, and Alex F. Roland; from former NASA Historian Eugene M. Emme; and from the Chief of Management Analysis at the Johnson Space Center—Leslie J. Sullivan. But the authors alone must shoulder the responsibility for any defects the text may still contain.

C.G.B.
J.M.G.
L.S.S.

Houston
September 1978

1

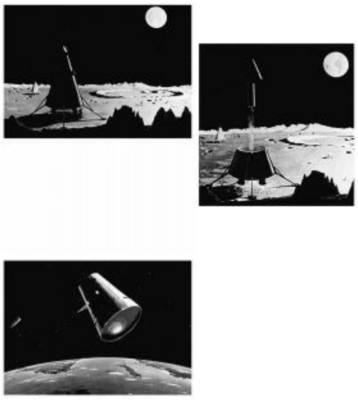
Concept to Challenge

1957 to Mid-1961

The orbiting of *Sputnik I* in October 1957 stirred the imagination and fears of the world as had no new demonstration of physics in action since the dropping of the atomic bomb. In the United States the effect was amplified by realization that the first artificial satellite was Russian, not American. Yet the few scientists and engineers working in Project Vanguard and other U.S. space projects were surprised only at the actual timing. Indeed, they had already considered means of sending man around the moon.

Modern rocket technology dates from the Second World War; the development of intercontinental ballistic missiles in succeeding years resulted in machines that could eventually launch vehicles on space missions. In this same time, man's flying higher, faster, and farther than ever before suggested that he could survive even in space. *Sputnik I* caused alarm throughout the United States and the ensuing public clamor demanded a response to the challenge.[1] During the next year, many persons in government, industry, and academic institutions studied means and presented proposals for a national space program beyond military needs. After decades of science fiction, man himself, as well as his imagination, moved toward an active role in space exploration.

Concurrently with the formation of the National Aeronautics and Space Administration (NASA) in late 1958—a year after the first Sputnik[2] -a proposal (which became Project Mercury) was approved to fly man in near-earth orbit.[3]



Artist's concepts sketched about February 1959 were used in a presentation by M. W. Rosen and F. C. Schwenk at the Tenth International Astronautical Congress in London, 31 August 1959. Above, astronauts leave the spacecraft to investigate the lunar surface. At right, the return vehicle takes off from the moon; below, the reentry vehicle begins to enter the atmosphere after jettisoning the Propulsion unit.

FORGING A NATIONAL SPACE AGENCY

The National Aeronautics and Space Act of 1958, passed by Congress in July of that year, said nothing about the moon or manned space flight. In its declaration of policy and purpose, however, the general objectives were to improve and use aeronautical and space capabilities "for the benefit of all mankind." If achieving international leadership in space meant that this nation would have to fly men to the moon, the Act encouraged that ambition.[4] Clearly NASA, as the nonmilitary agency of the United States, would be responsible for furthering the national interest in space affairs. But the new agency required more than just a charter before the President and the Congress could turn it loose on a task requiring a vast acceleration of activity and a large commitment of national resources.

Space Task Group Director Robert R. Gilruth, left, and Langley Research Director Floyd L. Thompson, center, welcome NASA Administrator T. Keith Glennan to Langley Field, Virginia, for a January 1961 tour.

Much of the preliminary planning for Project Mercury had been done by the National Advisory Committee for Aeronautics (NACA), NASA's predecessor. NASA's first Administrator, T. Keith Glennan, president of Case Institute of Technology (on leave), set about organizing and using the