

Foreword

Early on the morning of 26 July 1971, the crew of Apollo 15 in the good ship *Endeavour* with its cargo (the lunar module, *Falcon*, and *Lunar Rover-1*) departed Earth-space for the Hadley-Apennine landing site on the Moon.

The expedition had actually begun 20 months previously and required more than 100,000 people to prepare the launch vehicle, prepare the three vehicles, prepare the spacesuits, gather up equipment, provisions, and instruments, and generally plan the three-day exploration of the mountains of the Moon.

Just over ten years had passed since May 1961, when President John F. Kennedy committed the United States to “landing a man on the Moon and returning him safely to Earth”. During this period, twenty five US manned space missions had been flown (Mercury, Gemini and Apollo) – nineteen in Earth orbit, three around the Moon, and three to the lunar surface.

The crew of Apollo 15 was now embarking on the next phase, the first extended scientific exploration of the Moon. NASA termed it “[one of] the most complex and carefully planned expeditions in the history of exploration.” Only two more such missions were to follow, then there would be a hiatus lasting several decades, maybe even longer, before humans would once again set foot on the Moon.

I was the commander of the Apollo 15 mission. Jim Irwin accompanied me down to the lunar surface in *Falcon* while Al Worden looked after *Endeavour* in orbit. The planning and preparation for our mission had been so thorough that there was no doubt in our minds that we really knew “how to fly to the Moon” – and to do so in any conceivable situation. But as “we” (all 400,000 people working on the Apollo program) had learned during the many preceding missions, flying to the Moon and returning to Earth (successfully, that is) is very, very difficult. So, just how did we actually plan and prepare for this extraordinary adventure – how was our Apollo to fly to the Moon?

The Apollo program was implemented through five sequential tasks that evolved during two overlapping phases – perhaps the “ABCs” of how to fly to the Moon:

Phase 1

- A. Adopt a method by which men could fly to the Moon and return safely.
- B. Build the spacecraft and ground facilities to implement the method.

- C. Develop the techniques and procedures to accomplish the mission.
- D. Select and train the astronaut crews (the vital link between B and C).

Phase 2

- E. Upgrade the capabilities of the entire system to maximize the technical and scientific results of the Apollo phase of human lunar exploration.

In 1967 mission planners at NASA introduced an alphabetic nomenclature by which to describe where individual flights fitted into the overall scheme. This started at “A” with unmanned tests of the Saturn V launch vehicle and worked through a series of missions of progressively greater operational capability, finally reaching “G”, which was the Apollo 11 lunar landing, and “H” for a number of follow-on missions. These constituted Phase 1. Missions flown during Phase 2 were intended to maximize the science objectives, and were designated “J”. Apollo 15 was the first such mission.

A. ADOPT A METHOD

To pursue President Kennedy’s challenge, NASA defined three methods of achieving a lunar landing and safe return: (1) direct ascent from the surface of the Earth to the surface of the Moon; (2) rendezvous of all of the mission elements in Earth orbit and then proceed directly to the lunar surface (EOR); and (3) fly into lunar orbit and send down a specialised lander while the mothership remained in space, then rendezvous upon lifting off from the Moon (LOR). In June 1962 it was decided to use LOR. Thus “rendezvous” became the key to the method. Actually, at that time LOR was seen as the most hazardous option – we had not yet attempted a rendezvous of any type, even in Earth orbit (the first would not be for another 3½ years), much less around the Moon, 240,000 miles away, where, on the far side, there was no ground tracking nor any contact with the engineers in the Mission Control Center. But LOR drove the design of the entire lunar landing “system” – spacecraft (hardware and software); ground facilities, and in particular the resulting complex flight operations, techniques, and procedures.

To illustrate the necessary complexity of this method, ten distinct phases of a lunar surface mission were defined, each operating in a different domain: (1) launch from Earth; (2) Earth orbit; (3) translunar (and later trans-Earth); (4) entry into lunar orbit (and later departure from lunar orbit); (5) operations in lunar orbit; (6) descent to the surface and landing; (7) surface operations; (8) lunar ascent, (9) lunar rendezvous; and (10) Earth re-entry.

B. BUILD THE SPACECRAFT

Eight different “vehicles” were designed and built: three stages of the giant Saturn V launch vehicle; four spacecraft modules (command module [CM], service module [SM], together forming the CSM; and the lunar module (LM) with its descent stage

and ascent stage); and on the lunar surface, the lunar roving vehicle (LRV), the spacesuit, and its backpack with oxygen, cooling and communications. They were all required to perform an advanced Apollo lunar surface mission.

To provide operations, support, and supply, each of the four spacecraft modules required several major systems, including specific combinations of guidance and navigation, electrical, communications, control (rockets), environmental, sequential (pyrotechnics), and consumables (propellant, water, cooling). Of course each system itself consisted of several subsystems and a myriad of components. These essential systems had twenty-five modes of operation (automatic, semi-automatic, and manual for both prime and backup systems).

Additionally, Apollo was the first flight vehicle to be controlled through a digital computer (a “digital autopilot”, or DAP). This remarkable advance in computers would soon propagate through both government and industry as an essential element of both spacecraft and aircraft. At the time of Apollo, of course, the capability of the DAP was relatively meagre because each of the identical computers in the CM and the LM had only 38,000 words of memory (a mobile phone today can have over two billion words!) and what happened was that the spacecraft would be flown by the astronauts using the DAP as their main interface with operating systems.

And simultaneously with the spacecraft, the ground “systems” were designed and built, including a worldwide network of tracking and communications and especially the Mission Control Center (MCC) in Houston. In its broader sense the very complex and capable MCC was like a spider web in that it consisted of a central hub with ever expanding sequential “rings” and connected through nodes like spokes on a wheel. Each node was, in its own way, a “mission control center”, and was manned by the true experts in that particular discipline.

C. DEVELOP THE PROCEDURES AND TECHNIQUES TO ACCOMPLISH THE MISSION

This vast assembly of systems, subsystems, components, astronauts, flight controllers, support staff, and many others, had to be tightly integrated and they had to play in harmony – just like a 100-piece orchestra. Everybody had to be on the same page, the same line, and the same note; or there would be no music. In preparing this orchestra to play the complete symphony, four concepts were key: (1) crew procedures, (2) mission techniques, (3) mission rules, and (4) the “flight plan.”

Crew procedures. To fly the mission, the spacecraft had to be operated in a manner consistent with both the functions of its systems operation as well as with the sequence of mission activities. The crew procedures were developed for this purpose in the form of step-by-step checklists. Together they amounted to several volumes of switch-by-switch procedures for each system, each spacecraft, and each phase of the mission, stating whether they were to be operated either in primary modes, backup modes, emergency modes, or trouble-shooting to determine the cause of a failure or an anomaly.

Procedures had to be developed, integrated, and tested, time and again in order to ensure that in flight every action was performed in precisely the correct, and verified, sequence. This involved countless hours of training in mission simulators, procedures trainers, part-task trainers, mock-ups, and other representations of actual hardware and software, and even a simulated lunar surface.

Mission techniques. These defined the manner in which the mission would be flown, or more specifically, the manner in which the spacecraft “trajectory” would be controlled. Once the mission objectives, the crew procedures, and the trajectory are defined, it becomes necessary to specify exactly how the various components of the guidance, navigation, and control systems, as well as the rocket engines, should be used during each phase of the mission to maintain the “trajectory” for that phase. The mission techniques development task was basically: how do you decide how to fly an Apollo mission? It required detailed planning on precisely how well the systems must work to achieve the mission, including all of the options for use and/or failure of primary or backup systems. This was also termed the “data priority” task, and its detailed planning was absolutely essential to success.

As an example, LOR was key to both mission success and crew safety. During the LOR phase, five first-class systems computed the rendezvous manoeuvres – two in the LM, one in the CSM, the MCC, and even some simple charts used by the crew. If all of these sources agreed, the solution was clear. But if there was disagreement, there had to be a rationale for deciding which one to use.

Mission rules were established as a combination of crew procedures and mission techniques whereby, if any failure or anomaly occurred, a “rule” defined the action to take. Mission rules essentially answered the “what if” question. Even so, there were events during Apollo that had not been foreseen, and required thinking and action beyond mission rules – an excellent example being the oxygen tank explosion that aborted the Apollo 13 mission.

Flight plan. The flight plan was developed as an integrated time-line of events and activities to bring together the mission objectives, the mission techniques, and the crew procedures for each phase of the mission. It served many functions and included references to the particular technique to be used, an index to checklists, the equipment to be used, constraints on the use of spacecraft systems, limitations on consumables, specific tasks for each member of the crew, ground tracking coverage, day-night cycles, and even eat and sleep periods. Alternate and contingency flight plans were also included.

D. THE APOLLO ASTRONAUTS

The 12-year Apollo lunar exploration program (1961 through 1972) occurred during the second half of a transformational period between the end of WW-II (1945) and the demise of the Soviet Union in 1991, a period of major technological, political, economic, and cultural dynamics. Technologically, the digital computer was in its infancy, yet automation and robotics were clearly imminent. The Apollo astronauts were required to bridge this gap, as humans capable of using a computer to assist in

manually operating the vast array of systems, techniques, and procedures necessary to explore the surface of the Moon. The crew had to operate the hardware manually because computers did not yet have the reliability or capability necessary to operate autonomously and by the nature of the design strategy MCC did not really “control” the spacecraft.

And at any point in the mission, the crew had to be prepared to operate on their own without any contact from Earth, using only the equipment and computers on board, together with pre-calculated manoeuvre data. For, among the many potential emergencies that could occur on such a voyage, one of the most serious was loss of communications with MCC; whereby the crew and their spaceship would be alone in the ocean of space, perhaps even on the surface of the Moon and miles from the lunar module.

During each Apollo lunar exploration mission the three astronauts were obliged to be qualified and certified in essentially seven crew positions:

- The CSM had three crew positions: (1) Pilot (launch, major manoeuvres, rendezvous and re-entry); (2) Navigator (inertial navigation and rendezvous); and (3) Systems Engineer (all systems including fuel cells and propulsion).
- The LM had a crew of two: (4) Pilot (landing, launch, and rendezvous); (5) Systems Engineer (two computers, oxygen, electrical, thermal and water management)
- The surface exploration required a crew of two: (6) Lead geologist (also LRV driver); and (7) Geologist/systems engineer (for LRV, the suits and the backpack).

NASA training for the astronaut crews was superb – every aspect of the mission was covered by expert teachers and experienced professionals. Every spacecraft and all equipment and software were tested and verified by the astronaut crews (including flight spacecraft and spacesuits in vacuum chambers). In addition to the sophisticated (for that time) CSM and LM simulators, training was received in spacecraft systems, fundamental astronautics (navigation and rendezvous), and the operations of MCC. Commanders were qualified in helicopters and the Lunar Landing Training Vehicle. All astronauts maintained flight currency in T-38 jets, received SCUBA diving (for underwater weightless training), and jungle, desert, and water survival. And for the “J” missions in particular, crews had extensive geology training with many hours of classroom and laboratory work, and field exercises.

By late 1963, the first thirty astronauts had been selected – all were experienced pilots in high-performance jets (twenty-four were test pilots); all had engineering degrees (twelve also had graduate degrees); and all had been trained by the military (Air Force, Navy and Marines). This group would eventually command all twenty-nine US manned space missions (Mercury, Gemini, and Apollo) through the end of Apollo lunar exploration in 1972. But seven died during training or flight; and eleven more who were selected in later groups flew Apollo lunar missions.

The basic design of the lunar module had been frozen in mid-1963, but systems integration, test and checkout had not yet commenced. Apollo simulators had not yet been developed. One of the major challenges for these first astronauts (and their

operational support teams) was to develop and verify the procedures by which spacecraft would be operated. This required the integration and confirmation of the delicate sequence of operating the electrical, mechanical, computer, propulsion, life-support and other systems – and Apollo was far more complex than Mercury and Gemini, and certainly any contemporary aircraft. And in developing procedures, they also necessarily became major contributors to the development of mission techniques (data priority). And because of their experience and involvement in the evolution of the Apollo program, these original thirty astronauts participated in and contributed to major management and programmatic decisions at the highest level.

E. SCIENCE AND UPGRADES

In April 1970, after Apollo 11 (the “G” mission) and Apollo 12 (the first of the “H” missions), the most dramatic and hazardous halt to the program occurred with the near-fatal loss of Apollo 13. But four months later, in August, NASA made one of its boldest decisions. In the face of that near disaster in space, dwindling public support, and a rapidly declining budget, it decided to skip the final “II” type mission, press on with upgrading the total “system” (hardware, software, science, and operations) and finish the program with three full-up “J” missions to the most significant scientific sites on the Moon. This upgrade from “II” to “J” included, in particular, the lunar roving vehicle, which in turn greatly increased the exploration capability, especially to investigate several different geological areas miles away from the LM in different directions, significantly more scientific equipment and experiments, and importantly, a mobile TV camera to view and record the distant activities of the crew so that MCC (and the public) could participate in the exploration to an unprecedented degree. As a result, a single “J” mission that used an LRV to investigate multiple geological areas at a particularly worthy landing site became almost equivalent to sending a series of “II” missions to individual sites. Consequently, the “J” mission crews became very proficient in “planetary field geology”.

Of the thirty original astronauts, none had any formal geology training – NASA had to teach pilots how to be proficient planetary field geologists; adding science to engineering as a primary discipline. Again, the training was superb; and because of their previous spaceflight experience, the mission commanders played a major role in planning the training for their crew. After many hours of practical and effective geology training (classroom, laboratory, and field), the results justified the process, because it can be argued that during the “J” missions the performance of the eight “pilot-geologists” (in orbit and on the surface) was equal to the performance of the only “geologist-pilot” who reached the lunar surface on Apollo 17, which was the final mission of the program.

But this commitment to the “J” missions was surely one of the most rewarding decisions of the Apollo programme. It would have been a lot easier, safer, and cheaper to have finished up with the final two “H” missions as scheduled, because if one of the final missions had failed then the programme would surely have been

brought to an end and “Apollo” would have passed into history as a “failure”. In this regard, the lunar roving vehicle was the final element in the overall configuration of a complete “system” for human planetary exploration. For the future of Apollo and for human planetary exploration in general, in August 1970 NASA management truly made the “right” decision!

But as time passes, hardware for lunar exploration will come and go; software will come and go; and astronauts, cosmonauts, and the staff who support them in training and in flight will come and go. Although the future will see more automation and robotics, the manner in which manned spaceships fly to the Moon (and return!), like wheels rolling the roads and ships “sailing” the seas, will be the same for most likely decades to come. This exceptional book describes “how” for those who contemplate, for those who plan, and for those who fly; and also for the historical record.

*David R. Scott
Commander, Apollo 15
Los Angeles, California
January 18, 2011*

<http://www.springer.com/978-1-4419-7178-4>

How Apollo Flew to the Moon

Woods, W.D.

2011, XXXI, 555 p. 255 illus., 127 illus. in color.,

Softcover

ISBN: 978-1-4419-7178-4