FIREBALL IN THE SKY

Getting to the Moon in 7,650,000 easy steps

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PROLOGUE

Omo was a seasoned explorer. His age was twenty-five Long Rains, much of which he had spent on the move. Leaving the security of his tribe on the shores of the Endless Lake, he had followed the Rushing Waters and Green Gorges, slogged across the Vast Hot Sands, and scaled every Upland in his path. Now he stood on the highest ridge of all, staring at the Great White Fireball in the night sky.

Fireball

The time was about 195,000 years ago, in a region now called Ethiopia. Omo, one of the earliest members of our species, *Homo sapiens,* was gazing at Earth's big solitary
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satellite. He yearned to reach it, but no matter how far he trudged, it seemed ever farther away.

Nearly two thousand centuries would pass before Apollo astronaut Neil Armstrong would take his one small step from a spacecraft ladder and declare, "That's one giant leap for mankind," and human beings would at last realize Omo's dream of walking on the Moon.

But make no mistake. The trip from Earth to the Moon—and back—is immensely hard. The obstacles are staggering and the achievement so extraordinary as to defy belief. In fact, many people across the globe still aren't convinced that it was ever done. But it was.

How do I know? Because I helped make it happen.
Let me tell you a little about how we did it.

THE MISSION

Project Apollo began in 1961 when President Kennedy proposed to Congress the audacious national goal of landing a man on the Moon and returning him safely to Earth by the end of the 1960s.

The next year, on September 12, 1962, in his Rice University speech Kennedy declared that "…we do these things not because they are easy but because they are hard. Man, in his quest for knowledge, is determined and will not be deterred." The President could have been evoking our intrepid ancestor, Omo, when he referred to the late mountaineer George Mallory; when asked by a reporter in 1923 why he was so intent on climbing Mount Everest, the world's highest peak, Mallory had replied, "Because it's there."

Space, like Everest, was "there" too, for the young aerospace industry—especially we who worked at Cape Canaveral. So this new national commitment was an exciting, if sobering, test of our mettle. At the time of JFK's speech, the "manned space race" was already on. The Soviet *Vostok* program had successfully achieved over 8 days in orbit.

Our *Mercury* program had flown just four missions, two in low Earth orbit, for a total of slightly under 10.5 hours of manned flight. Not an auspicious start.

In stark contrast, the projected lunar mission would entail:

- Launching a 7 million-pound rocket from Cape Canaveral
- Sending a three-astronaut crew and two spacecraft to the Moon
- Exposing humans to nine days in space
- Making a soft landing, exploring the lunar surface, and returning
- Cruising 240,000 miles each way, from Earth to the Moon and back

THE CHALLENGE

In the Fall of 1962, the following absolutely crucial items did not exist:

- Saturn-V launch vehicle and launch pad
- Launch vehicle assembly facilities
- Apollo command module spacecraft
- Lunar exploration module spacecraft
- Gemini/Agena spacecraft docking proof-of-concept design
- Ground support computers and software
- Mission control centers at the Cape and Houston
- Flight computers and software
- Lunar excursion space suits
- Landing site selection
- Flight simulators and software
- Global flight tracking and communications facilities
- Selection of a second astronaut team
- Crew training programs and facilities
- Multi-phase operational procedures
- Multi-mode abort criteria and procedures
- Manned spaceflight “payload” protocols
- Flight readiness test procedures and software
- Launch and flight support staff and facilities

- National Airlines' daily "*Rocket Run*" between Melbourne, Orlando, New Orleans, Houston and Los Angeles to shuttle thousands of project personnel.

As the mission profiles developed, planners constructed graphical aids, "waterfall" charts and critical path analyses. The simplest of these had just a handful of milestones:

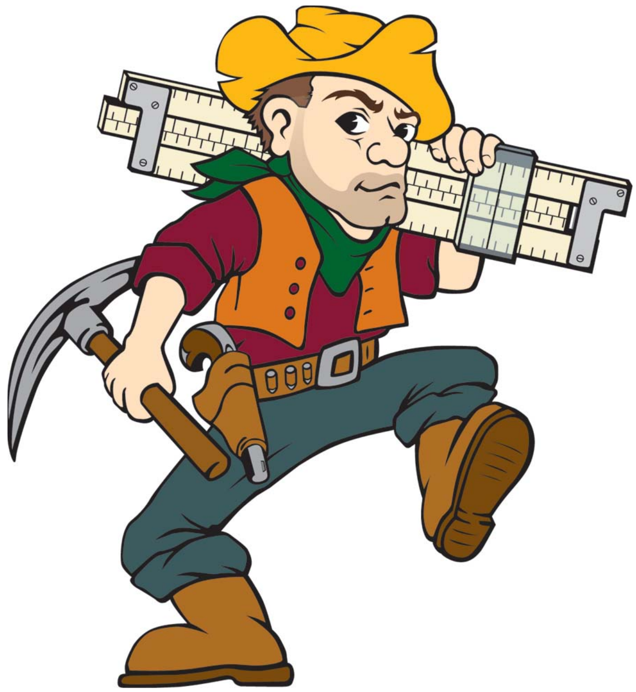
1. Launch manned payload to Earth parking orbit
2. Align and initiate rocket-burn for trans-lunar trajectory
3. Deploy and dock command & service module (CSM) with lunar module (LM)
4. Coast for 3 days in interplanetary space
5. Achieve lunar parking orbit
6. Transfer landing crew from CSM to LM (leaving a crew member in CSM)
7. Undock LM, de-orbit and descend to surface
8. Land (at one of several promising locations)
9. Conduct EVA (extra-vehicular activity)
10. Collect a small "contingency" surface sample
11. Launch LM ascent stage and return to lunar orbit
12. Dock with CSM
13. Transfer crew and jettison LM
14. Conduct return rocket-burn procedures
15. Transition to Earth by direct-return trajectory (3-day cruise)
16. Conduct atmospheric re-entry and descent procedures
17. Touch down in ocean recovery area

THE PEOPLE

These demands painted a daunting picture for a project start-up with technical, time and budget constraints. A tiny number of people had exposure to aerospace work, and fewer still had hands-on experience. No peacetime endeavor of this complexity, precision or magnitude had ever been attempted, so much of our work had no precedent. Many of us, though technically qualified, weren't sure at first what we were doing! We adopted trial-and-error methods and perfected them as we progressed.

Every milestone spawned a pyramid of sub-tiers and thousands of individual tasks by engineers, technicians, testers, astronauts, fabricators, software developers, trainers, HR experts, financial planners, and managers. Ultimately a huge labor force was built and trained on-the-fly as it were. Twenty thousand contractors joined the program, and contract management assumed an intricacy and attention to detail never seen before, even on the 1940s Manhattan Project. The population of Apollo eventually swelled to about 400,000—but aside from administrative positions there were very few women.

Computers presented a different staffing problem. It was understood from the outset that every phase, from lab to lunar landing, could only be done using computers. But computer science, as a recognized discipline, didn't yet exist. We needed thousands of programmers and electronic specialists with scientific and engineering aptitudes. But only a few hundred people, in large-scale computer facilities scattered across the country, were qualified or interested in working on the Moon mission. Furthermore, people with an aptitude for software development were not, for the most part, engineers. They came from every sort of background: musicians, history teachers, botanists, poets, chemists, athletes, accountants, bar-tenders, artists, English majors, car salesmen, geologists, you name it. We had to build a cadre of space computing experts, quickly, from the ground up.



Look out, Luna…here we come!

THE NUMBERS

Unlike today, crucial mathematics and physics disciplines were in the Dark Ages. Massive math problems were solved on chalkboards, slide rules, mechanical calculators. Even the lowly ball-point pen was new and of shaky quality. Data was recorded in 3-ring notebooks and on the backs of envelopes. Rocket thrusts, trajectories, and weight-and-balance equations were routinely hand-drawn on graph paper…and many, many damp cocktail napkins!

Solid-state computers, from IBM, Univac, and Control Data, were just coming on the scene. There were no hand-held calculators or lap-tops; no work stations, interactive screens, keyboards or mice. Real-time data-acquisition and computing were in their infancy. (For example: in 1961 I wrote a little program to post-process rolls of punched paper tape from an in-flight rocket tracking system!)

No one had ever conceived of an information environment as rich or voluminous as that needed for design, testing, problem resolution, flight control, and man-rating. The terms "data management system" and "relational data base" emerged, along with random-access disk hardware. Instead of sequential accounts-receivable and payroll files so familiar in commercial data-processing, we were now inundated with millions of megabytes* of disparate, often inter-dependent parameters:

- ✔ Astronaut biometrics
- ✔ 3-D trajectories
- ✔ Configuration control parameters
- ✔ Design requirements and specifications
- ✔ Down-range safety limits
- ✔ Drawings—millions of drawings
- ✔ Rocket fuel consumption figures
- ✔ Guidance tables and equations
- ✔ Instrumentation calibrations and read-outs
- ✔ Launch pad over-pressures
- ✔ Real-time tracking and trajectory data
- ✔ Rocket engine performance curves
- ✔ Strength-of-materials calculations
- ✔ Six-degrees-of-freedom course corrections
- ✔ Thermal performance data
- ✔ Thruster parameters
- ✔ Tracking and recovery-ship logistics
- ✔ Wire lists and connectivity charts
- ✔ Parts and materials inventories
- ✔ Budgets and spend plans
- ✔ Time lines and milestones
- ✔ And on, and on…and on

* Even the term "byte" didn't come into common usage until about 1964.

THE PROCESS

I realize that the above seems to describe a fantasy project—an enterprise so massive and exacting that it's unattainable. In my experience none us accepted that—so we plunged ahead and did it anyhow! Werner von Braun, the titular father of our space program, advised, "I've learned to use the word impossible with the greatest caution."

And a powerful aerospace discipline evolved that prevails to this day. The success of efforts like Space Shuttle, International Space Station, launch vehicle ventures by ULA and SpaceX, all owe much to the learning curve achieved during Apollo. Some examples:

- **Requirements** are key; define what's needed, not what's nice to have
- **Plan precisely**; otherwise if you don't know where you're going, any path will do
- **Reliability** is crucial; the goal is for every component, procedure, participant, action, and schedule to work flawlessly
- **Mitigate risk** at every opportunity; leave nothing to chance
- **Anticipate** anomalies; don't wait for them to rear their ugly heads
- **Deadlines** and **milestones** are intimidating, demanding, but crucial
- **"Murphy's Law"** is real; if something can go wrong, it will; be prepared
- Build in a "**cushion**"; everything takes longer than you expect
- **Test 'til you drop;** its value cannot be over-emphasized
- Never implement something because *it should work*; it probably won't; make a **prototype**; test it against **requirements**
- Formalize **communication**s and keep them open
- Make the organization's **chain-of-command** clear and observe it rigorously
- **Document** everything, and note how well (or poorly) it works
- **Never, ever, ever…ever…be late** for meetings
- **Humans are fragile**; design—and test—for their survival in hostile environments
- **People** are life-support systems for **brains**; treat both as **precious commodities**

Other factors I believe contributed to Apollo's success:

- Motivation – universal, sustained enthusiasm
- Dedication – long, intense hours were routine
- Patriotism – "can-do" national spirit and pride at taking part
- Competition – a "space race" with the Soviets; they were briefly ahead
- Technical excellence – an extraordinary concentration of brain-power
- Teamwork – direct contact was ubiquitous; no "virtual workplace" existed
- Discipline – rigorous attention to detail; precision was the rule
- Leadership – especially von Braun and other charismatic leaders, including the astronauts, who toured facilities and motivated workers
- Public support – the nation got excited about this wonderful accomplishment

THE TASKS

Exactly what were all those thousands of people doing for nine years to make that gargantuan thing happen? Our friend Omo would certainly have marveled that it took so much more than simply walking! It's not feasible to cover all the locations, research, disciplines, events and logistics. Suffice to say that for most, every day held a new opportunity. To help imagine the environment, here's a representative assignment:

I was a computer specialist with IBM at Kennedy Space Center. IBM was a "stage contractor", i.e. the company responsible for one of the Saturn-V's four stages: S-IC, S-II, S-IVB, and IU (Instrument Unit). The latter was *ours*, the vehicle's "brains"—electronics controlling the operations of the rocket from liftoff until the S-IVB was jettisoned in orbit.

Saturn-V checkout was largely conducted manually. Engineers at hundreds of consoles initiated electronic signals that activated components on the vehicle. Sensors recorded results and relayed data back to the consoles where "Go - No Go" determinations were made. Computers performed date storage and switching, but decision-making was very much a human activity. The IU was the smallest stage, 22 ft. in diameter x 3 ft. high, but arguably the most complex, so flight-readiness testing and launch operations were especially rigorous for its ground crew.

To reduce costly errors and fine-tune operations during long count-downs, my team built a high-fidelity training simulator. Computer-driven, it accommodated a crew of 30, mimicking Saturn-V Firing Room conditions. It's official label was "Instrument Unit Countdown/Checkout Training Simulator", with the arcane acronym IUC/CTS. Our nickname for it was "Count Checkula."

This was a dramatically advanced tool for the time, with electronic consoles, TV, audio and even an observation deck. We could conduct procedures, display realistic real-time data, respond to actions taken during countdowns and recycles and, most valuable, create or duplicate anomalies to evaluate operators' responses. Disk and tape recordings afforded post-test analysis and corrections.

This unique simulator was very expensive, but paid for itself many times over by preventing procedural glitches during live countdowns. For my part, Count Checkula was one my best assignments ever. I would have happily done it for free!

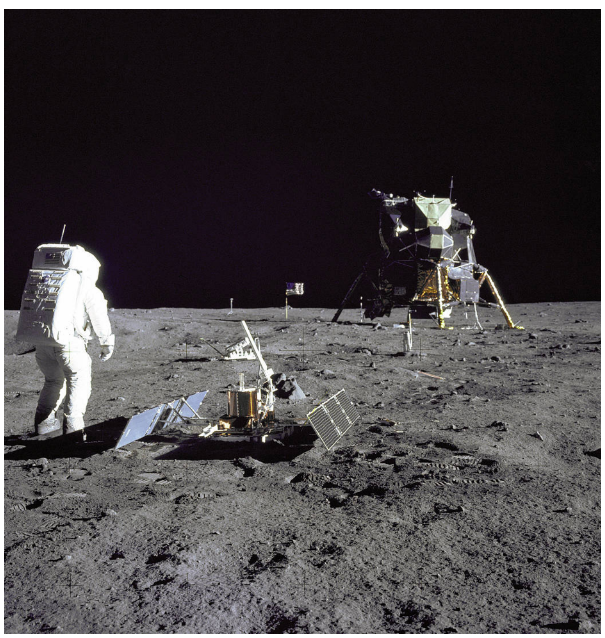
"THE EAGLE HAS LANDED"

Apollo was not all smooth sailing, and there were failures. In 1965 two Crawler/Transporters were built to convey the 9 million-pound Saturn-V and Mobile Launcher from the Vertical Assembly Building to the pad. Constructed in place at KSC, they were the world's largest self-powered tracked vehicles. In their first test, without loads, the monsters blew their traction bearings! The contractor, Marion Power Shovel, went back to the drawing board for almost a year, and reduced the rated speed of the redesigned units from 3 mph to 1 mph (which it remains to this day.)

The most dramatic, tragic set-back occurred on January 27, 1967. During an otherwise normal launch rehearsal a flash-fire swept through the crew capsule; instantly, astronauts Gus Grissom, Ed White and Roger Chaffee were dead. Redesign, exhaustive testing and re-training were required to produce a safe, reliable spacecraft. The incident entailed immense schedule adjustments to get the project back on-track, but no Apollo astronauts were ever lost again.

The project charged ahead. And on July 16, 1969, a Saturn-V thundered into the Florida sky, riding a 1000-foot tail of flame, casting its precious cargo into a truly vast unknown. Neil Armstrong, Buzz Aldrin and Mike Collins would have a journey unlike anything they—or anyone else—had ever experienced.

Their visit to the Moon was not a stroll in the park; plenty of problems arose and required fixing on the fly. But meticulous preparation and brilliant execution from a fabulous crew gave testimony to man's amazing capabilities in a peaceful, only partially political, mostly scientific enterprise.



Aldrin and The Eagle on the Moon

Eight days later, right on schedule, the Apollo 11 capsule dove through its fiery reentry plume and drifted sedately to the sea on its three candy-striped parachutes. JFK's promise of landing men on the Moon and returning them safely to the Earth had been met with phenomenal success. We were all proud to be part of it.

There were a total of six landings and extensive scientific discoveries through 1972, before our nation’s public interest in space exploration waned. America did not return to manned flight until the first Space Shuttle launch, April 12, 1981—and we still haven’t revisited the Moon.

THE MONEY

Everyone understood from the outset that manned lunar landings would cost a lot of money. But as JFK had quipped, the annual space budget was “somewhat less than we pay for cigarettes and cigars.” Apollo would ultimately cost about $25 billion ($158 billion today.)

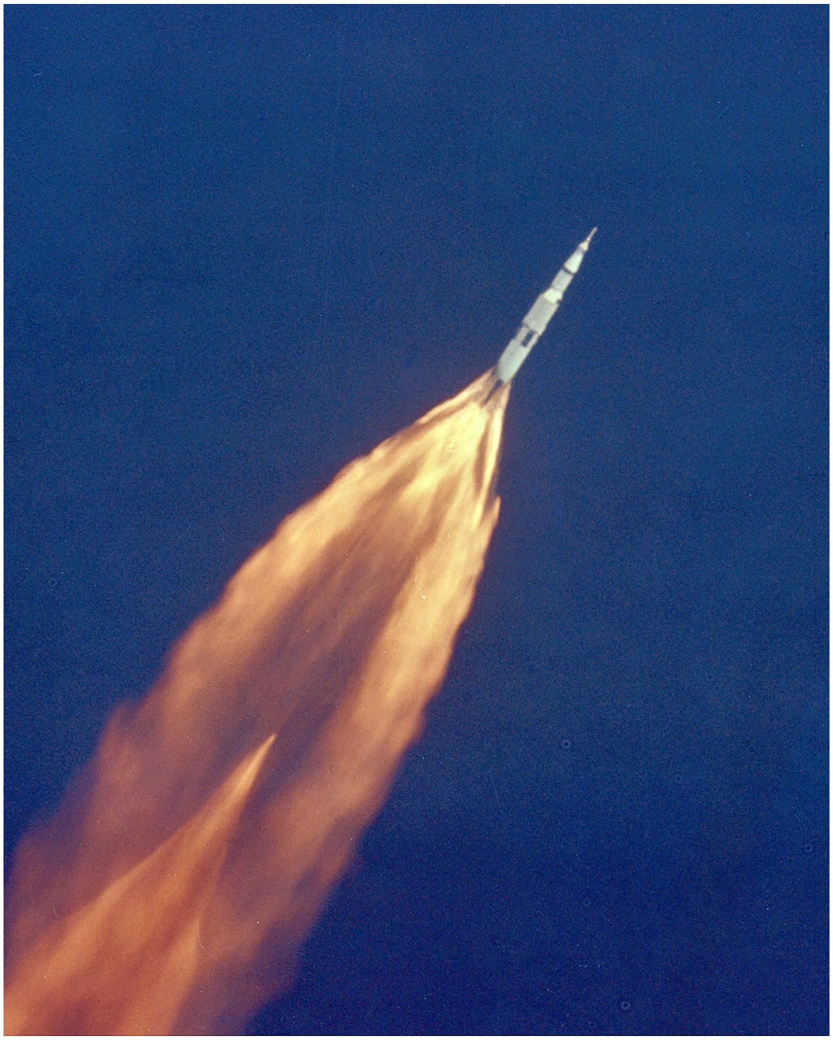
The public always believed NASA's budget was much larger than it is. A recent poll reported that Americans on average estimate NASA's share of the federal budget at 20%, whereas the actual amount still remains at about 0.5%, to carry out every scientific initiative we envision in space.

EPILOGUE

Would Omo have gone to the Moon? Of course. Or surely, given the means, he would have tried—in person—no robot could have satisfied his passion.

Say what you will about the social, economic, scientific, or even poetic justifications for space exploration. Ancient Omo embodied man’s timeless curiosity about what’s over that next mountain, what’s across that mysterious sea, what’s on that big fireball up there in the dark night sky.

Mankind is compelled to reach for the planets—and the stars—because they are there.



APOLLO 11 EN ROUTE TO TRANQUILITY BASE

by Lawrence B. Perkins

Photo credits: *Fireball* = GETTY Images

Moon wrangler = Slide Rule Museum; The Mascot Design Gallery

Eagle = NASA

En Route = NASA