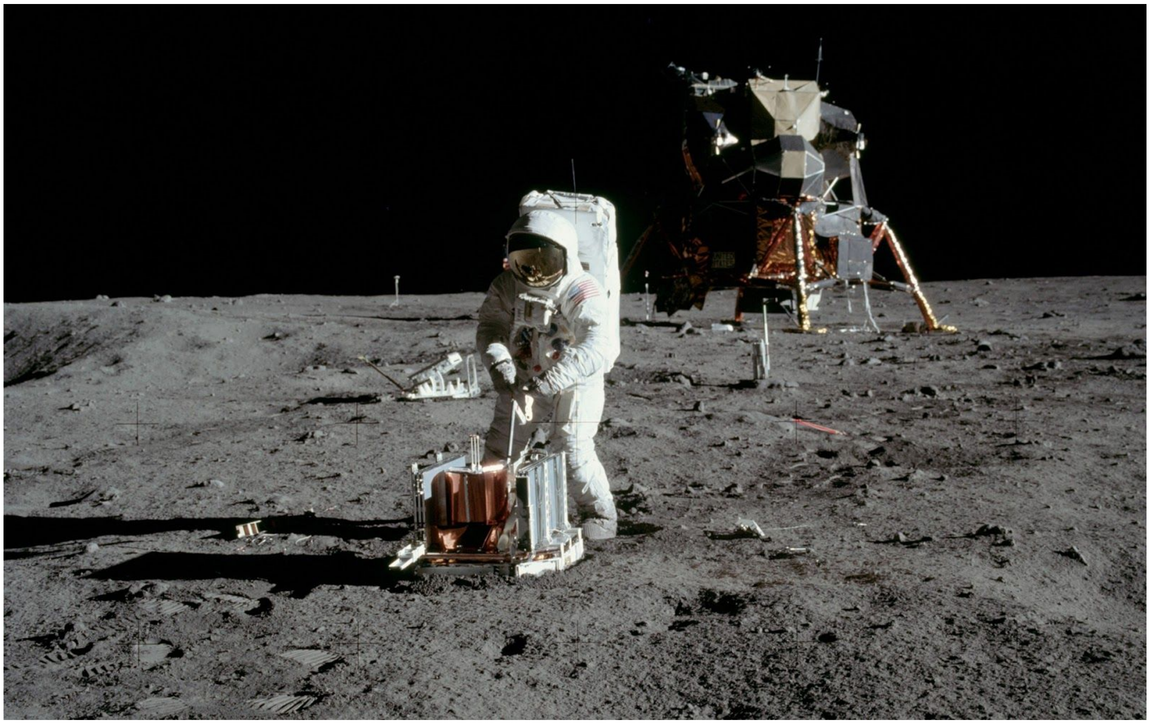


The first landing on the Moon cost $366 million. The United States spent $20.6 billion preparing for that expedition. Apollo 11 astronaut Edwin "Buzz" Aldrin sets up a seismometer at the Sea of Tranquility landing site.

How much did we *really* spend to go to the Moon?

The actual cost of going to the Moon was a fraction of the commonly cited figure. The commonly cited figure is $25.4 billion. Yet the actual cost of the first landing (Apollo 11) totaled $366 million. What accounts for this difference? We estimate that the United States spent $20.6 billion preparing to land astronauts on the Moon. The cost of preparations far exceeded the expense of the first surface expedition.

Subsequent missions (there were six) ranged from $386 million to $451 million. We estimate the total cost of Project Apollo -- preparations and lunar expeditions -- at $25.3 billion. That figure does not include equipment worth $1.6 billion left over when the Moon landings ended in 1972.

Use of the commonly cited $25.4 billion figure suggests that the United States would need to spend hundreds of billions of dollars in the value of modern currency to return astronauts to the Moon. That is misleading. Most of the money spent on Project Apollo represented investments in technology that do not need to be repeated. The investments purchased advances in rocket engine technology, computer miniaturization, tracking and communication, orbital rendezvous and other innovations that are with us now.

The United States could return to the Moon for a fraction of the commonly cited figure. An accurate assessment of the cost of Project Apollo is essential for estimating the costs of future missions to the Moon and planets. Such as assessment follows.

Analysis in detail

Ask an expert how much the United States spent to put Americans on the Moon and you will receive a definitive answer. The National Aeronautics and Space Administration (NASA), the experts say, spent $21.3 billion on Project Apollo through the first landing in July, 1969.[1] By the time NASA finished the Moon landings in December, 1972, they add, the agency had spent $25.4 billion on the whole endeavor.

NASA officials assembled these figures between 1969 and 1974 in response to inquiries from congressional science committees. The totals are accurate, but misleading. They suggest that the United States would need to spend at least $200 billion to return to the Moon. The NASA New Start Inflation Index (the standard measure for cost growth in aerospace goods) estimates that the cost of rockets, spacecraft and related equipment increased nine-fold between the late 1960s and 2015.

Unlike the conventional answer, our sum distinguishes between those activities that allowed the United States to acquire the capability to fly to the Moon and the lunar expeditions themselves. As such, our analysis provides a better basis for estimating the costs of returning to the Moon and venturing beyond. For that sort of analysis, more detail is needed.

NASA spent most of the money allocated to Project Apollo preparing for the lunar expeditions – gathering knowledge, refining technology, building facilities, designing equipment, and conducting tests. The state of spaceflight was primitive in May, 1961, when President Kennedy challenged Americans to the goal of "landing a man on the Moon and returning him safely to the Earth." NASA and its contractors worked hard to develop the national human spaceflight capability. Once prepared, outlays for the actual expeditions were small by comparison.

This essay explains the process for getting ready to go to the Moon, the elements of the actual expeditions, and the outlays associated with each.

Phase one: technology and facilities

In the first phase of preparation, the government needed to improve existing technologies, gather information about the Moon, and build facilities. The process of going to the Moon began with the effort to develop a lightweight guidance and landing computer. Existing

---

[1] Unless otherwise noted, all monetary figures are expressed in "real year" U.S. dollars -- that is, in the value of the currency at the time it was spent.

computers were large, bulky affairs. Flight engineers needed small ones that could be installed in the Apollo command module and associated lunar lander. This was the first contract that NASA officials signed once Project Apollo began.

Computer scientists at the MIT Draper Laboratory billed NASA $100 million for designing the Apollo guidance computer. We assigned this entire amount to phase one technology development. The cost of manufacturing the computers actually used will come later.

On Earth, the finished Apollo guidance computer weighed 70 pounds, massive by later personal computer standards but a huge advance in the existing state of miniaturization.

The people who created the Apollo guidance computer later helped to seed the nascent personal computer industry. The original task had enormous national value. Yet cost analysts assigned the whole expense of this new technology to the landings on the Moon. In a more accurate accounting, the cost would be identified as an enabling technology.

In addition to a flight computer, NASA needed an instrument that astronauts could use to navigate their spacecraft to and from the Moon. The AC Spark Plug Company received $55 million for the design of an inertial guidance unit the astronauts could use. Like the design of the guidance computer, we assigned this amount to technology development. The company received additional funds to manufacture the units, monies allocated to later phases of the project.

Overall outlays for flight computers and navigation equipment paid for the technologies needed to steer a path across what President John F. Kennedy called “this new ocean.” In addition to these two examples, we estimate that NASA spent $233 million creating the guidance and navigation technologies necessary to go to the Moon. A total of $388 million thus appears under technology development for guidance and navigation.

Flight controllers needed instruments that would allow humans on the Earth to track and communicate with astronauts flying to the Moon. This was a major challenge, one that had befuddled experts at the British Interplanetary Society two decades earlier when they had formulated an early plan for a lunar expedition. NASA spent $472 million developing its tracking and communication system, constructing (among other items) thirteen ground stations and a supporting communication network. By itself, the tracking station construction work cost $179 million (a figure contained within the aforementioned sum). Construction of the tracking stations provided a worldwide network of substantial value.

The United States needed launch facilities and field centers. NASA spent $1,631 million building space facilities, including the Kennedy Space Center and what would become the Lyndon B. Johnson Space Center. All of this money was written off against Project Apollo.

Robotic spacecraft preceded the astronauts to the Moon. Scientists worried that astronauts would sink helplessly into a thick mantle of dust that possibly covered the lunar surface. Before the astronauts arrived, five Surveyor spacecraft landed on the Moon and proved that the surface was sufficiently solid to support larger landing craft. The program cost $483 million. Because robotics was involved, budget analysts assigned the cost of Project Surveyor to the NASA science directorate, not to the human flight program.

To return from the surface of the Moon, astronauts needed to rendezvous with the remaining astronaut circling the Moon in an Apollo command and service module. Orbital rendezvous in three dimensions is a tricky business. In 1961, no one knew how to do it. NASA conducted Project Gemini largely as a means to perfect rendezvous techniques. The agency selected Edwin "Buzz" Aldrin for the Gemini and Apollo flight programs in large measure because he had written one of the first doctoral dissertations on guidance techniques for orbital rendezvous. By the time Aldrin and Neil Armstrong landed on the Moon, NASA had mastered the process.

Project Gemini cost roughly $1.3 billion. Because the flights perfected techniques whose applications extended a wide range of space activities, budget analysts rightly excluded that sum from the total cost of Project Apollo. We put it back in.

On top of these sums, NASA invested an additional $8 million in spacecraft technologies, $84 million in launch vehicle and related technologies, and another $244 million in supporting technologies. The latter paid for innovations that had advanced the capability of humans to survive for extended periods in space. Those innovations took the form of electricity-generating fuel cells, digital image processing equipment, water and air filtration systems, cordless power tools, space suits, Moon boots, and heart monitors for astronauts in flight.

So far, we have identified expenditures totaling $4.6 billion. The outlays were preparatory to the construction of the rockets and spacecraft needed to fulfill the lunar goal. Some or all of these funds could have been spent in the absence of a lunar goal. The Moon landing provided a justification for these expenditures, but they had value that went far beyond the Moon.

Appropriately, NASA excluded many of these expenditures from the Project Apollo accounts. They appeared under budget lines from other activities, such as technology, tracking, and space science expenditures, motivated by the lunar goal but supplementary to it. We included them.

Before leaving this phase, one needs to account for the government employees who completed these activities. The salaries, work space, and other expenses of NASA officials working on Project Apollo added about 14 percent to the base cost of the undertaking. Lots of people throughout the agency contributed to the lunar goal. NASA assigned only the expenses of people at the human flight centers working directly on Project Apollo. For phase one, that base was small relative to the total effort. It included guidance and navigation, spacecraft technology, and launch vehicle technology -- just $480 million. Other accounts carried the work forces assigned to remaining activities. Applied to the applicable items, the “administrative tax” produced an additional $67 million. The total sum for all phase one activities accordingly rose to $4.7 billion.

Now it is time to account for the rockets and spacecraft that allowed humans to actually venture 239,000 miles from the surface of the Earth toward the Moon.

<u>Phase two: rockets and spacecraft</u>

Three weeks before President Kennedy made his famous “Moon” speech, NASA workers propelled astronaut Alan Shepard on a fifteen-minute suborbital trajectory to the edge of space. Properly re-configured, the rocket that lifted Shepard could place an object in orbit around the Earth with a mass of thirty-one pounds. This was not sufficient to place humans on the Moon.

NASA officials studied the requirements for a Moon voyage. In an often told story, participants settled on an approach they called lunar orbit rendezvous. The agency spent $2 million preparing the mission plan and deriving the requirements for the machinery needed to implement it.

To reach its destination, NASA needed a rocket that could propel 140,000 pounds of mass from Earth orbit toward the Moon. Adding engines and propellant, this required a rocket capable of placing as much as 260,000 pounds in a parking orbit around the Earth. To transport the astronauts, NASA needed a spacecraft with living room for three. Agency workers needed a second vehicle capable of landing on the Moon, completing a lunar ascent, and rendezvousing with the first vehicle. The habitable volume in Shepard’s single-seat Mercury spacecraft, as a point of contrast, provided a modicum of space similar to what one might expect to find in a very small bathroom shower stall.

The second group of expenditures paid for the creation of the rockets and spacecraft used to transport humans to the Moon.

Creating a launch vehicle large enough for the undertaking posed a major technology challenge. NASA officials settled on the use of the giant Saturn V. Designing the rocket engines proved especially daunting. NASA officials assigned $980 million from the Apollo program budget to the development of engines with sufficient thrust -- only the engines, not the rocket itself.

Most important, rocket scientists under the direction of Marshall Space Flight Center Director Wernher von Braun and the Rocketdyne Corporation had to perfect the J-2 engines that powered the rocket’s second and third stages. Unlike the Saturn first stage, which would burn a refined type of kerosene, the J-2 burned cryogenic liquid hydrogen. The added thrust made possible the trips to the Moon and was a principal reason why the United States beat similar efforts in the Soviet Union.

Analysts traced $306 million to the effort to perfect the J-2 engine, along with the related RL-10 and M-1. The technology involved in liquid-fuel cryogenic rocket engines supported initiatives far beyond the trips to the Moon. The United States utilized a trio of hydrogen-fueled rocket engines to power the NASA Space Shuttle. The European Space Agency employs a similar engine as the main power plant on the Ariane 5.

NASA and its contractors spent another $365 million preparing the F-1, the more traditional kerosene-burning engine arrayed on the Saturn V first stage, along with the related H-1. Both sums are contained within the overall $980 million devoted to engine development.

To develop the rocket itself, von Braun and his agency-industry team created not one, but three vehicles – the Saturn I, Saturn IB, and Saturn V. They used the lesser models to test various spacecraft as work on the Saturn V progressed and reserved the giant (and most costly) model for the heaviest payloads.

The United States spent $440 million developing the Saturn I. That did not include the cost of building and flying the rocket, but only the development cost. Of that sum, the government allocated $85 million before the president's commitment to go to the Moon. The government assigned those funds to the U.S. Army, the department for which the von Braun rocket team worked before joining NASA. Overall, we estimate that NASA added $355 million to the development of the Saturn I, producing a sum total of $440.

The Saturn IB cost a similar amount to develop -- an estimated $395 million. The Saturn V followed. A massive rocket, it required a massive outlay recorded as $3.8 billion. Again, these are the non-recurring costs associated with the creation of each vehicle.

While work on the Saturn launch vehicles progressed, NASA developed a fourth rocket for use in the early Apollo test program. Rocket scientists produced a Little Joe II based on an earlier rocket design (Little Joe I). The small, inexpensive Little Joe duplicated launch conditions at the top of the launch vehicle stack, most particularly the Launch Escape Systems that if necessary could pull astronauts away from a malfunctioning first stage. We estimate that NASA spent $17 million perfecting Little Joe II.

With rocket development underway, NASA officials and their contractors attended to the design of the Apollo Command and Service module. The spacecraft that would take the astronauts to the Moon cost $3.6 billion to design and develop. Most of that money went to the Space Division of North American Rockwell, the corporation that built the machines. The $3.6 billion figure covered the non-recurring cost of design, development, and systems integration. It also includes $920 million for the integration studies and supporting activities designed to ensure that the spacecraft worked as planned. The cost of fabricating the actual spacecraft used during the flight program is not included; that will appear later.

Finally, NASA needed a lander that could take astronauts from lunar orbit to the Moon's surface and back. Agency officials awarded a contract to the Grumman Aerospace Corporation estimated to be worth between $2.1 and $2.3 billion for the purpose of developing and producing the vehicle. The contractor spent $1.4 billion of that amount on non-production costs. NASA added another quarter billion dollars for general design oversight and a half billion dollars for systems integration and supporting activities. In all, we estimate that NASA and its contractors spent $2.2 billion creating a suitable design for a machine that two astronauts, with support from mission control, could land on and launch from the Moon.

As part of its spacecraft development effort, NASA had to commission the construction of the Apollo flight computer. The MIT Draper Lab designed the computer; that expense falls under phase one. The Raytheon Corporation built them. Workers at Raytheon built 75 computers at an average cost of $360,000 each. We estimate that NASA utilized 32 flight-ready computers for its flight tests of Apollo spacecraft, for lunar expeditions, and for post-Apollo activities. We assigned the expense of the remaining 43 units -- a total of $15 million -- to component development. It appears under guidance and navigation for phase two.

The rockets and spacecraft needed to win the race to the Moon cost a sum total of $11.5 billion to create. Administrative expenses raised this sum to $13.1 billion. The funds produced a capability that the United States did not possess in 1961 when the Moon race began. The sum does not include the expense of flight testing, nor does it account for the production of the vehicles used. Those are assigned below. In practice, elements of design, flight, and production often occurred concurrently. The Moon race was a crash program, completed in just eight years, for which work had to be compressed.

<u>Phase three: flight tests</u>

Before the United States could risk the lives of astronauts on trips to the Moon, flight engineers needed to test their equipment. NASA conducted sixteen flight tests of its Apollo rockets and spacecraft before allowing astronauts to risk an expedition to the surface of the Moon. Most of the tests were automated – that is, without humans on board. Two tests involved astronauts piloting spacecraft in Earth orbit.

We estimate that NASA officials spent $5 million testing elements of the Launch Escape System using four Little Joe II rockets. The availability of smaller, less expensive rockets allowed NASA and its contractors to various components of the overall program without resorting to more expensive flights of larger launch vehicles.

NASA and its contractors built ten Saturn I rockets. Five were launched in tests of the rocket itself; we assigned that share of the estimated launch cost to the development program. The rocket team used four to test launch the Apollo command and service module. As was typical of the Apollo flight program, the Saturn rockets found uses that extended beyond Project Apollo. The tenth Saturn I launched a Pegasus micrometeoroid satellite. In fact, rockets eight and nine also carried a Pegasus satellite in addition to the command and service module. We assigned $298 million to the Apollo flight test regime. NASA carried the remaining expense (an estimated $99 million) on the Apollo accounting books, but that amount is more appropriately assigned to other uses, not Apollo.

The Saturn IB followed the Saturn I. The Saturn IB rocket could lift 46,000 pounds (21,000 kg) to low-Earth orbit and famously provided one of the standards by which NASA measured the cost-effectiveness of future launch vehicles. Each non-reusable Saturn IB cost $47 million to fabricate and launch. As such the Saturn IB cost about $1,000 for each pound of delivered payload, the sum flight engineers later sought to improve "by a factor of ten."

NASA and its contractors produced fourteen Saturn IB rockets. Four found use in flight tests of Apollo hardware. Intended for a flight test, a fifth was damaged in a launch pad fire. The remainder found other homes. In the mid-1970s, NASA assigned four left-over Saturn IBs to the Skylab Orbital Workshop program. The agency used a Saturn IB for the American half of Apollo-Soyuz. Other units wound up in rocket gardens or were sold for scrap. The production cost of the five Saturn IB rockets utilized in the Apollo test program totaled $234 million. We assigned the estimated value of the leftover vehicles ($373 million) to other lines.

NASA contractors manufactured sixteen Saturn V rockets at an average recurring unit production cost listed at $113 million each. A separate document lists the launch cost for a Saturn V at $185 million, which includes fabrication. We used the latter figure as the full launch cost.

NASA conducted the first flight test of the Saturn V "all up" (with all stages firing) on November 9, 1967. It conducted one more automated test the following April and a subsequent Earth-orbital test of the complete Apollo package with astronauts on board. The expense of the three Saturn V rockets used for the test missions totaled $555 million.

North American Rockwell produced thirty-four Apollo Command and Service Modules in various states of readiness. Nearly half were used for ground tests or early flight exercises; their cost appropriately assigned to spacecraft development. Most of the remaining eighteen fully flight-ready spacecraft cost an average $55 million to produce. The last three sent to the Moon (Apollo 15 through 17) cost $65 million. NASA used five on non-lunar Apollo flight tests: two with astronauts on board, two for "all up" unpiloted trials of the Saturn V, and one on an early test using the Saturn IB. The cost of those five modules ($275 million) is assigned to the phase three test program.

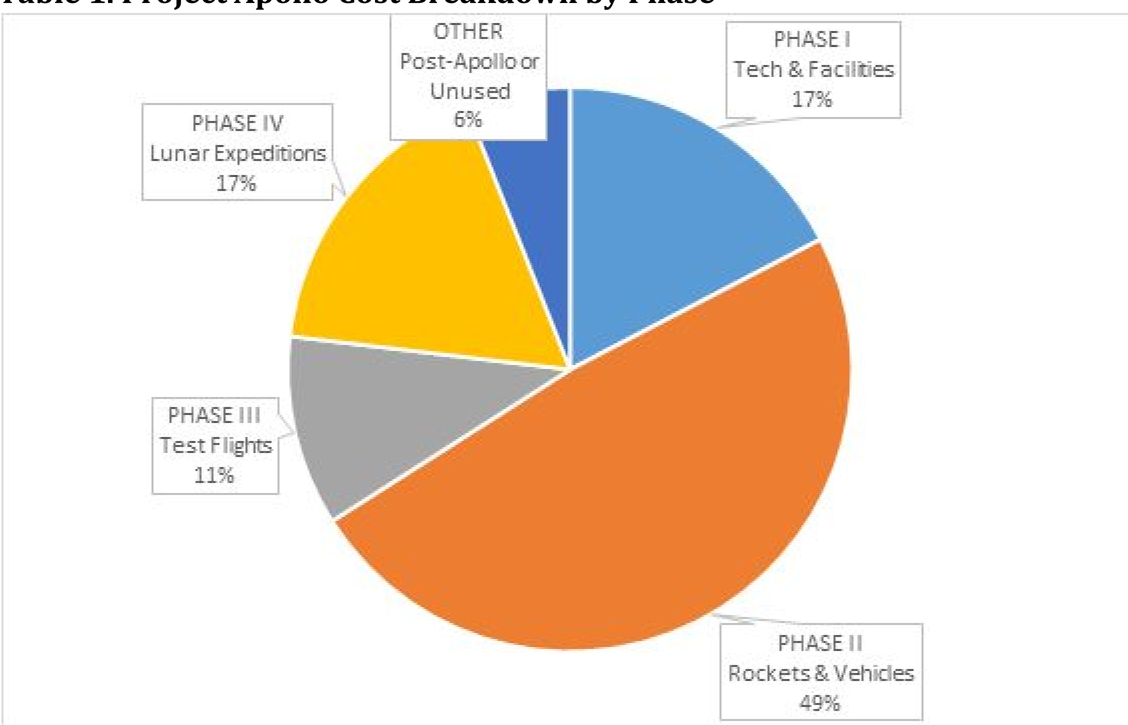
We estimate that the Grumman Corporation produced the lunar lander for an average recurring cost of $51 million per unit, a figure higher than other official estimates. Officials used two in flight tests, a total cost of $102 million.

As is the case with all transportation vehicles, from automobiles to spacecraft, the cost of manufacturing the vehicle and preparing it for use is only the first of many outlays. The expense of operating the vehicle follows. We estimate that NASA spent $940 million for flight operations undertaken as part of the pre-expedition test program. This covers the cost of launch, flight, crew, and recovery during the flight test period. The expense of tracking and communicating with the vehicles added $145 million.

Payments for flight computers and inertial guidance systems followed. We estimate that NASA paid $3 million for flight computers used during the flight test phase and $39 million for guidance equipment.

The preparatory flight test program thus consumed $2.9 billion: $1.1 billion for rockets, $275 million for command and service modules, $102 million for lunar landers, $42 million for computers, guidance and navigation, $940 million for flight operations, $145 million for tracking and communication, and an additional $341 million for program management. These figures represent the cost of testing the national flight capability necessary to go as far as the Moon. The cost of the hardware manufactured for use on the lunar expeditions has been removed from this calculation. That cost is assigned to the voyages themselves.

Table 1. Project Apollo Cost Breakdown by Phase



* The United States spent $25.3 billion on Project Apollo. More than four-fifths of that amount, $20.6 billion, was spent preparing for the lunar expeditions. When Project Apollo concluded, $1.6 billion worth of equipment remained for other uses.

With all but one of the Saturn V test flights complete, NASA was ready to send astronauts to the Moon. To recount, the United States spent approximately $4.7 billion improving technology, constructing space facilities, and collecting knowledge about the Moon (Phase I). It allocated $13.1 billion building the capability to go to the Moon: developing rockets, spacecraft, and landers (Phase II). It spent $2.9 billion testing that equipment on orbital and suborbital flights that did not go to the Moon (Phase III). Preparatory expenses totaled $20.6 billion.

These expenditures usefully may be viewed as the cost of getting ready to go to the Moon. Like mountain climbers assembling equipment at a base camp or sea captains preparing ships for a long voyage, the Apollo pre-expedition phases established capability. With that capability in place, Americans were ready to begin the expeditions.

Phase four: the expeditions

By the end of 1968, NASA officials were ready to allow astronauts to depart from orbits around the Earth and venture into the gravity well of the Moon. The first two voyages circled the Moon but did not land on it. An intermediate flight in Earth orbit completed a final equipment check. Its cost is assigned to the test program. Seven expeditions to the lunar surface followed. Six landed. Flight controllers guided one flight (Apollo 13) back to Earth after one of its oxygen tanks exploded on the outbound voyage.

After the expeditions that went, NASA officials calculated the expenses associated with the nine expeditions to the Moon. Officials responding to a congressional inquiry estimated that the lunar orbital flights Apollo 8 and Apollo 10 cost $310 million and $350 million, respectively. We suspect that the expense ascribed to the lunar module is low and raised the estimate for Apollo 10 (it carried a landing module) to $361 million. We estimate that Apollo 11 cost $366 million. The subsequent expeditions dispatched to land cost $386, $386, $411, $446, $446, and $451 million, adjusted for the larger lunar module estimate. The average cost for the seven surface expeditions would be $413 million. The average cost is somewhat misleading, since it is derived from the average production cost of mission components like the Saturn V rocket and command module. Average mission cost grows because increased surface equipment and operational costs, on top of fixed average component costs. In fact, the marginal cost of components like the rocked and command module would fall with repeated production. The engineers and analysts working on Project Apollo did not estimate marginal costs, however, necessitating the use of the less revealing average cost figures.

Broken down into the main components, the aforementioned sums paid for rockets ($1,665 million), spacecraft ($933 million), scientific equipment ($205 million), and flight operations ($760 million). We assigned an additional $96 million for guidance and navigation units (a separate budget line) and $6 million for seventeen flight computers, the point from which all preparations began. Another $474 million went to pay for tracking and communication. A final $509 paid for program management.

Based on this analysis, the United States spent $4.6 billion going to the Moon nine times -- the expense of the expeditions themselves. The nation spent $20.6 billion preparing to go. When summed, these two figures correspond to the often quoted totals identified at the beginning of this essay. They also provide useful details for interpretation.

Interpretation

The $4.6 billion figure is less than 20 percent of the oft-quoted figure for the total program cost of Project Apollo. The remainder largely consisted of preparation costs that allowed a nation with severely limited space flight capabilities in the early 1960s to reach the Moon in less than ten years.

NASA could have used the capability acquired through Project Apollo for future missions. For the most part, it did not. The largest hardware investments disappeared. The United States ceased production of the Saturn V heavy lift launch vehicle in 1969. It stopped making gumdrop shaped spacecraft capable of interplanetary flight in favor of a reusable space shuttle confined to near Earth orbits. Consequently, when the United States renewed its interest in deep space human expeditions, NASA officials had to restart the work on these machines.

Space spending is much more productively viewed as a continuing process of establishing capability from which missions of specific expense can be conducted. In that sense, much of the NASA budget can be viewed as preparation for the various space missions that the United States and its international partners undertake. Some preparations advance capability, others lead to dead ends. The abrupt conclusion to Project Apollo created the impression that space travel was something finite, with a beginning and an conclusion. In the long run, this is probably inappropriate. It discourages investment in expanded capability and fosters reluctance to undertake ambitious new goals.

A more productive approach would view space expenditures as a continuing process through which humans expand their ability to live and work in space. In that sense, discrete activities like trips to the Moon and Mars appear as specific expenses within a continuing stream of expanding capability. Preparation creates capability, which in turn advances human and machine presence in space.

The burden of preparing to go to the Moon financed capabilities whose significance extended well beyond the flights to the Moon. Some of those expenditures helped to create specific flight innovations, such as smaller and lighter guidance computers. Other expenditures simply established confidence. To our knowledge, no one has calculated the value of those capabilities. Officials simply assigned related expenditures to Project Apollo. In the 1960s, the Moon race was the money wagon to which most space advocates hitched their dreams.

The foregoing analysis allows us to offer some specific comments about accounting methods. First, the method used to represent the cost of specific lunar expeditions probably overstates burden of conducting more. As noted earlier, NASA kept average mission costs. A more appropriate distribution would account for *marginal* costs. The cost of producing the first rocket used for test purposes should not equal the cost of fabricating the tenth used for flight. Properly organized, the cost of going back to any destination should fall relative to the cost of going the first time.

Second, the Apollo program sums as a whole may be overstated. Of the amount commonly assigned to Project Apollo, $1.6 billion produced hardware used on other missions, notably the post-Apollo orbital workshop Skylab and the 1975 Apollo-Soyuz rendezvous. Contractors built sixteen Saturn V rockets before closing the assembly line in late 1969. SA-513 launched the Skylab workshop and two vehicles wound up in museums after the United States canceled the last two lunar expeditions. NASA used four Apollo Command and Service Modules in post-Apollo programs and scrapped at least two.

Third, insofar as they are based on Project Apollo, estimates of the expense of going back to the Moon or to destinations beyond probably overstate the burden imposed by such plans. The burden of preparing for an expedition typically exceeds the cost of conducting it, especially for human space flight. Once in place, the capability creates a foundation on which future efforts can build. Put another way, the gradual accumulation of flight capability makes the burden of going somewhere less onerous.

In a sense, everything that humans do in space –and a great deal of what they do on Earth – contributes to future spaceflight endeavors. The United States compressed a lot of space capability into the eight years between 1961 and 1968. To see how the gradual accumulation of capability may reshape the next phase of human space flight, watch for our forthcoming essay assessing NASA's strategic plan for reaching Mars.

The people who organized the first flights to the Moon thought that they were building capability for missions beyond -- a large space station, a lunar base, and expeditions to Mars. The abrupt cessation of that momentum as the landings occurred disconnected future human flight missions from the Apollo build-up. Assembly lines shut down. Moderate improvements in existing capabilities probably would have been more productive in the long run than the fits and starts to which the United States subjected its human flight program in the following half century. A careful understanding of the true costs of Project Apollo helps to illuminate the relationship between achievements in space and the acquisition of capability to make them occur.

Dr. Howard McCurdy, Professor
Jason Robinson, MPA
Shawn Janzen, Ph.D. Candidate
December, 2015

Table 1. Total Cost of Project Apollo by Mission Phase (in Millions of Real Year Dollars)

ITEM	*PHASE I* *Tech & Facilities*	*PHASE II* *Rockets & Vehicles*	*PHASE III* *Test Flights*	*PHASE IV* *Lunar Expeditions*	*OTHER* *Post-Apollo or Unused*	TOTAL
Guidance & Navigation	388	15	42	102	48	**595**
Tracking & Communication	472	--	145	474	--	**1,091**
Facilities Construction	1,631	--	--	--	--	**1,631**
Project Surveyor	483	--	--	--	--	**483**
Project Gemini	1,283	--	--	--	--	**1,283**
Spacecraft Technologies	--	--	--	--	--	**8**
LV, Propulsion, and Related Technologies	84	--	--	--	--	**84**
Supporting Technologies	244	--	--	--	--	**244**
Mission Design	--	2	--	--	--	**2**
Engine Development	--	980	--	--	--	**980**
Little Joe II	--	17	5	--	--	**22**
Saturn I	--	440	298	--	99	**838**
Saturn I-B	--	395	234	--	373	**1,002**
Saturn V	--	3,764	555	1,665	555	**6,539**
CSM	--	3,631	275	525	330	**4,761**
LM	--	2,224	102	408	204	**2,938**
Flight Operations	--	--	940	760	--	**1,700**
Experiments	--	--	--	205	--	**205**
Program Management	67	1,584	341	509	0	**2,500**
GRAND TOTALS:	4,660	13,052	2,937	4,648	1,609	**26,905**
Grand Total for Project Apollo Missions	25,296				--	--
Preparatory Costs (Phases 1 to 3)	20,648			--	--	--

SOURCE ESSAY

Most of the materials collected for this analysis can be found in the archives of the NASA History Office at NASA Headquarters in Washington, D.C. Additional explanations regarding the interpretation of data and methods of calculation can be found in a separate document prepared by the authors of this study, titled "Apollo Summary Sheet."

An earlier study dealing with cost issues can be found in McCurdy, Howard E. (1994) "The Cost of Space Flight." *Space Policy*, Vol. 10 (4) 277-289. Oxford, UK: Butterworth & Heinemann, Ltd.

The frequently quoted $21.3 billion estimate for the cost of Project Apollo through Apollo 11 can be found in T.O. Paine's letter to Clinton P. Anderson dated November 21, 1969. The Paine letter details incurred costs by general program area. Paine's letter noted that the figure included approximately $2 billion in hardware "available for future flights" and $2.8 billion in capital assets "of continuing national value." In spite of these disclaimers, the $21.4 billion figure lodged in the minds of observers as the cost of the first landing. This information can be found in: Paine, Thomas O. Letter to Clinton P. Anderson. (21 Nov.

1969). MS. Office of the Administrator, National Aeronautics and Space Administration, Washington, D.C. The figures in the Paine letter are derived from *Apollo Program accrued costs through July 31, 1969*, Folder 17, Box 2, Record No. 18195, NASA Headquarters Historical Reference Collection, Washington, DC.

The full cost of Project Apollo, as well as the cost of individual missions, is generally taken from Congressional hearings on the NASA Authorization Act of 1974. The document contains a breakdown of total cost by major categories, such as spacecraft, rocket engines and tracking, as well as cost estimates for individual missions. See *Hearings before the Subcommittee on Manned Space Flight of the Committee on Science and Astronautics*, U.S. House of Representatives, 93rd Congress, 1st Session on H.R. 4567. (1973).

An extensive breakdown of the cost of Project Apollo by program element and year can be found in *NASA Space Operations* (June 1992), Apollo Numbers (Kelly's) Folder, Box 1, Record No. 18194, NASA Headquarters Historical Reference Collection, Washington DC. Hereafter, this document is referenced as "the spreadsheet." It is a major source for this study.

Regarding the Apollo command and service modules (CSM), the total cost was calculated from the spreadsheet, and includes row marginal totals identified for systems engineering, supporting development, integration and checkout, and support. The production cost of individual CSMs is taken from page 6 in *History of Manned Spaceflight* (November 1972), Manned Lunar Landing Costs Notebook Folder, Box 1, Record No. 18194, NASA Headquarters Historical Reference Collection, Washington, DC. This contains a two-page summary individual mission costs for Apollo 7 through 17, with breakdowns for major mission components. Similar figures can be derived from North American Rockwell, *CSM Costs/Schedule/Technical Characteristics Study, Final Report, Volume 11* (Report No. SD71-35), April 30, 1971, available from NASA Headquarters Historical Reference Collection, Washington, DC (Record 18197, Box 4, Folder 1), accessed on September 19, 2015. Rockwell produced 18 units for use of flight at a recurring cost of $55 million each. We reached the nonrecurring cost by subtracting the production unit cost from the total cost estimate.

The total cost for the lunar module was calculated in the same manner as the CSM, taken from the single line in the spreadsheet for the LM and a prorated share of the additional four items on the spreadsheet. Cost figures for the LM wobble more than other program components. A low figure for the production cost of each finished LM can be found in "*History of Manned Spaceflight.*" We used the higher number derived from *MSC Manned Flight Data*, Folder 17, Box 2, Record No. 18195, NASA Headquarters Historical Reference Collection, Washington, DC. Confirmation of the number of Lunar Modules produced (15) can be found in Grumman, *LM Cost Study Final Report Volume II Schedule Data* (LM CCA No. 2690), Folder 17, Box 2, Record No. 18195, NASA Headquarters Historical Reference Collection, Washington, DC.

The expense of Projects Surveyor and Gemini were taken from pages 205 and 121, respectively, in Ezell, L.N. (1988), *NASA Historical Data Book: Volume II, Programs and Projects 1958-1968* (Report No. SP-4012), Washington, DC, Scientific and Technical Information Division, National Aeronautics and Space Administration. Those figures were derived from page 5 of *History of Manned Spaceflight*, (November 1972), Manned Lunar Landing Costs Notebook Folder, Box 1, Record No. 18194, NASA Headquarters Historical Reference Collection, Washington, DC. Cost estimates for Surveyor tend to wobble based on the source, often without explanation.

The sum total of costs related to guidance and navigation (including the Apollo Guidance Computer) was taken from the spreadsheet. Product components were contracted out to a variety of non-governmental entities, and the financial information was collected accordingly from several sources. The Massachusetts Institute of Technology developed the first Apollo Guidance Computer (AGC) for $100 million, according to: Mindell, David A. (30 September 2011). *Digital Apollo: Human and Machine in Spaceflight.* Cambridge, Massachusetts: MIT Press. Pages 104-106. In addition, AC Spark Plug Division of General Motor Corporation received $235 million for the fabrication of the inertial, gyroscope-stabilized platform, as recorded by: General Motors Corporation. "The Apollo Guidance System." *GM Heritage Center: Generations of GM History.* Retrieved from <https://history.gmheritagecenter.com/wiki/index.php/The_Apollo_Guidance_System>. For the most part, NASA officials did not distinguish between the design of navigation equipment and its fabrication. Most of the outlays paid for new technologies, so we assigned the sums not otherwise distinguished to technology development. The Raytheon Corporation produced 75 computers for $27 million, as documented on the NASA website: Tomayko, James E. U.S. National Aeronautic and Space Administration. (March 1988). "Chapter Two: Computers On Board The Apollo Spacecraft, Part 5: The Apollo guidance computer: Hardware." *Computers in Spaceflight: The NASA Experience*, NASA Contractor Report 182505. Retreived from <http://history.nasa.gov/computers/Ch2-5.html>. We estimate that 32 of the computers were placed into 32 separate flight modules.

Price estimates and unit production costs for the Saturn family of rockets can be found on pages 422 and 406 respectively in Bilstein, R. E. (1980). *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Report No. SP 4206). Washington, D.C.: U.S. Government Printing Office, National Aeronautics and Space Administration. Additionally, costs associated with engine development for Project Apollo (e.g., the J-2, RL-10, M-1, F-1, and H-1) are located on the spreadsheet. The production expense of individual rockets can be found in the "Cost of Missions" document.

Much technical information can be found in the various lunar landing press kits. See, for example, U.S. National Aeronautics and Space Administration. (6 July 1969). *Apollo 11 Lunar Landing Press Kit*. Retreived from <https://www.hq.nasa.gov/alsj/a11/A11_PressKit.pdf>.

The cost of Little Joe II rocket is an approximate estimate derived from two known estimates using a normal production learning curve. NASA officials paid the contractor

(General Dynamics) $337 thousand to produce the fifth Little Joe II rocket. The source is from the "1963 April" section of the *Little Joe II Chronology* (n.d.), Encyclopedia Astronautica, retreived from <http://www.astronautix.com/lvs/litjoeii.htm>. The entire Little Joe II flight program cost NASA $21.5 million, as recorded in the *Manned Space Flight: Research and Development Program Operating Plan 64-4*, (November 1964), Folder 3, Box 3, Record No. 18196, NASA Headquarters Historical Reference Collection, Washington, DC. The Little Joe II is one of the few elements of flight hardware for which we know the marginal cost of producing an additional unit.

In its aggregate statistics, NASA officials treated tracking and communications as a supplement to operations. Tracking was handled by the Office of Tracking and Data Acquisition, co-equal to the Office of Manned Space Flight at NASA Headquarters, each with their own budget lines.

NASA's New Start Inflation Index can be found on the web page for the agency's Cost Analysis Division, under publications. See <www.nasa.gov/offices/ooe/CAD> (accessed October 22, 2015).