To what extent did the evolution of both integrated and remote computer systems support the increasing complexities of NASA's early space programs from Mercury through Gemini to Apollo?

History

Word Count: 3,975

Table of Contents

Introduction.. 3

The First in Space: Mercury (1958-1963)..5

The Bridge to the Future: Gemini (1961-1966)...9

The Culmination: Apollo (1961-1972)...13

Conclusion.. 17

Bibliography.. 19

Introduction

On July 20th, 1969, NASA's *Eagle* Lunar Module touched down on the surface of the Moon. As it landed with Neil Armstrong and Buzz Aldrin onboard, Michael Collins would continue orbiting the Moon in the Command and Service Module.

The Lunar Module and Command and Service Module were each controlled by an Apollo Guidance Computer. Consuming fifty-five watts of power—roughly the same as a light bulb—the AGC had less processing power than a modern-day phone charger (Heller). However, the AGC was not a simple machine. It represented the peak of computing at a time when vacuum tubes were on the way out and transistors were on the way in. The AGC and a multitude of other computing systems were critical to the mission's success.

Just a few hours later, Armstrong took his first small step onto the surface of the Moon. Aldrin soon joined him, even as they stayed in touch with Collins and Earth. Twenty-one hours later, the *Eagle* ascended from the lunar surface, rendezvoused with *Columbia*, and began the four-day trip back to Earth. All three astronauts landed safely in the Pacific Ocean and were hailed as heroes (Loff).

Despite the massive scale of this groundbreaking event, many minuscule parts came together to make the mission a success. Behind every detail, computers played an instrumental role in mission preparation, communication, and control. When NASA was created in 1958, though, computers were considered a radical new technology. The development of more and more advanced computer systems worked in tandem with NASA's ability to conduct ever more ambitious missions.

Computers played only a tertiary role in NASA’s first program: Project Mercury. In 1958—Mercury’s start—computers were still very limited (NASA). In fact, the Mercury spacecraft did not have any on-board digital computing power, a fact impressive in its own right. In 1961, with the start of Project Gemini, NASA began integrating computers into the spacecraft. The Gemini Guidance Computer, a precursor to the well-known Apollo Guidance Computer, enabled more complex navigation and rendezvous capabilities. Finally, in 1969, the Apollo Guidance Computer took the stage—as one part of a network of systems spread across Earth, linking the Saturn V rocket, the *Columbia* Command and Service Module, and the *Eagle* lunar module. This network enabled humans to walk on the surface of the Moon.

The satellite that started the Space Race, *Sputnik 1*, was simple—at least in terms of processing capabilities. It contained only a power supply and a radio transmitter that broadcast temperature and pressure information. NASA’s reaction, Project Mercury, relied on a modified version of the U.S. Army’s Redstone ballistic missile from 1958. This rocket was, in turn, based on the Nazi V-2 rocket, which was controlled by nothing more than a gyroscope, steering tabs, and a motor cutoff system (National Air and Space Museum). Technology advanced as the space program did. From Mercury to Gemini to Apollo, technology evolved continuously rather than in two discrete jumps. Changes in computing were gradual, consistent, and eventually immense—the key to NASA’s early successes. The evolution of both integrated and remote computer systems supported the increasing complexities of NASA's early space programs from Mercury through Gemini to Apollo to a great extent.

The First in Space: Mercury (1958-1963)

It is critical to understand NASA's mission trajectory from 1958 to 1972 to understand computers' role in it. From 1958 to 1963, NASA's focus was on Project Mercury—the first American manned spaceflight program. On May 5th, 1961, during the Mercury-Redstone 3 mission, Alan Shepard became the first American in space, just one month after Soviet astronaut Yuri Gagarian first flew (Howell).

The Mercury-Redstone rocket is the only rocket that America sent into space without an onboard guidance computer (Rutter). Many early astronauts were actually against computer control; more specifically, they were wary of giving up human control. Popular media at the time portrayed astronauts as solely responsible for their mission, but, in reality, they were more of a backup system in case of failure. Because all of the Mercury Seven—the first seven Americans selected for spaceflight—were test pilots, they felt strongly that they should have full control, but this is not what happened (Ross-Nazzal): Chuck Yeager, the first person to break the speed of sound, famously described the role of an astronaut as "spam in a can" (qtd. in Mindell 74). The Mercury program's philosophy was that the spacecraft would generally fly itself—with the astronaut taking an active role in case of emergency. This way of thinking continued throughout all of NASA's early programs. In fact, prior to Shepard's famous first flight, several unmanned Mercury-Redstone launches were carried out, showing that humans were not necessary for a successful—albeit simple—flight.

The Mercury capsule's systems were primitive, with two redundant control systems. Specifically, one system was automatic and one was manual, and each had separate fuel systems and thrusters. Initially, the astronaut was to be given great control over the manual system, but it was fuel-inefficient and challenging to control precisely. Therefore, a new “fly by wire” system was implemented, in which a basic control system on Earth would take the astronaut’s command and filter it for more fine-grained control—much to the chagrin of the Mercury Seven (Mindell 79).

Even without an on-board processor, computers still had a role in the mission. Back on Earth, a worldwide network of ground stations received and processed data from the spacecraft. Eighteen tracking stations—and two ships—were responsible for relaying information back to the Goddard Space Flight Center in Washington, D.C. This system made up the Manned Space Flight Network, which was the first worldwide computer network; in fact, it predated the famous U.S.-only internet precursor ARPANET by eight years (Globytė).

Mission controllers were located in the Mercury Control Center at Cape Canaveral, Florida, where every NASA mission launched. The Mercury Control Center was very simple: It had no digital displays; instead, it had a large world map on the front wall with a physical model of the spacecraft that was manually moved to indicate its real position above Earth (Kranz 25).

Ground stations communicated among each other using Teletype machines and occasionally voice calls. Covering over 160,000 kilometers, a network of Teletype lines were used for spacecraft telemetry and text-based communication (Heller). One hundred thousand kilometers of telephone lines were also used, but any voice communications were repeated over Teletype for redundancy. In normal circumstances, Teletype was ideal, but quick voice communications were crucial during emergencies (Kranz 25). As Mercury spacecraft began orbiting around the entire globe, NASA needed to remain in contact with the astronaut at all times. These redundant communications systems enabled the Mercury spacecraft to contact Earth throughout a mission.

A pair of recently-developed IBM 7090 computers at the Goddard Space Flight Center took in telemetry data from those remote ground stations. Then, they performed calculations to understand the spacecraft's trajectory, and how it could achieve a desired flight path. Another IBM 7090 in Mission Control was responsible for outputting data to flight directors who, in turn, ensured nominal spacecraft operations (Heller). Additionally, an IBM 709 in Bermuda calculated orbital information right after a rocket's launch and evaluated local telemetry data (Gass). An IBM 7281 at the GSFC was responsible for communications between all of these systems. It could receive data at a speed of just one kilobit a second—roughly half a million times slower than a modern home fiber internet connection (IBM). Despite these systems' limited nature, they were adequate in supporting Mercury. Because of their ability to predict a spacecraft's path, they were crucial in enabling flight controllers to determine their go/no-go calls. As a spacecraft began to re-enter Earth's atmosphere, this specially-developed combination of computers determined when the rockets aboard the craft should fire to land in a given area.

Again, however, Mercury did not have an onboard digital computer. Sensors collected data aboard the spacecraft which were then immediately sent to those duplexed 7090s and Mission Control, which then transmitted input control data back to the spacecraft. In fact, John Glenn referred to an advanced slide rule that all Mercury astronauts had as a "satellite hand computer," and he—and all of the Mercury Seven astronauts—were prepared to use this mechanical back-up calculator if necessary (Pan; The Ohio State University).

Because of the simple computer systems behind this first program, Mercury missions were limited. Also, because all calculations had to be relayed between the spacecraft and Earth, reliability was limited, and astronauts had to be prepared to take over in the event of an issue. In the Mercury-Atlas 9 mission, Gordon Cooper experienced such a glitch. An indicator light lit up prematurely, forcing him to switch to autopilot mode and skip over earlier mission phases. Because of this change, Cooper had to manually execute several mission steps out of order. Just one orbit later, attitude readings and power transformers went dark. Eventually, he managed to land manually, but this incident highlighted the true limitations of these early computing systems. Mercury was over, and it was time for Gemini to deliver—with significantly more complex and capable computers.

The Bridge to the Future: Gemini (1961-1966)

From 1961 to 1966, NASA operated the Gemini program. Gemini served as a bridge between the relatively simple Mercury program and the immensely complicated Apollo program. Even though the role of computers in Gemini's successes is often ignored in favor of Apollo's greater complexities, a few simple figures illustrate the degree to which computers played a part: In 1962, the federal government and NASA were purchasing 100% of total integrated circuit shipments worldwide. While the government's share of chips purchased decreased to 53% by the end of the Gemini program in 1966, its spending increased twenty-fold from four million dollars to seventy-eight million dollars (Nelson 63). Even early in the Gemini program, NASA was investing in the promises of computers. Computers played an ever-more-important role throughout the more complex Gemini program.

The Gemini spacecraft was the first to have a computer on-board: the Gemini Guidance Computer, often referred to as the On-Board Computer or OBC. The novel OBC weighed twenty six kilograms and was about the size of a large microwave (Burkey). It was programmed using assembly code, a type of limited, low-level programming. Its programmers used a newly-developed technique called "math flow," where they first determined the correct equations for a given situation and then translated those into assembly (Tomayko). With no backup computers on board, programmers had to be accurate.

Astronauts could interface with the OBC in a few ways: Their primary control interface was the Manual Data Insertion Unit. The MDIU consisted of a number pad-style keyboard with just ten buttons. Another display showed the spacecraft's velocity, among other statistics (Tomayko). These figures allowed astronauts to better understand their flight characteristics.

Some later Gemini missions had the goal of docking with another spacecraft. In upcoming Apollo missions, several sections of the astronauts' vehicle would be required to disconnect and reconnect in various ways; Gemini would prove the feasibility of this concept with the Agena spacecraft, which was designed to dock with the Gemini capsule (Kranz 150). The Soviet Union attempted a similar docking several times but repeatedly failed. On the other hand, the Gemini-Agena missions were successful precisely because of the OBC. In fact, in the first rendezvous attempt, astronaut Jim McDavitt tried to dock using his eyes alone, but found it much too challenging. However, the Gemini Guidance Computer was capable of running calculations to help him. In fact, an astronaut could choose to either be in control or to hand control over to the OBC (Mindell 87).

From a control perspective, Gemini was only a slight departure from Mercury. Because missions became more complex—such as docking in Gemini-Agena—astronauts needed the extra data that the Gemini Guidance Computer could process. Paradoxically, Gemini was a step both toward and away from manual astronaut control. Dr. David Mindell, a professor of astronautics at the Massachusetts Institute of Technology, noted that "Advancing technology would mean not more automation, but more human control" (Mindell 83). Specifically, compared to Mercury's focus on pre-programmed sequences, Gemini allowed for greater manual control. The OBC determined when to adjust a parameter, but the astronaut was often responsible for making the change. Gus Grissom, one of the original Mercury Seven, understood that Mercury astronauts could primarily override predetermined flight plans. He explained,

> The most important difference [between Mercury and Gemini] is the amount of control the pilot exercises over all functions. Until now, man has been a self-experimenting

> guinea pig… Gemini is the first true pilot's spacecraft. Gemini will be a pilot controlled operational spacecraft, not just a research and development vehicle… The test pilot will have stepped into his proper role—the explorer of space. (qtd. in Mindell 83)

With Gemini's OBC, an astronaut could actually fly his spacecraft. Notably, though, Gemini's computers were not infallible. On Gemini VI, the launch sequence stopped prematurely. Typically, such a scenario would call for an emergency eject, but astronaut Wally Shirra believed that the rocket had not yet launched. Against procedure, he did not abort. He was correct—the computer was not—and his quick decision saved the spacecraft and its booster.

Gemini's Mission Control facilities also greatly evolved from Mercury. Most visibly, Mission Control moved from Cape Canaveral to Houston, Texas. Still, the Goddard Space Flight Center was responsible for coordinating communications across the Manned Space Flight Network (Wallace 71). Computers on the ground were upgraded to three IBM 7094s, with faster and higher-capacity memory (IBM). Flight Director Gene Kranz noted that many flight controllers were skeptical of computers but recognized their utility. With computers, controllers could automate some processes and better focus on supporting astronauts. Still, Kranz described himself as "a dinosaur stumbling forward into a technical revolution" (Kranz 120).

There were a number of changes in the Mission Control room itself. Compared to Mercury's physical spacecraft models moving on a world map, Gemini Mission Control had digital projectors—some of the most advanced in the world. Mercury Control used hand-updated numerical displays, but Gemini's Mission Control had automatic digital seven-segment displays (Kranz). These upgraded methods of displaying information allowed flight controllers to understand a given situation more clearly.

Compared to Project Mercury's eighteen tracking stations, Gemini had just four ground-based stations and two ship-based stations. Additionally, these new stations transmitted data using digital—not analog—systems that could transfer data at 2.4 kilobits a second, compared to Mercury's one kilobit a second. Kranz noted that, because there were fewer tracking stations, "the control team skills were the highest in [their] brief history." The more advanced communications systems allowed for fewer but more capable flight controllers (Kranz 120).

Throughout the Mercury program, automations became ever more prevalent. By Mercury 11, the OBC could land in a five-kilometer range of the targeted touchdown zone without any astronaut involvement. Still, an astronaut could have some control if he wished. With the Gemini program ending, this redundancy would prove crucial in later Apollo missions.

The Culmination: Apollo (1961-1972)

From 1961 to 1972, NASA ran the Apollo program—in fact, overlapping some Gemini missions. The Apollo program took what NASA had learned from Gemini and put it on course for the Moon. While Gemini was a step up from Mercury, Apollo—with its goal of landing humans on the Moon—was inherently an order of magnitude more complex than Gemini.

Appreciating these complexities requires understanding the basic process of an Apollo lunar mission: First, a Saturn V rocket takes off from Cape Canaveral, Florida. After two stage separations, the Apollo spacecraft begins orbiting Earth. Another stage propels the spacecraft towards the Moon. On its way, the Command and Service Module separates from its booster and the Lunar Module, before re-docking with the Lunar Module, allowing astronauts to move between the two spacecraft.

Once the two combined spacecraft begin orbiting the Moon, two astronauts enter the Lunar Module, which then separates from the CSM. The LM descends to the surface, where the two astronauts conduct research and extravehicular activities. Meanwhile, one astronaut continues orbiting the Moon in the CSM. After some time—anywhere from one to three days—the ascent module of the LM launches back into lunar orbit to dock with the CSM. Finally, the two astronauts enter the CSM, which fires its engines to return to Earth.

Outside of this significantly more complex mission profile, Apollo had numerous other challenges that Mercury and Gemini avoided. The calculations required to manage these complicated maneuvers were much more intricate than anything attempted before. Something similar to Mercury's complicated docking would be repeated several times during each Apollo lunar mission, this time with astronauts in both spacecraft. Advanced computers were necessary to make this procedure a reality.

This fact leads to an important question: How did Mercury and Gemini—even with their relative simplicity—succeed without advanced on-board computers? The answer, as described earlier, was simple: Mercury and Gemini both relied on ground-based computers—even considering Gemini's OBC. This approach could not work for the Apollo program, though, simply because of the distance between the Earth and the Moon. Because wireless signals are transferred at the speed of light, there was an unavoidable delay: Specifically, it took one and a quarter seconds for a signal to travel one way, and that time is doubled to two and a half seconds for the round trip. If a bit of data sent by the Lunar Module had to go all the way to Earth and back, the latency would cause unsolvable problems. A new, more powerful spacecraft-mounted computer would solve this issue.

The separate Command and Service Module and the Lunar Module each had an Apollo Guidance Computer built in, and each computer played a crucial role in the Moon landings. In fact, the AGC's designers referred to it as the "fourth crew member" (Tomayko 38). While its processing power was very limited—similar to a toaster, even—the AGC was comparable to even a modern smartphone in terms of features (Madrigal). Specifically, the AGC could run multiple programs at the same time, could process errors, and had a straightforward interface. Even more impressively, it could be reprogrammed or updated on the fly—which happened during Apollo 13—and had a functional program interpreter (O'Brien).

The Apollo Guidance Computer was just one cog in an immense network of computers, though. As mentioned, there were not one but two AGCs on board each mission—which coordinated rendezvous processes—along with two other computers. The Launch Vehicle Digital Computer, mounted in the Saturn V rocket, was responsible for guidance and navigation on the trip to orbit. The Abort Guidance System computer, on the other hand, would only be used if a lunar ascent or descent needed to be aborted (Burkey).

To understand the significance of any of these computers, though, it is crucial to appreciate the context of their creation. Transistors had recently been invented in 1948. Transistor technology is what allows smartphones to be so small, and it is also what allowed the Apollo Guidance Computer to be as groundbreaking as it was. The AGC was one of the first transistor computers, which allowed it to be much smaller than it otherwise could (Chandler). It weighed about thirty kilograms and measured about sixty centimeters by thirty centimeters by twenty centimeters—not large, especially considering the room-filling IBM 7090 at Goddard Space Flight Center. If transistors had not existed and the AGC had been made with vacuum tubes instead—like most computers at the time—it would have been massive in both size and weight. Furthermore, vacuum tubes had very poor reliability and durability and consumed much more power than transistors, which also means they emit excessive heat. Clearly, the invention of the transistor was necessary for the Apollo program's success.

Telemetry and communications also increased in complexity for the Apollo program, although those developments were more of a linear continuation of the developments started with Gemini. Of course, the greater distance that Apollo spacecraft traveled meant that powerful high-gain antennas were needed to send telemetry, voice, and video over the vast emptiness of space. Towards the end of the Gemini program, though, NASA's data transfer systems were, broadly speaking, already suitable for the goals of the Apollo program.

More advanced simulations were also crucial for the preparation of flight controllers. In fact, simulations played an important role throughout all three early space programs, although none were as important as in the Apollo landings. Prior to the Apollo 11 landing, the mission control team spent extensive amounts of time in simulations. Flight Director Gene Kranz recalls a particularly tricky scenario: a 1201 computer alarm during lunar descent. This alarm indicated that the computer could not process all of its tasks. Unfamiliar with the alarm, Guidance Officer Steve Bales called for a risky, mission-ending abort. During debriefing, they were informed that an abort was not actually necessary because the alarm represented a warning, not a critical failure (Kranz).

During the actual Apollo 11 descent, another 1201 alarm triggered. This time, flight controllers knew exactly what the alarm represented, and they were confident that the landing could continue. Without these extensive computer-enabled simulations, flight controllers likely would have called for an unnecessary, dangerous abort (Kranz).

The Apollo Guidance Computer even had the potential to help astronauts during that final descent stage. In fact, it could land the Lunar Module on its own while still allowing astronauts to select specific landing zones. It also had a downward-facing radar measuring elevation and descent rate. However, similar to their attitude towards computers in previous missions, all astronauts preferred to land on the Moon under manual control. Ultimately, the AGC combined with astronauts' quick wits allowed each landing to succeed (Mindell).

Conclusion

Early NASA programs and the evolution of computers had a symbiotic relationship. Without the development of computer systems as missions were carried out, NASA's early missions could not have even been attempted. In fact, these missions incentivized the advancement of computing. More complex computers developed in tandem with more complex missions.

The early Mercury program was hamstrung by its lack of an on-board digital computer. Astronauts in the Mercury capsule were broadly without control and relied on ground-based computers to send commands at certain pre-programmed points. Still, developments from the Mercury program were carried into Gemini and Apollo. Specifically, the Manned Space Flight Network and its central mainframe formed the first worldwide network of computers. Later, it would be adapted for Gemini and Apollo.

The Gemini program was a massive leap forward in computing technologies. Of course, Gemini brought forth the On-Board Computer. Without the OBC, the complex maneuvers that were carried out in the Gemini program could not have succeeded. Even more than that, Gemini brought humans and machines together: Astronauts were able to assume control from or delegate control to the OBC as they wished, marking a major change from Mercury. Back on Earth, the Manned Space Flight Network was upgraded with faster data transfer speeds and a more powerful mainframe. Gemini gave NASA a testing ground to kick-start the technologies needed for Apollo.

NASA took everything it learned from Mercury and Gemini to put men on the Moon, as promised by John F. Kennedy nearly a decade before. The most significant jump between

Gemini and Apollo was the Apollo Guidance Computer, a milestone not just for NASA, but for computing as a whole. As one of the first transistor computers, it relied on a groundbreaking technology that was just beginning to change the world—or, rather, space. The computers that were integrated into the Saturn V launch rocket and the Command Module allowed astronauts to travel to the Moon, and the Lunar Module touched down with the help of the AGC.

The role of computers in space exploration has evolved from the Mercury Seven astronauts' initial skepticism, through Gemini's On-Board Computer, and to Apollo's worldwide network of ground and spacecraft-integrated computers. The future of space exploration will depend on a powerful combination of human ingenuity and the technologies we create.

Bibliography

National Air and Space Museum. “What Was the Mercury Program?” *The Smithsonian*, 22 Sept. 2022, airandspace.si.edu/stories/editorial/what-was-mercury-program.

Burkey, Ronald. “The Gemini Spacecraft Computer.” *Www.ibiblio.org*, 30 May 2023, www.ibiblio.org/apollo/Gemini.html#gsc.tab=0.

Chandler, David L. “Behind the Scenes of the Apollo Mission at MIT.” *MIT News | Massachusetts Institute of Technology*, 18 July 2019, news.mit.edu/2019/behind-scenes-apollo-mission-0718.

Gass, Saul I. “Project Mercury’s Man-In-Space Real-Time Computer System: ‘You Have a Go, at Least Seven Orbits.’” *IEEE Annals of the History of Computing*, vol. 21, no. 4, 1999, pp. 37–48, https://doi.org/10.1109/85.801531. Accessed 28 Sept. 2020.

Globytė, Ema. “What Is ARPANET? The Creation of the Internet.” *NordVPN*, 10 July 2023, nordvpn.com/blog/what-is-arpanet/.

Heller, Forrest. “Apollo 11 vs USB-C Chargers.” *Forrestheller.com*, 6 Jan. 2024, forrestheller.com/Apollo-11-Computer-vs-USB-C-chargers.html.

Heller, Niles R. “Worldwide Network Support.” *National Aeronautics and Space Administration*, 1963, www.hq.nasa.gov/pao/History/SP-45/ch8.htm. Accessed 12 Nov. 2024.

Howell, Elizabeth. “Project Mercury: America’s 1st Crewed Space Program.” *Space.com*, Space, 21 Aug. 2018, www.space.com/24638-project-mercury.html.

IBM. “Project Apollo.” *IBM*, 2025, www.ibm.com/history/apollo#.

---. “Project Gemini.” *IBM*, 2025, www.ibm.com/history/gemini.

---. “Project Mercury.” *IBM*, 2025, www.ibm.com/history/mercury.

Kranz, Gene. *Failure Is Not an Option : Mission Control from Mercury to Apollo 13 and Beyond*. Simon & Schuster Paperbacks, June, 2009.

Loff, Sarah. “Apollo 11 Mission Overview.” *National Aeronautics and Space Administration*, 17 Apr. 2015, www.nasa.gov/history/apollo-11-mission-overview/.

Logsdon, John M., and Roger D. Launius. *Exploring the Unknown*. National Aeronautics and Space Administration, 2008.

Madrigal, Alexis C. “The Underappreciated Power of the Apollo Computer.” *The Atlantic*, The Atlantic Monthly Group, 19 July 2019, www.theatlantic.com/science/archive/2019/07/underappreciated-power-apollo-computer/594121/#selection-1715.24-1721.123. Accessed 19 Jan. 2025.

Mindell, David A. *Digital Apollo : Human and Machine in Spaceflight*. Mit Press, 2008.

NASA. “In the Beginning: Project Mercury.” *National Aeronautics and Space Administration*, 1 Oct. 2008, www.nasa.gov/missions/project-mercury/in-the-beginning-project-mercury/.

---. “Project Gemini Mission Control Center.” *National Aeronautics and Space Administration*, 14 Mar. 2012, www.nasa.gov/image-article/project-gemini-mission-control-center/. Accessed 4 Feb. 2025.

National Air and Space Museum. “Accelerometer, Gyroscopic, V-2.” *National Air and Space Museum*, The Smithsonian, 2025, airandspace.si.edu/collection-objects/accelerometer-gyroscopic-v-2/nasm_A19880369000. Accessed 18 Jan. 2025.

---. “Computer, Guidance, Gemini 2.” *The Smithsonian*, 2025, airandspace.si.edu/collection-objects/computer-guidance-gemini-2/nasm_A19680032000.

---. “Saturn v Instrument Ring.” *National Air and Space Museum*, The Smithsonian, 2025, airandspace.si.edu/collection-objects/instrument-unit-saturn-v/nasm_A19780160000.

O’Brien, Frank. “A Deep Dive into the Apollo Guidance Computer, and the Hack That Saved Apollo 14.” *Ars Technica*, Condé Nast, 30 Jan. 2020, arstechnica.com/science/2020/01/a-deep-dive-into-the-apollo-guidance-computer-and-the-hack-that-saved-apollo-14/.

Pan, Deanna. “Artifacts at OSU Evoke Glenn’s Dramatic Mission.” *The Columbus Dispatch*, 18 Feb. 2012, www.dispatch.com/story/business/information-technology/2012/02/18/artifacts-at-osu-evoke-glenn/23364494007/. Accessed 12 Nov. 2024.

Parker, Phill. “The Apollo On-Board Computers.” *Apollo Flight Journal*, National Aeronautics and Space Administration, 2017, www.nasa.gov/history/afj/compessay.html.

Ross-Nazzal, Jennifer. “From NASA’s First Astronaut Class to Artemis II: The Importance of Military Jet Pilot Experience.” *National Aeronautics and Space Administration*, 9 Apr. 2024, www.nasa.gov/history/mercury-7-to-artemis-ii/. Accessed 12 Nov. 2024.

Rutter, Daniel. “Computers in Space.” *Dan’s Data*, 2017, www.dansdata.com/spacecomp.htm. Accessed 12 Nov. 2024.

School of Earth and Space Exploration. “March to the Moon.” *Arizona State University*, 2022, tothemoon.ser.asu.edu/about/mercury_history.

The Ohio State University. "'Satellite Hand Computer' Carried by John Glenn Aboard His Friendship 7 Space Flight." *The Ohio State University*, 1962, kb.osu.edu/items/5109ef2e-79a2-588b-984f-9529afecbd6b. Accessed 12 Nov. 2024.

Tomayko, James E. *Computers in Spaceflight the NASA Experience*. 1988, ntrs.nasa.gov/api/citations/19880069935/downloads/19880069935_Optimized.pdf.

Wallace, Lane E. *Dreams, Hopes, Realities*. National Aeronautics and Space Administration, 1999, ntrs.nasa.gov/api/citations/19990054617/downloads/19990054617.pdf.