THE PORTRAYAL OF EARLY MANNED SPACEFLIGHT IN *HIDDEN FIGURES*: A CRITIQUE

Harold Beck, Kenneth Young, and Charles Murray, 2023

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Introduction

Charles Murray

How This Document Came to Be

On November 24, 2015, Katherine Johnson received the Presidential Medal of Freedom from President Obama. He introduced her by saying, "From sending the first American to space to the first moon landing, she played a critical role in many of NASA's most important milestones."

On September 6, 2016, Margot Shetterly's book *Hidden Figures* was published, telling the story of African American women who worked at Langley Research Laboratory, with Katherine Johnson playing the lead role. It quickly reached *The New York Times* Best Sellers list. The book was followed by the film version, a box-office hit that was nominated for three Academy Awards.

Three months later, in early December 2016, I received an email from Ken Young, one of the key people in the Manned Spacecraft Center's Mission Planning and Analysis Division during the 1960s. I had interviewed Ken while Catherine Cox and I were writing our history of the Apollo program. Ken and I hadn't been in touch for more than thirty years. His email read in part:

> I could send along a thread of emails from mid-2015 to this fall from various "human space pioneers" whose names you would recognize (e.g., Dr. Chris Kraft, Glenn Lunney, Jerry Bostick, Hal Beck, Clay Hicks, etc.) but Hal suggested I just ask you to Google one name (which you may well recognize from PC news, a book, and movie called *Hidden Figures* coming in January): Katherine Johnson.
>
> Suffice it to say, the majority of us who actually worked every US human spaceflight program from Mercury to ISS, believe you will find that fine lady, who is still alive at about 93, is at the center point of what is perhaps the most egregious instance of REVISIONIST space history ever! Not saying it's all her doing. There have obviously been journalists, politically correct politicians and bureaucratic activists who have run with the "hidden" stories!
>
> I'll leave it at that. And, should you and Catherine, for whatever reason: 1. Retired and just too weary of controversy; 2. Too busy to "tilt any windmills"; 3. Rightly fear being labeled a skeptic, or even worse, a racist (I still have my copy of your taboo work *The Bell Curve*); 4. Have researched her/it and are "fine with the stories," and don't want to get involved—we'll

totally understand. But I'm hoping you want to hear more from the people who were *really* there, did that! Just let me know!

Sincerely,

Ken

Reason #3 applied. I have been called a racist ever since *The Bell Curve* was published in 1994. And now I'm supposed to debunk the celebration of a lovely and accomplished African American woman in her nineties? Does Ken really think I'm that crazy? I sent this response:

Hi Ken,

Great to hear from you. Yes, somehow in interviewing a few hundred people, we failed to recognize Ms. Johnson's pivotal role. But she does look like a fine lady, and I'm not about to say anything that would mar her golden years. This too shall pass.

Warm regards to you and any of our Apollo friends you run across,

Charles

Ken's response a few days later was genial, but it nagged at me for weeks thereafter. It read in part:

> Sadly, that's what most who know the truth concluded also—but as to "this too shall pass", sorry, but it won't, and history will indelibly (mis)record her "pivotal role!" We should have raised some eyebrows—like bringing it to the attention of the Inspector General of NASA—about 1.5 years ago when this started to snowball from some "innocent misremembering" (to be kind) in interviews of an ancient lady who understandably exaggerated her role in EARLY Mercury, then let no-doubt leading questions expand into out-and-out falsehoods about her Gemini and Apollo "achievements"! The saddest thing is that I could easily name (and prove) that we in MPAD alone in Houston had black engineers and mathematicians who truly contributed a thousand times more than ANYONE at Langley to Apollo's success---and they NEVER received ANY award—much less a presidential Medal of Freedom!

There matters lay until the spring of 2023, when I made a joke on Twitter (never a good idea) about the press's uncritical reporting of black high school students who were said to have proved the Pythagorean theorem using trigonometry, a feat previously thought to be impossible. In the Tweet, I wondered when we could expect to see the movie "Hidden Trigonometricians."

The Tweet got a lot of reaction. One response chided me for not using the correct word, "trigonometers." The rest were indignant, objecting to my implied denigration of Katherine Johnson and linking to articles that made even more extravagant claims for her contributions to the space program than the ones made during the presentation of the Presidential Medal of Freedom. I learned that I had been wrong. The Katherine Johnson story had not faded. It had spread and intensified. Serious journalists and historians now believed that Katherine Johnson played a central role in the manned spaceflight program. "This too" had not passed.

During the six years since my email exchange with Ken Young, no one who had been part of the manned spaceflight program during the 1960s had said publicly the things they had been discussing among themselves. As I write in August 2023, those who remain are in their mid-eighties or older. If their knowledge about the events described in *Hidden Figures* does not get into the historical record soon, it never will. So, in early May, hoping that Ken Young was still with us and at the same email address, I told him that I was prepared to post any documentation about Katherine Johnson's role that the surviving veterans could put together.

Ken emailed back, telling me that Hal Beck had already written a long unpublished review of *Hidden Figures* and that he would write up his own "footnotes" to *Hidden Figures.*

Ken's response was just what I had hoped for. The claims made for Katherine Johnson's contributions are focused on launch and entry trajectories, rendezvous, and how manned spaceflight missions were planned. Hal Beck and Ken Young were at the center of these activities throughout the Mercury, Gemini, and Apollo programs.

They sent me their commentaries. I acted as their copy editor, fixing typos and suggesting reorganization and consolidation of text. I occasionally edited syntax as well but tried to do so in ways that did not tamper with their authentic voices. Both commentators are aerospace engineers, not professional writers. I consider that to be a feature of their presentations, not a bug.

I follow their commentaries with a postscript that attempts to synthesize Hal's and Ken's complementary accounts and gives my appraisal of the totality of the evidence.

The Commentators

Harold D. Beck. Hal Beck reported for work at the Langley Research Center in July 1959 following graduation from North Carolina State University with a degree in aeronautical engineering. He was assigned to the Maneuver Loads Branch of the Flight Research Division. While working in the branch alongside Katherine Johnson, he was involved in trajectory studies related to space rendezvous.

In early 1961 Beck transferred from Langley to the Mission Analysis Branch of the newly formed Space Task Group. With lunar landing missions on the horizon, Beck was assigned to develop the basic concepts for lunar trajectory analysis. After his group moved to Houston and the new Manned Spacecraft Center, Beck became head of the Lunar Trajectory Section of the renamed Mission Planning and Analysis Division. Specialists within the section created software applications for spacecraft guidance and control, maneuver targeting, rendezvous and docking operations, spacecraft communications, translunar injection targeting, and lunar orbit maneuvers. These applications were integrated into a realistic simulation of a lunar landing mission from launch at Kennedy Space Center through lunar orbit and landing to the spacecraft's return to earth. The simulation was the primary tool used in lunar mission planning and analysis and in the generation of the official Apollo Reference Missions.

After the end of the Apollo missions, Beck occupied successively more senior positions in the Mission Planning and Analysis Division. He retired from NASA in 1992 and worked in the aerospace industry for another twenty years.

Kenneth A. Young. Ken Young joined the Manned Spacecraft Center in June 1962 after graduating from the University of Texas at Austin with a degree in aerospace engineering. Young was one of six engineers assigned to the Rendezvous Analysis Branch to develop the new space disciplines of rendezvous and orbital mission planning. By the end of the Gemini Program, Young had become one of NASA's leading experts on applying these disciplines to rendezvous and orbital trajectory analyses, computer software development, mission designs, plans, and real-time flight operations support. During the Apollo missions, Young applied these skills as head of the Mission Design Section of the Orbital Analysis Branch.

After Apollo, he went on to orbital trajectory planning for Skylab and Apollo-Soyuz. In 1980, he became head of the Shuttle's Flight Planning Branch. He retired from NASA in 1987 and subsequently worked as an expert consultant on rendezvous, flight dynamics, and space systems integration for the aerospace industry.

Notes on Presentation

Acronyms and capitalization. Using acronyms as freely as NASA engineers do makes life difficult for outsiders. I have converted Beck's and Young's acronyms to full labels except for a few basic ones—STG (Space Task Group, original name of the manned space program), MSC (Manned Spacecraft Center near Houston, renamed the Johnson Space Center in 1973), MPAD (Mission Planning and Analysis Division, pronounced "em-pad"), NACA (National Committee for Aeronautics, the predecessor of NASA), and NASA (National Aeronautics and Space Administration).

The capitalization issue is what to do with "earth," "moon," and "sun." If you go to style books, they will tell you that they should be capitalized whenever they refer specifically to the planet we live on, the satellite specifically associated with the planet earth, and the star specifically associated with planet earth. NASA's internal documents and books written about spaceflight routinely (though not always) leave them in lower case. A case can be made for either choice. *Hidden Figures* capitalizes them, and they are capitalized here when quoting from *Hidden Figures*. Hal Beck and Ken Young did not capitalize them during their careers in NASA, nor did Catherine Cox and I capitalize them in the book we wrote about the space program, so our presentations follow our own precedents.

Sourcing. The commentaries by Hal Beck and Ken Young are presented as they were written, containing some informal citation of sources, but mostly based on their own expertise. The postscript, which blends their evidence with additional information, is fully sourced.

Review of *Hidden Figures: The American Dream and the Untold Story of the Black Women Mathematicians Who Helped Win the Space Race*

Harold D. Beck

Preface

The book *Hidden Figures* by Margot Shetterly was very popular and widely acclaimed. It quickly made the *New York Times* best-seller list. When the book was published in early September 2016, the stories related to Katherine Johnson and her role in early mission planning for manned spaceflight missions were, of course, of great interest to the Johnson Space Center staff and the many people who were retired but still lived nearby.

In the early days of Project Mercury, mission planning was the responsibility of the Mission Analysis Branch of the Space Task Group (STG) at Langley Field, Virginia. Former members of the STG here at the Johnson Space Center were concerned with what seemed to them to be an obvious re-writing of NASA history. They had a particular interest in that history because they were the pioneers in mission planning for NASA's manned space missions—they were the "old timers."

I happen to be one of those old timers. Soon after the publication of *Hidden Figures*, I began researching the claims in the book and collecting material that is included in this document. In the process, I evaluated many articles, award presentations, biographies, and of course, *Hidden Figures*. In the book I found that despite Margot Shetterly's extensive research, there were numerous inaccuracies and exaggerations relative to Katherine Johnson's contributions to early manned spaceflight.

It is easy to see how the discrepancies came to be. In 2015 when Shetterly was researching the career and accomplishments of Katherine Johnson, the Internet was fraught with misinformation related to Katherine's role in manned spaceflight. For example, in November 2015, a year before the book's publication, Katherine was awarded the Presidential Medal of Freedom by President Obama.

At the presentation in the White House, President Obama, said that "[f]rom sending the first American to space to the first moon landing, she played a critical role in many of NASA's most important milestones."

Charles Bolden, the NASA Administrator, and former NASA astronaut, stated that "…she's one of the greatest minds ever to grace our agency or our country" and that "Katherine's legacy is a big part of the reason that my fellow astronauts and I were able to get to space."

Dr. Dava Newman, the NASA Deputy Administrator, stated that "…for Katherine, finding the 'why' meant enrolling in high school at the age of 10; calculating the trajectory of Alan Shepard's trip to space and the Apollo 11's mission to the moon and providing the foundation that will someday allow NASA to send our astronauts to Mars…. She literally wrote the textbook on rocket science… At NASA, we are proud to stand on Katherine Johnson's shoulders."

These are just a few examples, on the Internet and in published articles elsewhere, of the many overstated and misleading accounts of Katherine's role in manned spaceflight. In my research, I did not come across a single article that was historically accurate relative to Katherine's role in mission planning for manned spaceflight. Margot Shetterly simply had no reliable accounts to work with.

It's unfortunate that the writers of the many biographies and other articles related to Katherine Johnson did not spend more time concentrating on her real career and many accomplishments. In my early days at NASA, I worked with Katherine, and we became close friends. She was an accomplished mathematician, highly regarded by her colleagues and was a true pioneer. With her dedication and hard work, she overcame harsh racial and gender barriers and became an important member of the NASA team.

In this review I concentrate on Katherine's role in mission planning for manned spaceflight and explore the controversial claims that are so prevalent on the Internet and in the book *Hidden Figures*. I provide detailed comments related to significant discrepancies in the book that were most evident to me. I have presented what I consider to be a factual account of the real story of Katherine Johnson. I think it is essential that I do so because NASA's manned spaceflight program was undoubtedly among the most significant technological endeavors in history. A historically accurate account of the early days of spaceflight is of importance for us today and for future generations. It is intended that the material presented here will be a valuable data source for researchers in the years to come.

1. A Brief History of Mission Planning for Manned Spaceflight

Conceptual Planning for Manned Spaceflight

In the early 1950's, as a full-fledged program to develop large ballistic missiles got underway, the National Advisory Committee for Aeronautics (NACA) began to consider the prospect of space flight. By the last half of the 1950s, several engineers in the Flight Research Division at Langley were starting to think about concepts involved in space flight. John Mayer, Carl Huss, Bill Tindall, Ted Skopinski, Clay Hicks, and Jack Eggleston were developing analytic capability in orbital mechanics and flight dynamics. John Mayer developed mission planning concepts which would evolve over the years and become the basis for the mission planning process used for all NASA manned spaceflight missions.

In early 1958, Henry Pearson of the Flight Research Division had organized a "self-education" course on space technology. His group compiled a comprehensive set of technical papers written by aeronautical engineers within the Research Division, the Pilotless Aircraft Division, and the Compressibility Research Division. The extensive document was titled "Notes on Space Technology" and included papers related to spacecraft guidance, propulsion, aerodynamic heating, materials, etc. The document was the first textbook on space technology and guided the early months of the space program.

The Space Task Group Is Formed

On July 29, 1958, President Eisenhower signed the National Aeronautics and Space Act establishing the National Aeronautics and Space Administration (NASA), which absorbed NACA's staff and facilities. NASA was formally opened for business on October 1, 1958. A month later, on November 5, the STG was formed, headed by Robert Gilruth, who had been director of the Pilotless Aircraft Research Division. Thirty-five people from Langley Research Center and ten people from the Lewis Research Center in Cleveland transferred to the newly formed organization.

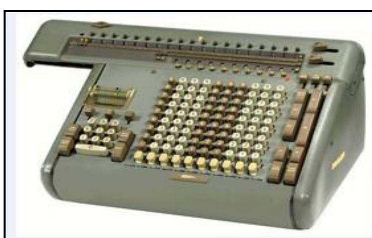
Space Task Group Headquarters

Responsibility for mission planning was assigned to the STG's Mission Analysis Branch, NASA's first formal manned spaceflight mission planning organization. It was later renamed the Mission Planning and Analysis Division (MPAD), part of the Flight Operations Directorate of the Manned Spacecraft Center in Houston (MSC). MPAD was responsible for the mission planning for all NASA manned missions until the organization was disbanded in 1990. John Mayer directed the Mission Analysis Branch and subsequently MPAD from the first Mercury flights through the end of the Apollo Program.

On 26 November, the manned satellite program was officially designated Project Mercury. Initially, the Space Task Group was located on the East Side of Langley Research Center north of Hampton, Virginia.

The Development of a Mission Planning Capability

One of the most basic tasks within the Mission Analysis Branch was to develop a capability in orbital mechanics, something that required extensive mathematical calculations. Before the advent of computers, the Friden calculator was used for such calculations, but its limitations forced compromises on the models that could be calculated. Historically, a two-body orbital mechanics model was the base in classical orbital mechanics textbooks. In computing orbits in the two-body


The Friden Model STW10

mathematical model, both bodies (e.g., earth and spacecraft) are considered point mass objects, i.e., the mass of each body is concentrated at the center of the body. The computation of a trajectory is greatly simplified; atmospheric drag, irregularities in the gravitational potential, external forces acting on the spacecraft, etc. are not considered. The two-body orbital mechanics equations were solvable on the Friden, and the solutions were reasonably accurate for short earth-orbit mission simulation. At Langley, Friden orbital mechanics programs were used extensively in earth orbit trajectory analyses and for conceptual mission design.

In early 1959, Langley acquired its first computer, an IBM 704. A priority project within the Mission Analysis Branch was to develop a high-fidelity trajectory simulation for Mercury mission planning. John Shoosmith, an experienced software engineer in the branch, was given the task. The program his team developed was dubbed CO3E. The significance of this program will be explained subsequently in the discussion of John Glenn's flight. CO3E was initially developed on the IBM 704 at Langley but later converted to the IBM 7094. It was used for years within MPAD supporting Mercury and Gemini mission planning and analysis.

Mission Planning for Mercury

There were six manned missions in the Mercury Program: two Mercury-Redstone suborbital missions and four Mercury-Atlas orbital missions. The Mercury manned missions spanned a two-year period from May 1961 until May 1963. The mission planning for each flight, including preflight data generation and documentation, started months prior to the launch date.

Branch personnel also supported mission operations at Cape Canaveral (subsequently the home of the Kennedy Space Center) prior to and during the mission. There was no computation capability in the Mission Control Center at the Cape. The computers in those days were still centralized at the Goddard Space Flight Center in Maryland. Goddard was the link between the remote stations and the Mission Control Center. There was also near real-time computation support at the STG at Langley. During the missions, mission planners computed essential data such as contingency deorbit opportunity updates and transmitted the data to mission control via phone.

The STG becomes the Manned Spacecraft Center and Moves to Texas

By September 1961, the STG had already grown to hundreds of people and soon would become thousands. James Webb, NASA's administrator, announced that it would become the Manned Spacecraft Center and be run out of a new facility to be constructed at Clear Lake, Texas, 25 miles south of Houston. The staff of MSC left Virginia in February and March of 1962, moved to Houston, and worked out of temporary facilities in and around south Houston while the new buildings at Clear Lake were being completed. The staff at Langley Research Center remained in Virginia. This included Katherine Johnson.

She had considered joining the STG and moving to Houston, but her family ties and her work at Langley kept her in Hampton.

Langley remained the NASA center of aeronautical research. But, like most NASA Centers, Langley also was involved in space research and development. For example, the NASA Lunar Orbiter Program was a Langley program. During Apollo, data from the Orbiter Program played an important role in MPAD's development of a high-fidelity lunar geopotential model for the Apollo planning system and for the Mission Control Center. Another example of Langley's involvement in the space program was the instrumental role of Dr. John Houbolt, director of the rendezvous studies group at Langley, in convincing NASA to choose lunar-orbit rendezvous as the method for getting to the moon.

2. My Personal Knowledge of Katherine Johnson's Work

Katherine Johnson was born August 26, 1918, in White Sulphur Springs, West Virginia. She attended West Virginia State College and graduated with honors in 1937 with a Bachelor of Science degree in mathematics. After graduation, she taught school in a black public school in Virginia.

Katherine joined the NACA's Langley Aeronautical Laboratory (as it was then called) in June of 1953. She initially went to work in an organization called the "West Computing Section." It was a group of African American mathematicians who were responsible for data reduction, transforming raw wind tunnel data into engineering parameters for use in aeronautical research. The mathematicians were called "computers." Their data reduction support services were critical to aeronautical research and development.

Katherine initially worked under the supervision of Dorothy Vaughan in the West Computing Section. After only two weeks, Dorothy arranged for Katherine to work in the Maneuver Loads Branch of the Flight Research Division where her position later became permanent. Her branch chief was Henry Pearson (and later, my boss also). Katherine had an excellent background in basic orbital mechanics.

I first met Katherine in 1959, shortly after the creation of NASA and the Space Task Group. I was a new graduate of North Carolina State University with a degree in aeronautical engineering. I went to work at Langley Research Center in the Maneuver Loads Branch where Katherine worked. I worked there for about two years.

Katherine at her desk – taken around 1962

When I first started work, I was an apprentice to a senior engineer, Jack Eggleston. He was working on several projects in orbital mechanics. My first assignment was to invert a 25 x 25 matrix of aerodynamic coefficients using the Friden calculator. It was a formidable challenge for me; I had never used, or even seen, a Friden calculator. Eggleston explained that it would not be a problem because my co-worker, Katherine Johnson, would "teach me the shortcuts" with the Friden in no time. Katherine did come to my assistance, and I soon became somewhat proficient with the Friden. She had infinite patience and was a whiz with the machine!

Katherine got me started in my new career; she showed me the ropes. In the nearly two years that I worked with her we became close friends. She was very proud of her hard-earned position at NACA/NASA. Her positive attitude made working with her a pleasure. As we became friends, I occasionally visited her home, met her family, and attended concerts and special events at the local Hampton Institute. I kept in contact with Katherine for several years; then we went our separate ways.

In early 1961 I transferred from Langley Research Center to the STG. I worked for John Mayer in the Mission Analysis Branch, the beginning of a long and rewarding career.

3. The Book *Hidden Figures*

Hidden Figures is a nonfiction account of the lives of three black women, Katherine Johnson, Dorothy Vaughan, and Mary Jackson, who worked as "computers" at NACA from the 1940s through 1958 and subsequently at NASA. They were called "computers" because they did the work that was later done by electronic computers, carrying out the complex and time-consuming calculations that were necessary to reach solutions for the equations that were essential to aeronautical research. After the formation of NASA, they were called "math aides." *Hidden Figures* chronicles the lives and achievements of the three women. It's also the story of the racism and gender discrimination they overcame during World War II, the Civil Rights Movement, and their careers at NACA/NASA.

While writing the book, Margot Shetterly conducted extensive research. For Katherine Johnson's story, she did her own interviews with Katherine and read the bios and articles written about her. In the spring of 2016, when the book was mostly written, Shetterly contacted retirees in the Houston area looking for names of former members of the STG who might have known Katherine. She located a friend of mine, Jerry Bostick, who remembered that I had worked at Langley Aeronautical Laboratory in the late 1950s before joining the STG. Jerry provided Margot with my contact information. Serious dialog between Margot and me began in April of 2016. Here is an excerpt from an initial email that I received from Margot on April 29, 2016:

> Jerry Bostick gave me your contact information. I'm a writer currently working on a book entitled Hidden Figures, which tells the story of the African American women who worked at NACA/NASA Langley from 1943 through the 1970s. One of the central figures in the book is a woman named Katherine Johnson, who is best known for having coauthored with Ted Skopinski the report that defined the trajectory math that was used in John Glenn's orbital mission MA-6. She was awarded the Presidential Medal of Freedom in November of 2015. I've been able to track down and review most of the documents involved in that mission, and I have interviewed Mrs. Johnson at length, but I was hoping that you might be available to talk by phone, so that I could ask you some of the outstanding questions that I have and get your memories of the time leading up to that day. Mr. Bostick mentioned that you worked with Mrs. Johnson at Langley before transferring to the Manned Spacecraft center in Houston.

Margot included many questions relative to Katherine's role in the mission planning for early manned missions. I provided a detailed response to Margot's questions and comments. The key exchange is given in its entirety in Appendix B. As we continued to exchange emails afterward, it was evident to me that there were significant inconsistencies between the book-in-progress and historical facts.

None of the material I provided was incorporated into the published text. At the time, I was told that there wasn't enough time to make significant changes. After the book appeared, I never asked Margot directly why none of the material that I and other NASA veterans gave to her was used in the book. Perhaps Margot decided that her interviews with Katherine and the Internet information were reliable and therefore corrections based on the information that I gave her were not needed, but that is only my guess.

4. Significant Inaccuracies in *Hidden Figures* and Other Accounts of Katherine Johnson's Work

In this section, I list major discrepancies, provide related historical information, and offer explanations related to the origin of the discrepancies. Some of these discrepancies are found in *Hidden Figures.* Others come from newspaper and magazine articles about Katherine that I found on the Internet. My objective is to provide a factual data source for future researchers interested in the mission planning for early NASA manned missions.

Item 1) Responsibility for Mission Planning for Mercury Missions

Margot Shetterly describes the STG as "a brain trust at mother Langley" that was "a nimble, semi-autonomous working group." (183) She goes on to describe the early days of the Mercury Program as if the people went back and forth between the STG and Langley, mingling and sharing responsibilities informally. Here is an example "…even after [John] Mayer transferred from 1244 to the offices on the East Side, he "bootlegged" the overflow work to his old buddies Carl Huss and Ted Skopinski, getting them to help out with whatever time they could squeeze in around what they owed to Henry Pearson." (189)

This is a misleading description. The STG was not a "semi-autonomous working group." It was a completely independent NASA center. Bob Gilruth reported directly to NASA Administrator Abe Silverstein in Washington. This distinction between "semi-autonomous working group" and an independent NASA center is extremely important for understanding why so much of *Hidden Figures*' description of Katherine's role is mistaken. Here's how the STG actually ran in the early days:

The key person in mission planning for Mercury flights was John Mayer. He was one of the original 35 Langley employees who transferred to the STG. Prior to transferring, Mayer had been in the Flight Research Division working with Carl Huss, Ted Skopinski, and Clay Hicks. John was assigned to form the Mission Analysis Branch. John reported to the director of the STG and later to the director of the MSC. He had ultimate responsibility for everything that went into every Mission Plan for all the Mercury, Gemini, and Apollo flights.

In the very early days of the Mission Analysis Branch, John needed support from his Flight Research Division colleagues who were still working at Langley. He met with the division's management and formally arranged for short-term trajectory analysis support. Nothing was "bootlegged." There were signed agreements at the highest level. The Mission Analysis Branch defined the tasks and monitored the results.

Within a few weeks, Carl and Ted were working nearly full-time on the STG support task. They transferred to Mayer's group and both Carl and Ted became major players in the new organization. By early 1961, the STG was fully operational. During Mercury, no planning products were developed from groups outside the Mission Analysis Branch.

Another important thing to keep in mind is "configuration control." In manned spaceflight, one of the biggest dangers is that someone will make a change to the hardware, firmware, or software of a system and not document it. Failure in configuration control of the Apollo spacecraft was one of the reasons for the fire that killed the crew of Apollo 1. In the Mission Analysis Branch, strict measures were in place from the very beginning to ensure that nothing was done without documentation. This is not bureaucratic red tape. It is absolutely essential. Preflight trajectory data was under strict configuration control within the Mission Analysis Branch. If anything involving trajectory planning had been outsourced to anyone working with Katherine Johnson, it would have been documented.

When Katherine said that she computed the trajectory for Alan Shepard's flight, that was probably a true statement, but it was grossly misleading. Mathematicians and engineers in organizations around the country were beginning to develop the two-body programs for earth-orbiting satellites. The two-body equations were readily solvable on the Friden calculator, and the approximate two-body solutions were adequate for trajectory studies. When the early Mercury missions were flown and actual "real-world" flight data became available for analysis (how great that was!), engineers attempted to replicate Mercury flight data using their personal programs. It was a popular way to validate their two-body programs in use at the time. One could input the initial conditions for the "official" trajectory, compute the trajectory and compare the results. Katherine was still working at Langley. If she was one of the people who attempted to replicate Shepard's flight, Mercury-Redstone 3, on the Friden, those calculations had nothing to do with the actual mission planning products for the flight.

Item 2) Racial or Gender Barriers within Katherine's Organization

The book states that Henry Pearson, Katherine's branch chief, "was not a big fan of women in the workplace." That was certainly not my perception. On the contrary, my first-hand experience was that he had the highest regard for the women in his organization—and especially for Katherine. I worked for Pearson for about two years, and I got to know him well. I personally witnessed their relationship since my desk was next to Katherine's and Henry often dropped by her desk to "shoot the bull." Katherine was an able co-worker and respected by all the senior engineers in the group. I never did get the idea that she was at all sensitive to barriers due to race or gender. One of her closest friends and coworkers was a young white woman, also an accomplished mathematician. Katherine always worked as a team player and was very good at what she did.

Item 3) The Importance Attributed to the TN D-233 on Determining Azimuth Angle at Burnout

Hidden Figures attaches great significance to TN D-233 coauthored by Ted Skopinski and Katherine Johnson, titled "Determination of azimuth angle at burnout for placing a satellite over a selected earth position" (the prefix "TN" stands for "technical note). According to *Hidden Figures*, the document was used to program launch and reentry trajectories for Mercury missions. That is not correct.

For Mercury mission planning, the launch trajectories for both the Mercury-Redstone and the Mercury-Atlas launch vehicles were generated using CO3E, the three-degrees-of-freedom program developed within the Mission Analysis Branch by John Shoosmith. The launch vehicle simulations in CO3E were from sources external to the STG; specifically, the Army Ballistic Missile Agency was the source for the Mercury-

Redstone launch vehicle simulation and the Space Technologies Laboratory in Los Angeles was the source of the Mercury-Atlas launch vehicle simulation.

The retro and entry trajectory data were also computed using CO3E. The trajectory data included the retro maneuver simulation and the impact target parameters. The entry trajectory data included aerodynamic forces, the spacecraft heating profile, and the trajectory event timeline. The programming of CO3E was underway months before even a draft of TN D-233 was available. Nothing in TN D-233 was used in CO3E's subsequent iterations.

While *Hidden Figures'* description of the importance of TN D-233 is wrong, the work that went into the paper was put to use. Its value is not described in *Hidden Figures* or to my knowledge in any history of the Mercury Project

In 1958, work began on the design and development of the Mercury world-wide tracking and communications network. The newly defined manned-satellite program drove special communications requirements. For instance, the network would require real-time, wide-band communications to monitor the spacecraft's status. Ground-based flight controllers, some of whom would be stationed at tracking sites, had to be able to talk directly with the astronaut during a pass. The most important difference between satellite and manned spaceflight communications was the far greater reliability required when a human being's safety was at stake.

These important differences were known to Langley engineers even before the STG was formed. A team called the Tracking System Study Group was formed to design the entirely different type of network necessary to support the new man-in-space project. The Group began addressing the network issues in earnest in the fall of 1958. The primary task in defining the network was to determine the number of stations required, the station locations, and the optimum orbital inclination to optimize communications coverage.

From the beginning, it was known that Bermuda, 900 miles east of the South Carolina coast, would be the most critically important location. This was because the flight path of the Mercury Atlas took it almost directly over the island, providing a short but crucial 25 second window to track and make decisions on its status during ascent into orbit. The critical Bermuda pass determined the orbit inclination (32.54 degrees) for all Mercury missions. That orbit inclination also enabled maximum use of DOD range facilities and kept the ground track of the spacecraft over the continental United States much of the time, limiting over-flight of countries that might not cooperate. It also resulted in acceptable recovery areas close to US Naval facilities.

The design team started with the assumption that the network would support a three-orbit Mercury mission at an inclination of about 33 degrees. Next, it determined just how long a communication gap could be tolerated between stations. The first design iteration had 20 stations scattered around the globe. Eventually, the number was reduced to 18. As the Mercury network took shape, station locations that were consistent with the defined orbit inclination were determined by a number of factors ranging from geography to the cooperativeness of the local government.

Ted Skopinski and Katherine Johnson were important contributors to the design and development of the network. Early in the project definition phase, Ted developed the two-body equations to determine the launch azimuth to place a satellite over a specified geographical location. The analyses were essential in selecting options for ground station and tracking ship placement. Katherine supported Ted in the complex parametric analyses and she was responsible for generation of the ground-track data used in the study.

Later, Ted and Katherine went through the process of converting their work into the official Langley Technical Note, TN D-233, that gets so much attention in *Hidden Figures*. In mid 1959, shortly after I joined Pearson's group and started working with Katherine, Ted transferred to Mayer's group in the STG. *Hidden Figures* says that because Ted had transferred to the STG and was occupied with other work, Katherine took the lead in completing the TN and shepherding it through the long and demanding Langley review process. As someone who was sitting at the desk next to Katherine's during this period, that description sounds accurate. It is consistent with her enthusiasm and independence. I did not think of Katherine as "just a math aide." Katherine actively participated in the work that developed the Mercury tracking network and thereby contributed to its effectiveness. It is just not the contribution described in *Hidden Figures* or in Katherine's NASA biography.

Item 4) John Glenn's Concern with the Preflight Data for the Mercury-Atlas 6 flight

John Glenn's flight, Mercury-Atlas 6 (MA-6), was the first crewed American orbital mission. The launch date was February 20, 1962. In *Hidden Figures*, as the story goes, before launching MA-6, John Glenn was not confident that the official preflight trajectory data was accurate. According to Katherine, she overheard a phone conversation from John to her supervisor (Henry Pearson?). In the conversation, John asked the engineers to "get the girl" (Katherine Johnson) to run the same numbers through the same equations that had been programmed into the computers, but by hand on her Friden calculator. According to the story, John Glenn says "If she says they're good, then I'm ready to go."

It's not at all clear how that story evolved, but I am certain that John never questioned the accuracy of the Mercury trajectory data. If for any reason he had a question or an issue, he would have gone to Bob Gilruth, Chris Kraft, John Mayer, Carl Huss, or Clay Hicks. The Space Task Group was a relatively small team at that time and everyone worked together with absolute open communication. John Glenn's office was down the hall from Mayer's office.

The story also doesn't make sense because John Mayer's group was responsible for the preflight mission data, had generated the trajectory data for all the previously flown Mercury missions, and the nominal trajectory for John's flight was exactly the same as the trajectory that had been flown on Mercury-Atlas 5 (an orbital test flight with a chimpanzee named Enos onboard). The trajectory program, CO3E, had been cross-checked and verified with actual flight data from Mercury-Atlas 5. The numbers that John was said to be concerned about were not new in any way, and John would have known that.

Another problem with Katherine's account is that John Glenn would have known that it was impossible for Katherine to run the same numbers through the same equations that had been programmed into the computers on her Friden calculator. The program used to compute John's trajectory was a high-fidelity trajectory simulation package implemented on an IBM 704 computer. It was developed incrementally from 1959 onward. The software's basic requirement was to compute the position of an orbiting body at a given time after some known orbit state. The "Kepler" equations provide that capability, but the equations could not be solved analytically. A numerical method known as a variable-step fourth-order Runge-Kutta method was employed to integrate the Newtonian equations of motion considering the aerodynamic characteristics of the capsule and all the external forces acting on the vehicle.

CO3E was also used for on-orbit trajectory propagation and for re-entry trajectory computations. During the early Mercury missions, it was used for back-up calculations to determine retro-fire times for emergency re-entry to contingency recovery areas. During MA-6 (February 1962), it was used to support the retro-fire officer at the Cape with the computation of retro-fire times for contingency landing areas. The computations were done on the Langley IBM 704 using CO3E, and the results were phoned to the Cape.

As Mercury mission planning requirements were better defined, CO3E was augmented with additional functionality and output-parameter options. Mercury spacecraft characteristics were incorporated to provide the capability to calculate accurate ground track data, tracking acquisition data, spacecraft retrofire attitude and retrofire times, landing area data, and other ancillary information. Katherine (or anyone else) could not possibly "run the numbers" with a Friden calculator.

I don't know what happened that made Katherine think John Glenn wanted her to "check the numbers." I think the most likely scenario is that someone in Henry Pearson's branch had access to the classified document, Working Paper 217, "Project Mercury Calculated Preflight Trajectory Data for Mercury-Atlas Mission 6 (MA-6)," provided Katherine with the input parameters for use in her two-body calculations, and asked her to see how a two-body calculation would compare with the high-fidelity trajectory parameters. In those days, we did often compare two-body results to fidelity simulations in software assessments. Apparently, something gave her the impression a check was needed to catch possible mistakes in the CO3E computer-generated trajectory, but none of her supervisors would have thought that was possible.

Hidden Figures reports that the work took Katherine a day and a half. That's certainly a reasonable amount of time for the task. Katherine was quite familiar with the two-body equations. Setting up the spreadsheet in preparation for the computation was a bit time consuming but Katherine was one of the best when it came to the Friden operation. She could outperform almost everyone in the organization. The number of calculations she had to do depends on the chosen "time steps" or granularity of the solution. But no matter how granular, the Friden computation is not actually a hand check of the computer run. There are levels of accuracy in trajectory propagation: the two-body is one level (and represents an approximation) and the numerical integration is the second level. But whatever the chosen time step, she wasn't checking for mistakes in the software. Without a doubt, the two-body solution *would never* be used to validate a high-fidelity trajectory simulation!

Item 5) Katherine's Involvement with Translunar Trajectory Calculations for Apollo 11

In several of the online biographies, it is stated that Katherine calculated the trajectory for the 1969 Apollo 11 mission. In the book, it is implied that Katherine had something to do with those trajectories (Katherine is said to be confident about the success of Apollo 11 because she was confident that her numbers were right).

The design and generation of the translunar trajectory for a lunar landing mission is not a simple operation. Translunar trajectory targeting and design requires a precisely accurate, high-fidelity simulation of the earth-moon system, the launch vehicle, spacecraft systems, and trajectory targeting techniques for all maneuvers.

The lunar landing mission simulation for the Apollo lunar landings was developed within MPAD at Houston. The simulation was called the Apollo Reference Mission Program and was under development for years. It was used to generate the official reference missions for all Apollo lunar missions. *None* of the preparation for Apollo 11 (or any Apollo mission) was done at Langley, where Katherine continued to work. The reference mission for Apollo 11 was published as MSC Internal Note 69-FM-186, dated July 3, 1969. It was titled "Revision 1 to the Spacecraft Operational Trajectory for Mission G (Apollo 11), Volume I Operational Mission Profile, Launched July 16, 1969." The document was published by MPAD, MSC. The reference mission is available through the NASA History Office. It is not clear how Katherine could have calculated the translunar trajectory for Apollo 11 and there is no reason why she would have wanted to do so, but it is certain that she had nothing to do with mission planning and analysis for Apollo 11.

Item 6) Katherine Computed Backup Navigation Charts for Apollo 11

Katherine stated in some interviews that she computed backup navigation charts for the astronauts to use in case of computer failure. The back-up procedures for use during the flights were developed by the flight control team and by the astronauts at MSC. Detailed procedures were defined for all contingency operations and were simulated/verified on the flight simulators. Perhaps Katherine remembers that she and Al Hamer at Langley developed star-charts from data derived from the nautical almanacs. But those products were not used in the development of operations procedures by the Flight Operations Division at MSC. Neither *Hidden Figures* nor the NASA biography mention anything about these backup navigation charts for Apollo 11.

Item 7) Katherine's Involvement with the Apollo 13 Aborted Mission

The NASA biography says that "In 1970, Apollo 13's aborted mission to the Moon made use of her earlier research on backup parameters and charts, enabling the crew to safely return to Earth four days later."

Apollo 13 was the seventh crewed mission in the Apollo space program and the third mission meant to land on the moon. The spacecraft was launched from Kennedy Space Center on April 11, 1970. The lunar landing was aborted two days into the mission when an oxygen tank in the service module exploded. The mission was a near tragedy; the flight control team had to quickly devise methods and procedures to bring the flight crew safely back to earth.

At the time of the accident, the mission planning team, astronauts, and all major Apollo spacecraft contractors were on hand to support the flight controllers in the "return-to-earth" mission analyses. In near real-time, flight simulators were used to check and verify crew procedures and operations. The mission planning team in the backrooms ran countless "what-if", return-to-earth scenarios. The flight directors and NASA high level management were making countless operations decisions. In the Mission Control Center, the flight control team used return-to-earth contingency planning software in the Real Time Computer Complex and verified crew procedures generated at MSC.

Item 8) Katherine's Involvement with the Apollo Lunar Ascent Module Launch Time

When Katherine was asked to name her greatest contribution to space exploration, she said that her calculations "helped synchronize Project Apollo's Lunar Lander with the moon-orbiting Command and Service Module." It is hard to imagine how such a story came to be.

In the preflight "end-to-end" mission planning for a lunar landing mission, the nominal lunar ascent stage lift-off time is determined by lunar rendezvous specialists, consistent with all spacecraft systems requirements and operational constraints. In real time, the ascent launch time is calculated using specialized ascent/rendezvous software developed within MPAD and implemented by IBM in the Real Time Computer Complex within the Mission Control Center.

The lift-off time and ascent and rendezvous maneuvers are optimized within the performance capability of the spacecraft systems and the ascent profile is constrained by operational considerations. The ascent and rendezvous simulation required modeling the ascent engines, ascent guidance, and the rendezvous and the docking maneuver sequence. The simulation also required an accurate modeling of the lunar geo-potential; that modeling took years of analysis and model development within MPAD.

There were no calculations from external sources that “helped synchronize Project Apollo’s Lunar Lander with the moon-orbiting Command and Service Module.” The Lunar launch time, the ascent trajectory and rendezvous sequence were computed in real time in the Mission Control Center at MSC.

Footnotes for *Hidden Figures*

Ken Young

Hidden Figure's description of Katherine Johnson's role in the US manned spaceflight program appears to me to be fiction, but the author of *Hidden Figures*, Margot Shetterly, says *Hidden Figures* is history. I take her at her word. In my critique of her book, I don't comment on anything except technical issues involving spaceflight with which I am personally familiar, but for everything that falls within that category, I call her out whenever I am sure she is exaggerating or wrong. Some of my "footnotes" to *Hidden Figures* are about major errors and others are about minor ones. I include most of the minor ones because I want people to realize just how many things in the book are incorrect, and to seriously question the book's space history editing—if ANY!

Each footnote is preceded by the boxed text from *Hidden Figures* that I am commenting on and is followed by the page number in the Digital Edition (March 2021, ISBN 978-0-06-236391-9, Version 03222021). "KJ" refers to Katherine Johnson.

• • • • •

> I [the author] had been the only black woman in enough drawing rooms and boardrooms to have an inkling of the chutzpah it took for an African American woman in a segregated southern workplace to tell her bosses she was sure her calculations would put a man on the Moon. (xv)

Chutzpah indeed! Not "would HELP put a man on the Moon", but "…sure HER calculations WOULD put a man on the Moon." A little hyperbole here, perhaps? Exactly what calculations/equations would those be? Calculations of a translunar trajectory, including the three-body gravitational effects, the propulsive dynamics, the lunar landing powered descent? And when and where in this nonfiction book did said lady document and provide said calculations/equations, or at least references; and to what organizations? Apparently not to the Mission Analysis Branch of the STG, or, later to MPAD of the MSC where, in fact, ALL the Apollo flight trajectories to "put a man on the Moon" were developed, computer programmed, flight planned and documented.

This passage comes from the prologue, and the author doesn't claim that KJ said those actual words. But in a nonfiction account of contributors to US manned spaceflight history, allusions to such significant technical contributions must be backed up with far more specific evidence and notes referencing that evidence. We'll look for it!

> Well into her nineties, Katherine Goble [KJ's first marriage name] would recall watching the winking dot of light in the sky as vividly as if it were still October 1957. She stood outside in the unseasonably warm autumn nights of that year and tracked the shiny pinpoint as it moved low across the horizon. (161)

KJ could not have seen Sputnik with the naked eye. Since perigee of its orbit was near its insertion point over Siberia, the apogee was over the Western Hemisphere. Thus the range was likely hundreds of miles above her Virginia home. The not-quite two-foot diameter sphere could not be seen at such distances even with the momentary correct sunlight angle. More likely she was remembering the first Echo satellite, launched in 1960 and large enough to be seen from earth.

We're talking here about a problem that keeps returning throughout the book: Before accepting the recollections of a person in her nineties as fact, it should be standard operating procedure to check out those recollections with others who were in a position to know. As far as I have been able to determine, the author did that with just one person, Hal Beck, who told her in detail why KJ's recollections didn't check out. None of his corrections made it into the published book.

> In the early stages of researching this book, I shared details of what I had found with experts on the history of the space agency. (xv)

None of these space history experts are named in the text or the Notes section. Some of the people she "shared details" with may be experts on Langley's history but she needed experts on manned spaceflight history. As my later footnotes will highlight, I cannot find evidence of editorial scrutiny by any spaceflight history expert. In fact, there is a glaring absence thereof!

> They surfed the radio dial trying to lock on to the artificial moon's beeping, its sound like an otherworldly cricket. (161)

An ordinary AM/FM radio dial could not find a live pickup of the actual sound. Perhaps in her old age she recalled hearing local radio broadcasts of the recorded "beep-beep" that the USSR sent out as propaganda.

> Now, with Sputnik circling overhead every ninety-eight minutes…. (161-62)

Sputnik passed over the American mainland about three or four times a day for a total of only 15-20 minutes.

> Any craft that traveled into space first had to traverse the layers of Earth's atmosphere, accelerating through the sound barrier and increasing numbers on the Mach speed dial, before escaping the pull of Earth's gravity and settling into the eighteen-thousand-mile-per-hour speed that locked objects into low Earth orbit, following a circuit of between 134 and 584 miles above the planet. (163)

A botched description of a launch and orbit insertion trajectory of a low earth-orbit satellite. The satellite does not "escape the pull of Earth's gravity." It reaches a velocity in the horizontal direction such that as gravity pulls it back toward the center of the earth, it "misses" hitting the horizon and continues in orbit. Those specific orbit altitudes she cites (134 and 584 miles) might have been true for a specific launch but are not true for "*any* craft that traveled into space." More evidence of the author's lack of knowledge about spaceflight and/or the absence of an expert editor!

> To the engineers on Katherine's desk fell the responsibility of the trajectories, tracing out in painstaking detail the exact path that the spacecraft would travel across the surface from the second it lifted off the launchpad until the moment it splashed down in the Atlantic. (189)

What does the phrase "To the engineers on Katherine's desk…" even mean?? It's not NASA jargon I ever heard. I suppose it could be interpreted to include KJ if the author had written: "to the staff on Henry Pearson's desk," although Pearson's branch was never responsible for Mercury launch or orbital trajectories. Furthermore, it is highly unlikely that she calculated "the exact path that the spacecraft would travel," as that would be for the ascent trajectory of the launch vehicle (Redstone or Atlas) and the entry of the Mercury spacecraft—a task not possible without an electronic computer simulation!

More likely, "to the engineers on Katherine's desk" is intended to suggest that KJ was working with the STG engineers. Here's the whole paragraph:

To the engineers on Katherine's desk fell the responsibility of the trajectories, tracing out in painstaking detail the exact path that the spacecraft would travel across Earth's surface from the second it lifted off the launchpad until the moment it splashed down in the Atlantic. As the head of the Space Task Group, Robert Gilruth had been given his pick of NASA employees to fill the ranks of *Project Mercury's nerve center.* Katherine's office mate, John Mayer, had jumped ship for the new endeavor a week after it was created, in November 1958. The workload generated by Project Mercury was so onerous that even after Mayer transferred from 1244 to the offices on the East Side, he "bootlegged" the overflow work to his old buddies Carl Huss and Ted Skopinski, getting them to help out with whatever time they could squeeze in around what they owed to Henry Pearson. He got them to do "computing runs" for him—which meant getting Katherine to do computing runs for them. The group took on the additional tasks with zeal, because space looked like "a hell of a lot of fun." They turned their desks into a trigonometric war room, poring over equations, scrawling ideas on blackboards, evaluating their work, erasing it, starting over. (189)

The passage correctly reveals that the STG occasionally delegated tasks to Henry Pearson's Maneuver Loads Branch of the Flight Research Division, Carl Huss and Ted Skopinski were two of the Flight Research Division's engineers, and KJ was one of the Maneuver Load Branch's computers (called "math aides" after electronic computers came in). The passage therefore also correctly puts KJ at the end of a long chain separating her work from the people who had responsibility for the Mercury flight plans.

The author's choice of "Project Mercury's nerve center" to describe the STG makes it sound as the STG was still just a part of Langley Research Center. It was a distinct entity that had independent and total responsibility for and administrative control over the Mercury flights, located far from the main buildings at Langley soon after the STG began and after 1961 located a thousand miles away. KJ was never part of the STG. Does it make sense that John Mayer treated one of his central responsibilities, the calculation of launch, orbital and reentry trajectories, as "overflow" to be farmed out to Langley instead of using his own hand-picked staff and contractors?

Successful orbital flight required the engineers to adjust the tennis ball machine's chute to the correct angle and arm its launcher with enough force to send the ball up through the atmosphere and into an orbit around Earth on a path so precisely specified, so true, that when it came back down through the atmosphere, it was still within spitting distance of the navy's waiting racket. (190)

Such "spitting distance" accuracy of even a suborbital flight, much less an orbital one, was NEVER achievable in those days—even with the most precise launch azimuth. The many dispersions, such as booster engine performance, daily atmospheric conditions, guidance errors, insertion velocity and vehicle attitude variations, as well as drag uncertainties and gravitational unknowns, retrofire timing and attitude variations, etc., all could cause very significant landing dispersions, on the order of many miles.

“Tell me where you want the man to land, and I’ll tell you where to send him up,” she said. (190)

If KJ had really said that—which I can’t believe she did—she would have been laughed out of the room! The location of a launch doesn’t determine the location of the landing. But let’s suppose that what she actually said was something like, “I can use the math in our paper on the azimuth launch angle to calculate the launch and entry trajectories for the orbital flight.” She couldn’t even have done it for the suborbital flights!

She could have approximated it with two equations, both actually just spherical trigonometry, i.e., the launch azimuth value that gives the launch trajectory a heading angle off the launch pad and an “insertion” booster cutoff at some altitude and latitude/longitude over the Atlantic. In other words, the approximation was basically a ballistic missile trajectory, no different from what ballistic missile engineers had been doing for years. But that basic math is only the beginning. The approximation could not match the boost trajectory with its huge aerodynamic drag loads acting on the booster. And, after cutoff, even any theoretical prediction of the entry and landing by parachute would be very crude. The basic math—and that’s what the Skopinksi/Johnson paper consisted of—had to be augmented by the much more complicated math required take these factors into account, and those calculations had to be done by electronic computers.

And remember that those calculations pertained to a suborbital trajectory, such as Shepard’s and Grissom’s. The orbital trajectories required many more parametric studies, such as global communication coverage, atmospheric drag and second order gravitational effects, deorbit/entry dynamics, and recovery area logistics, including emergencies and international negotiations.

Her grasp of analytical geometry was as good as that of the guys she worked with, perhaps better. And the unyielding demands of Project Mercury and the sprawling, still-forming organization that was being built to manage it stretched everyone to the limit. Soon after John Mayer put on the Space Task Group jersey, Carl Huss and Ted Skopinski followed suit, making Katherine the natural inheritor of the research report that would describe Project Mercury’s orbital flight. (190)

The “research report” is the one based on work that Skopinski and KJ had done in 1959 was published in late 1960 under the title “Determination of azimuth angle at burnout for placing a satellite over a selected earth position.” It was just one of many parametric studies being prepared during that period. It consisted of a set of generic spherical trigonometry equations, along with the Mouton orbital elements that described a satellite in a two-body gravitational field. It captured the well-known launch azimuth equation for ballistic missile trajectories, plus resultant orbital position and velocity insertion parameters.

The purpose of the Skopinski/Johnson work was to help select the sites for the Mercury tracking station. Some background:

The launch azimuth is simply the heading angle of the booster/payload from the pad, measured from true north in an inertial, earth-center coordinate system, that will result after an essentially ballistic ascent to an insertion point and a maximum latitude at its due east heading.

The heading angle of the capsule/satellite at the insertion point sets the orbital inclination, along with the three inertial velocity components. The in-plane insertion velocity dominates to establish the orbital altitude of the apogee generally about 90 degrees later along the ellipse—with, generally, insertion altitude as the perigee. This "orbit size" is what sets the period and hence the revolution time. The "ellipse size" is the range of orbit altitudes from perigee to apogee. Ellipse size is a variable almost as important as inclination in terms of global communications. Other very important factors are tracking and communications antennae capabilities, keyhole blockage around the zenith, terrain, and land communications at remote sites. All of these factors were considered by the Tracking System Study Group. Ted and KJ's parametric analyses enabled the Group to vary the inclinations and ellipse orbit sizes, using two-body Keplerian orbital trajectories. Very helpful for selecting tracking station sites, but those trajectories, per se, were not intended to be precise. The technical note that was eventually published did not contain anything that was used by the Mercury mission planners/controllers for the actual flights—no more so than, say, any textbook of Newton's gravitational equations or Moulton's 1914 orbital equations were "used."

Equation A3 accounted for errors in longitude. (191)

Errors in longitude of the satellite could be due to uncertain effects, such as initial insertion dispersions in position or velocity, variations in atmospheric density or the vehicle drag characteristics, or even in second-order gravitational effects. Did equation A-3 cover those? Not a chance—only computer-generated numerical integrations containing complex algorithms could give such critical detailed satellite positions, especially after orbit insertion.

Equation A8 adjusted for Earth's west-to-east rotation and oblation. (191)

Oblation is related to the earth's rotation? Not really, at least to the first order—but this may just be more evidence of the author's lack of space-related understanding. A satellite's position in terms of geodetic (for an oblate earth) vs. geocentric latitude must be accounted for in its subsatellite map location, as well as the effects of earth's non-homogeneous gravity, but calculations with a Friden would not have included such second- and third-order effects.

> Stepped on, turned out, pulled apart, and subjected to every stress test the editorial committees could throw at it, Katherine's road map would help lead NASA to the day when the balance of the space race was tipped in favor of the United States. (192)

Roadmap? Gross hyperbole! Those fundamentally simple spherical trigonometry equations and orbital element calculations were already well known and were certainly used by the Russians (and all ballistic missile experts)! That report was published long after the Russians and US had programmed them (and many more precise algorithms) for actual launch and satellite trajectory parameters used both for planning and analysis AND actual real-time predictions. You can bet that the Russians never had to steal it to try to keep up in the Space Race!

> Despite the relatively large group of women now working at the center, most female technical professionals, black and white—even someone as gifted as Katherine Johnson—were classified as mathematicians or computers, ranked below engineers and paid less, even if they were doing the same work. (196–97)

There is no evidence in this book that the computers or even mathematicians at Langley were "doing the same work as engineers." Plugging numbers into a Friden or plotting a graph is not engineering.

> Constant contact with the astronaut during every minute of every orbit was a prerequisite for the flight. (207)

Constant contact was never a prerequisite and was not even a physical possibility at the time—not even close!

> The eighteen communications stations set up at measured intervals around the globe, including two set up on Navy ships (one in the Atlantic Ocean, another in the Indian Ocean), used powerful satellite receivers to acquire the radio signal of the Mercury capsule as it passed overhead. (207)

"Measured intervals" is a misleading description of the actual comm station situation. Yes, it was desired to optimize coverage (radio/radar) at convenient, spaced points, but that was not possible because of both orbital geometry and international situations with some foreign countries. The earth was, of course, constantly rotating under the orbit plane. Thus the coverage varied greatly from "excellent" for three or four revolutions over the US, but later in the 24-hour day, some revs had only one or two contacts—even using the two ships mentioned here. Another example of lack of an editor who knew something about spaceflight.

> The computers also sounded the alarm at the first sign of trouble; any deviation from the projected flight path, evidence of malfunction on board the capsule, or abnormal vital signs from the astronaut, which were also being monitored and transmitted to doctors on the ground, would send Mission Control into troubleshooting mode. (207)

Simply wrong. There was NO automated computer alarm at "at the first sign of trouble."

> Mary Shep Burton, Catherine T. Osgood, and Shirley Hunt Hinson, the math aides who ran the trajectory analysis software on the group's IBM 704, also decided to go [to Houston]. (210)

Yes! Those three KEY math aides WERE in the STG and DID run some software, reduce data, and prepare products (plans, technical reports, etc.) while assisting engineers on Project Mercury mission analyses and plans. Their contributions were important enough that Osgood and Hinson were interviewed by NASA historians. MPAD had a number of women and African Americans (plus other minorities!) during Mercury, Gemini, and Apollo. They did great work, along with hundreds of others who have never gotten public recognition. Out of all these people, why single out KJ for acclaim and the Presidential Medal of Freedom when her contributions to the manned spaceflight program were so much smaller than those of other women and African Americans who WERE part of MSC?

> Katherine and Ted Skopinski had laid out the fundamentals of the orbital trajectory nearly two years earlier, in their important Azimuth Angle report, then handed off the responsibility for the calculation of the flight launch conditions to the IBM computers. (211)

The key phrase here is "…then handed off responsibility..." The simple trigonometry of the Skopinski/Johnson paper was nowhere close to being an actual flyable "orbital trajectory"! All that was planned, analyzed and programmed into the computers by STG engineers and their contractors by the time that report was completed and KJ had nothing to do with ANY of that!

> Like her fellow West Virginian John Henry, the steel-driving man who faced off against the steam hammer, Katherine Johnson would soon be asked to match her wits against the prowess of the electronic computer. (211–12)

Nice literary allusion, but "wits" using a Friden calculator were no match against a numerical integration computer program like the STG's CO3E, even in the early days. One could use the Skopinski/Johnson report for selected "point" calculations for initial launch azimuth of the booster/capsule, then approximate the orbit insertion position and velocity conditions, then, with two-body time hacks, make a few orbital element propagation points "around" an orbit. But accounting for second and third-order effects like atmospheric drag and gravitation variations, even over a couple of orbits, would have been futile in terms of matching the IBM predictions!

> Titov followed Yuri Gagarin's April 1961 triumph with a successful seventeen-orbit flight, nearly a full day in space, on October 6, 1961. (215)

August 6, not October 6. Another example of poor editing.

The next several footnotes are about the most famous claim in *Hidden Figures*, that John Glenn asked KJ to check the accuracy of the trajectory analyses for his flight, MA-6. It looks like the story will enter the history books. It is also unbelievable. John Glenn was not flying with an untested system or trajectory! MA-4 was flown in September of 1961 with a capsule containing a dummy astronaut and it got into and out of orbit very successfully. There were some critical systems problems, but the orbit and landing numbers were almost as STG planned. MA-5 carried Enos, the chimpanzee, for two orbits on virtually the same trajectory being planned for Glenn's three-to-seven orbit flight. So why would Glenn be worried and ask for a check of his orbital parameters? And why suddenly get worried just before the fourth launch attempt when apparently he wasn't worried before the three prior launch attempts? But let's take some of the statements on pages 216–17 one at a time.

> The astronauts, by background and by nature, resisted the [electronic] computers and their ghostly intellects. (216)

Baloney! The Mercury Seven may have been presented as silk scarf, fly-by-the-seat-of-your-pants guys, but they were actually highly intelligent engineering types. They resisted other human beings who wanted to take decisions out of their hands, just as Tom Wolfe described in *The Right Stuff*, but they knew that high-speed computers were absolutely essential to any launch trajectory/orbital mission.

> In a plane, at least, it was the pilot's call; the "fly-by-wire" setup of the Mercury missions, where the craft and its controls were tethered via radio communication to the whirring electronic computers on the ground, pushed the hands-on astronauts out of their comfort zone. (216)

This overblown statement implies that the ground controllers could actually, at any time, take control of the spacecraft and maneuver it. In fact, that capability was highly constrained by lack of frequent ground coverage, as well as the limited onboard computer and maneuver systems capability! It had been demonstrated by necessity on the unmanned MA-4/5 flights that the ground could command the deorbit maneuver as well as control certain attitude modes. But for the manned orbital missions the crewman was mostly in control.

> "The human computers crunching all of those numbers—now that the astronauts understood. (216)

Really? By Glenn's flight, the astronauts were not even around Langley. And the math aides had stopped "crunching all of those numbers" long before Glenn's flight. All the calculations used for the flights (preflight and real-time) were being done by electronic computers.

> Most importantly, the figures flowed in and out of the mind of a real person, someone who could be reasoned with, questioned, challenged, looked in the eye if necessary. The process of arriving at a final result was tried and true, and completely transparent. (216)

<u>The author just described what STG engineers and mission planners did with every Project Mercury trajectory flight</u>, even conceptual and preliminary ones done years or months ahead of the final plan! The figures that came in reams of computer printout did flow "in and out of the mind of a real person, someone who could be reasoned with, questioned, challenged, looked in the eye if necessary." The astronauts could and did talk to them whenever they wanted. They just weren't "real persons" who were part of Langley Research Laboratory. They were in Houston at the MSC or, like John Shoosmith, still in Virginia but were on real-time mission support, running his IBM 704 and phoning information to the controllers at the Cape!

> He [Glenn] did, however, trust the brainy fellas who controlled the computers. And the brainy fellas who controlled the computers trusted their computer, Katherine Johnson. It was as simple as eighth-grade math: by the transitive property of equality, therefore, John Glenn trusted Katherine Johnson. (216–17)

What does this flowery statement mean? Did the author just say that Glenn was not trusting the people in the STG, and that therefore he was trusting KJ at third hand, over in Pearson's shop? That he didn't know her personally?

Even taken at face value, the sentence doesn't make sense. Elsewhere, the author says that the request to check the numbers came in three days before MA-6 launched. That means it was mid-February 1962, three years since the people in Henry Pearson's branch had switched over to the STG. Since KJ never joined the STG, she had been invisible to people in the STG, including John Glenn, throughout that period. She played no part in preparing the CO3E software or assisting on the two suborbital flights of Shepard and Grissom or the two unmanned orbital flights. Meanwhile, the STG had been relying on its own math aides for three years. The "brainy fellas who controlled the [electronic]computers" couldn't be said to have "trusted their computer, Katherine Johnson" because she WAS NOT "their computer" and never had been!

> The message got through to John Mayer or Ted Skopinski, who relayed it to Al Hamer or Alton Mayo, who delivered it to the person it was intended for. "Get the girl to check the numbers," said the astronaut. If she says the numbers are good, he told them, I'm ready to go." (216)

In the Notes section of *Hidden Figures*, no source is given for this passage. There is no record that John Mayer, Ted Skopinski, Al Hamer, Alton Mayo, or John Glenn ever mentioned it. Three pages later comes this paragraph:

> When the phone call came in, forty-three-year-old Katherine was at her desk in Building 1244. She overheard the call with the engineer who picked it up, just as she had overhead the conversation between Dorothy Vaughan and the engineer in 1953, the request that sent her to the Flight Research Division two weeks after she arrived at Langley. She knew she was the "girl" being discussed in the phone conversation. She had seen the astronauts around the building, of course; they had spent many hours in the hangar downstairs, preparing for their missions on a simulation machine called the Procedures Trainer. Some of their briefings with the brainy fellas had happened upstairs, though she was not invited to attend those meetings. *That John Glenn didn't know, or didn't remember, her name didn't matter*; what did matter, as far as he was concerned—as far as she was concerned—was that she was the right person for the job. (219–20) [Italics added]

So John Glenn didn't know or couldn't remember "the girl's" name. John Mayer's group had several "girls." They, not KJ, had been participating in the trajectory calculations and flight documentation for the previous Mercury flights. They were the ones that Glenn would have possibly interacted with and could trust or not trust. But somehow, the "girl" over in Henry Pearson's shop, a thousand miles away, who hadn't done any work related to Project Mercury for two years, had stood out in Glenn's mind.

It gets worse! Glenn is working side by side every day with Deke Slayton, who ran the astronaut office, Walt Williams, leader of manned spaceflight operations, Chris Kraft, who would be flight director for Glenn's flight, and Tec Roberts who would be the flight dynamics officer, the one directly responsible for monitoring the launch, orbit and reentry. Glenn worked near John Mayer with his team of trajectory engineers, programmers, and math aides who had prepared repeated mission plans that worked perfectly. Glenn had been a disciplined, by-the-books Marine lieutenant colonel who respected the chain of command. We're supposed to believe that John Glenn said to any of these close colleagues, "I'm worried about the trajectory, and I don't trust you or your people to do the job right, even though you've done it right for every mission, so get hold of Ted Skopinski's math aide in Langley to check the numbers." Really?

Finally, the John Glenn story doesn't make sense because KJ COULD NOT have checked the numbers—it was literally impossible. The flight plan for MA-6 used computations far beyond the capabilities of a Friden calculator. Possibly, the simple launch azimuth angle could have been "checked" using the Skopinski/Johnson report, but why? It was essentially the same used on MA-4 and MA-5!

The John Glenn story is unverifiable and frankly unbelievable to the engineers who actually computed and checked and double-checked all the calculations, including for all the missions leading up to MA-6.

> At the Cape, a behind-the-scenes camera captured extensive footage of the astronaut as he walked through each station of the trip he had already taken hundreds of times in NASA simulators. (217)

Perhaps "dozens," not "hundreds." More hyperbole!

> In the final section of the Azimuth Angle research report she completed in 1959, Katherine had marched through the calculations for two different sample orbits, one following an eastward launch and the other a *westward, as Glenn was scheduled to fly*. (220) [Italics added]

What?! ALL flights from the Cape were EASTWARD! It never crossed anyone's mind to launch westward. Putting aside the performance penalties of launching westward (going against the earth's rotation), NASA didn't want a launch vehicle to explode over Orlando! Ted and KJ did include a theoretical westward launch in their paper—but it was purely theoretical. That the author wrote "westward, as Glenn was scheduled to fly" and an editor (if any existed) didn't notice is more evidence that they were in over their heads on the subject of space flights.

> Once she had worked out the math for the test scenarios on her calculating machine, substituting the hypothetical numbers for variables in the system of equations, the Mission Planning and Analysis Division within the Space Task Group took her math and programmed it into their IBM 704. (220)

WRONG. The programming of the math for the trajectories took place in the STG by John Shoosmith when he began building the CO3E trajectory program months before the Skopinski/Johnson paper had been completed! (And she got the name wrong. It was the Mission Analysis Branch. There was no MPAD until late 1963.)

> The work she had done in 1959, double-checking the IBM's numbers, was a dress rehearsal—a simulation, like the ones John Glenn had been carrying out—for the task that would be laid on her desk on the defining day of her career. (220)

The work in 1959 wasn't a dress rehearsal for anything. One more time: The Skopinski/Johnson calculations had not been used to program CO3E and that program had been used for the MR series flights as well as MA-4 and MA-5, and had been repeatedly checked against actual flight data, not with two-body Friden hand checks.

> When the Space Task Group upgraded their IBM 704 to the more powerful IBM 7090s, the trajectory equations were programmed into those machines, along with all the other programs required to guide and control the rocket and capsule and compare the vital signs of the flight at every moment to the flight plan programmed into the computer. (221)

It's a trivial point compared to the fabricated role assigned to the Skopinski/Johnson equations, but it was not possible during Mercury to load the entire flight plan from launch to entry into the ground computers and compare the plan to the actual flight as it was unfolding. In fact, it's still impossible except in very limited cases. (And it should be "MSC upgraded…" The transition from the IBM 704 to the 7090 computers occurred after the move to Houston.)

> If the rocket misfired and was on track to inject the capsule into an incorrect orbit, the flight controllers could decide to abort the mission—a go–no/go moment—automatically detaching the capsule from its rocket and sending it off into the sea in a mangled suborbital trajectory. (221)

A misleading description of aborting a mission. It wasn't a single-option "go-no/go moment" to detach the spacecraft from the launch vehicle. The flight controllers, in coordination with the Cape Range Safety Officer, prepared a variety of abort modes for different situations, one of which involved an immediate splashdown and others that initiated procedures with the malfunctioning launch vehicle that gave the best chance to recover the crew.

> Once the capsule climbed through the launch window, separated from the Atlas, and settled into a successful orbit, it established communication links with the ground stations. (221)

A spacecraft doesn't "climb through the launch window." "Launch window" refers to the period of time (usually several hours) when conditions are right for launch. "Launch trajectory'" or "ascent trajectory" are the correct terms. These are not arcane terms or concepts. More evidence of the author's and editor's ignorance of basic terminology.

> The capsule's signal bounced from one tracking station to the next as the orbit proceeded, like a very fast and expensive game of telephone, constantly communicating its position and status. (221)

Not "constantly." Sometimes there was close to an hour between consecutive station contacts.

> The output included a constantly updated time for retrofire, the moment when the capsule's rockets had to be fired in order to initiate its descent back to Earth. (222)

Again, nowhere near "constantly." Even "frequently" would be misleading.

> She worked through every minute of what was programmed to be a three-orbit mission, coming up with numbers for eleven different output variables, each computed to eight significant digits. It took a day and a half of watching the tiny digits pile up: eye-numbing, disorienting work. At the end of the task, every number in the stack of papers she produced matched the computer's output; the computer's wit matched hers. (223)

A ridiculous claim. A computerized time-integrated set of orbital elements being continuously perturbed due to gravitational effects of the oblate earth alone, much less the altitude variation in density and a tumbling capsule experiencing atmospheric drag effects, could not possibly be duplicated on a Friden calculator, let alone to eight decimal places. And, by the way, she couldn't have planned on three orbits for her calculations. The plan was for up to seven orbits if the mission was proceeding nominally.

> Each year, NASA made progress toward converting the theoretical concepts of how to reach the Moon into operating practice. Each mission closed the distance, brought the fruit closer to their grasp. But this last step, with its complicated dance between the Moon and the lander and the waiting command module, was the most complicated. Katherine Johnson had given her best to her part of the grand puzzle, of that she was sure. The day was soon coming when the world would see if her best, if the brainy fellas' best, if NASA's best, was good enough. (234)

The author is referring to post-Mercury here, 1963–69. As an MPAD rendezvous analyst and mission planner throughout that Gemini-Apollo period, I can vouch to my certain knowledge that Hamer and KJ never provided ANY data for EITHER of those programs' orbit mechanics plans or analyses. Possibly something in the safety realm? But I doubt it. In fact, only a few veterans of the STG like Hal Beck, John Mayer, Ted Skopinski, Chris Kraft and Carl Huss, had ever heard of Hamer and KJ.

> Katherine knew better than anyone that if the trajectory of the parked service module was even slightly off, when the astronauts ended their lunar exploration and piloted their space buggy back up from the Moon's surface, the two vehicles might not meet up. (233)

Not true on two counts: 1) Whatever KJ or her colleagues at Langley did regarding Apollo, it never was used in any actual mission planning or execution. That was all done at MSC by the Flight Operations Directorate, MPAD and their contractors. 2) Slight deviations in the orbits of either the Command and Service Module or the Lunar Module—the "space buggy"—were easily handled in the nominal rendezvous scheme. The Flight Operations Directorate and MPAD had contingency measures in place for fairly large deviations in the orbits or in the Lunar Module's liftoff time, and, furthermore, had extensive plans for rescuing the Lunar Module with the Command and Service Module for a variety of Lunar Module failure modes after its ascent to low lunar orbit. Thankfully, we never had to use any—but we were prepared!

> The command service module was the astronauts' bus—their only bus—back to Earth: the lander would ferry the astronauts to the waiting service module and then be discarded. If the two vehicles' orbits didn't coincide, the two in the lander would be stranded forever in the vacuum of space. (233)

The author is referring to the LM, which was in a relatively low lunar orbit of roughly 60 n.mi. apolune and 10 n. mi. perilune. As noted above, there were extensive rescue plans for the Lunar Module crew, even if the Lunar Module had to be left in that "low orbit." And the Lunar Module would have crashed into the lunar surface after a few weeks, or months at most, due to the moon's non-homogeneous gravitational effects.

> Still, the broadcasters knew—everyone in the audience knew—that even with twenty-six manned flights under NASA's belt, this was different, and they struggled to come up with superlatives to capture the moment. (239)

6 Mercury + 10 Gemini + 4 Apollo = 20 manned flights under NASA's belt before Apollo 11, not 26. There were another seven missions from Apollo 11 through Apollo 17, giving a grand total of 27 manned missions when Apollo ended.

> The actual landing had been the one part of the mission that had been impossible to rehearse prior to the actual moment—and the most dangerous. (244)

Rehearse had been impossible?? Uninformed. All the Apollo crews that landed had rehearsed the landing exhaustively, both in actual training flight using the Lunar Landing Research Vehicle and its successor, the Lunar Landing Training Vehicle, which achieved a high level of fidelity in mimicking the flying characteristics of the Lunar Module; and in joint mission simulations with the crew in the Lunar Module simulator and the flight controllers in the MCC. These simulations have been well-publicized in numerous books about Apollo by the astronauts and Apollo historians.

> The Apollo 11 astronauts had given the mission only a middling chance of success: though Neil Armstrong handicapped the odds of returning to Earth safely at 90 percent, he thought they had only a 50-50 chance of landing on the Moon on the first go. Katherine Johnson had confidence: she knew her numbers were right, and she assumed that everyone else—Marge Hannah and the fellas there in her office, Mary Jackson and Thomas Byrdsong and Jim Williams, everyone from the top of NASA to the bottom—had given their all to the mission. (244-45)

Just what were KJ's numbers? The author is extremely vague on that, as she must be. The mission planners at MSC, and I was one of them, know that KJ never contributed ANY actual "numbers" or other analyses or data that was used in flying ANY Apollo mission.

> She watched the men in the dust of the Moon and thought of the orbiting command service module, out of view of the camera, circling the Moon every ninety minutes. (245)

The Command and Service Module circled the moon closer to every 120 minutes! A 90-minute lunar orbit is NOT possible—a vehicle would hit the surface!

> Each leg carried the specter of the unknown; only after their landing matched the numbers of her equations, when they had been plucked from the ocean and cosseted in the waiting navy ship, would she be able to exhale. (245–46)

"Matched the numbers of her equations"?? The implication is that KJ's "numbers" were used on Apollo missions, apparently including not only the return-to-earth trajectory but also the extremely precise flight path angle required by the high-energy entry associated with a lunar mission! <u>All such plans and their associated parameters</u>

were done in real time by the Mission Planning and Flight Control teams at the MCC at Houston. No one else made any such calculations. None were even made, to our knowledge, by Langley in pre-mission! (These inferred claims are actually more egregious than KJ's alleged number checks for Glenn's flight. During the early Mercury flights, Langley was still at least peripherally involved. By Apollo, Langley had been completely uninvolved in mission planning for years.)

> [Planning for the course to Mars] was built on the same idea as the rendezvous in the orbits of Earth and the Moon, where a spaceship doing a flyby of one planet used the planet's gravity to slingshot it on ahead to the next. (246)

The gravity-assist planetary flyby technique has absolutely no relationship to rendezvous maneuvers and techniques in earth or lunar orbits.

> She considers her work on the lunar rendezvous, prescribing the precise time at which the lunar lander needed to leave the Moon's surface in order to coincide and dock with the orbiting command service module, to be her greatest contribution to the space program. (248)

Those of us in the Rendezvous Analysis Branch of MPAD and the Flight Crew Operations personnel in the Flight Operations Directorate who did that work never heard of her or her "precise time" of the Lunar Module's liftoff. More specifically, J. David Alexander, our leading lunar rendezvous expert, who had come to MSC in 1963, was among those at MSC and MPAD in the early days who had never heard of Katherine Johnson or her calculations.

What did KJ have in mind? Perhaps she had once calculated the lunar liftoff time based on a simple Hohmann transfer, which is the most basic mathematical expression of an orbital maneuver over 180 degrees of travel to transfer a spacecraft between two circular orbits of different altitudes around a central body, and, maybe, she thought this was the method used for the Apollo missions. But the Lunar Module's catchup, intermediate and closing maneuver profiles were prepared based on our Gemini earth-orbit rendezvous totally successful experiences, and they were calculated using co-elliptic orbits and complex, non-180-degree Lambert solutions.

By the way, the Lunar Module liftoff time did not have to be particularly precise. Likewise, the Lunar Module's exact surface position could be off by a few miles—the intermediate catchup phasing and height maneuvers were flexible to account for those initial errors and any resulting ascent dispersions.

It's also worth mentioning that Langley had once played an important role in lunar-orbit rendezvous—it was a Langley engineer, John Houbolt, who played a big role in selling the lunar-orbit concept to MSC and Marshall Space Flight Center. But even Houbolt's numbers were very approximate. Neither he nor any of his colleagues at

Langley had a part in the years of detailed analyses and planning of any of the Apollo rendezvous.

> And in 1967, Johnson and Hamer coauthored the first of a series of reports describing a method for using visible stars to navigate a course without a guidance computer and ensure the space vehicle's safe return to Earth. This was the method that was available to the stranded astronauts aboard Apollo 13. (248)

In the epilogue to the digital edition of *Hidden Figures*, the author acknowledges that debris from the damaged Command and Service Module made it impossible for the crew of Apollo 13 to use this technique. Al Hamer and KJ did in fact calculate some star charts, but they weren't used by MSC. Flight Activity Officer Bob Nute, working with the US Geographical Agency in St. Louis, prepared them for Apollo 13 to aid in the standard backup navigation procedures. According to Nute and other Flight Activity Officers in Gemini and Apollo, no Langley star charts were ever used.

> Katherine Johnson worked with Al Hamer and John Young for the rest of her years at Langley, developing aspects of the space shuttle and the Earth resources satellite programs. (249)

I and then Hal Beck directed the Flight Planning (Integration) Branch in MPAD. It integrated and planned the entire Operational Trajectory Plan and associated data products for every shuttle flight flown, beginning in 1981 and ending in 1990. We cannot recall ANY plan data or flight procedures ever coming from Langley!

Postscript
Synthesis and Appraisal

Charles Murray

The main purpose of this postscript is to pull together the complementary information in the Beck and Young commentaries and source it, making it as easy as possible for future writers on manned spaceflight to check out this document's empirical assertions and to assess the historicity of the assertions in *Hidden Figures*.[1]

I suggest those future writers treat the Beck and Young commentaries as they treat the transcripts of NASA's oral history interviews: primary source material provided by people who were first-hand participants and experts on the topics they discuss. Almost all their unsourced observations are "falsifiable"—that is, evidence exists that can be used to confirm or refute them. In some cases, other aerospace engineers can judge their technical accuracy. Observations about the information known by MSC independently of work done by Katherine Johnson (KJ) can be checked by going to the NASA archives.[2]

The postscript also includes material that I found while copy-editing the commentaries and examining the sources and methods in *Hidden Figures.* That additional material is sourced, along with citations of background material pertaining to the Beck and Young commentaries.

The subsidiary purpose of the postscript is to offer a frankly speculative answer to a natural question: If the claims for Katherine Johnson's contributions to the manned spaceflight program are without foundation, how did the story get started and how did it achieve such wide acceptance?

My credentials for taking on these roles are modest compared to Beck's and Young's, but I do know a lot about the first decade of manned spaceflight from researching *Apollo*. I have spent the rest of my career writing social science analyses that are judged by criteria of factual accuracy and supporting evidence similar to those used to judge historical works. It is also relevant that I have published a dozen nonfiction books with commercial publishers and am familiar with the process.

• • • • •

I begin by emphasizing something that is easily lost in the technicalities: *Hidden Figures* is not the story of early US manned spaceflight. Rather, it is the story of Langley Aeronautical Laboratory's unprecedented employment of African Americans in highly technical occupations in the 1940s and 1950s at a federal research center in a Virginia town where the Civil War was still described as "the late war," told through the experiences of African American women who had grown up in the segregated South and had successful careers at Langley. Margot Shetterly's narrative is absorbing. Nothing in this document criticizes the heart of the book.

It is also important to recall Hal Beck's description of Katherine Johnson (KJ) during the nearly two years he worked at the desk next to hers. She was not just a competent computer, but, in his word, a "whiz" who showed him the ropes. As someone who struggled to calculate correlation coefficients on a Monroe calculator in the late 1960s, I cannot imagine how Langley's human computers managed to process the far more complex mathematics of aeronautical engineering on their Friden calculators. KJ was a standout even among them. Her career at Langley spanned four decades. She was a coauthor on twenty-one publications or conference papers. KJ was an appropriate choice to represent the unsung women, black and white alike—yes, hidden figures—who were the human computers at Langley in the era before electronic computers.

All the material in this document has been about arcane issues involving the relatively small number of pages in *Hidden Figures* that deal with KJ's role in the manned spaceflight program. The concern prompting this document is that *Hidden Figures*' account of KJ's role has been accepted as accurate by just about everyone except the people who were part of the Mercury, Gemini, and Apollo Programs, and has already worked its way into the historical record.

If you have gotten this far, you know that Hal Beck and Ken Young make a case that KJ's alleged role in manned spaceflight is not just exaggerated but largely fictional. I doubt that many who worked at the Manned Spacecraft Center (MSC) during the 1960s disagree with them. Neither do I. Here's why:

Matching the Claims for KJ's Impact Against the Evidence for Them

"Fictional" is a much stronger word than "inaccurate" or "exaggerated," and requires correspondingly systematic justification. I proceed by identifying the claims made for KJ's contributions and then compare each separately to the evidence for and against it.

I limit the relevant sources to the text of *Hidden Figures* and NASA's biography of KJ posted online and given in full in Appendix A.[3] I limit the topics to ones involving manned spaceflight through the Apollo missions, ignoring claims about KJ's work on the space shuttle and other post-Apollo activities.

The claims for KJ's role involve four topics, with somewhat different positions taken by *Hidden Figures* and NASA's biography of KJ.

1. *KJ's role in the Mercury manned missions.* The strong position is taken in *Hidden Figures*, which describes KJ's role as instrumental in developing the launch, orbital, and entry trajectories during the Mercury program. The NASA biography is more circumspect, noting her co-authorship of a paper with Ted Skopinski about orbital mechanics but attributing the

stories about the Shepard and Glenn flights to KJ's interviews without explicitly endorsing their accuracy.

2. *KJ's role in plotting the trajectory for Apollo 11.* The NASA biography takes the explicit position: "After Project Mercury, she joined the Space Mechanics Division, and calculated the trajectory for the 1969 Apollo 11 flight to the Moon…." *Hidden Figures* implies that she did so without an explicit statement.
3. *KJ's role in rendezvous for the lunar missions.* Both sources treat the claim that KJ calculated the liftoff times for the Lunar Module as factual.
4. KJ's *role in Apollo 13.* The NASA website takes the strong position, saying that her navigational contributions were used to return the Apollo 13 crew safely to earth. The Epilogue in the digital edition of *Hidden Figures* as of 2023 claims that KJ did pioneering navigational work but acknowledges that it was not used on Apollo 13.

In trying to make sense of the accounts in *Hidden Figures* and the NASA biography compared to the commentaries of Beck and Young, it is useful to start with four important and incontestable facts:

1. KJ was exclusively an employee of first Langley Aeronautical Laboratory and then the Langley Research Center from beginning to end. She was never employed by the NASA organizations (STG and then MSC) that had exclusive responsibility for planning and conducting manned spaceflight.
2. Neither *Hidden Figures* nor the NASA biography claims that KJ communicated personally with anyone in the manned spaceflight program except immediately after engineers from her division at Langley transferred to the STG.[4] Nor would it have been easy to do so. STG staff were on the East Side at Langley, separated by Langley airfield's runways from the main buildings on the West Side where KJ worked. Once the STG became MSC, located in Houston, personal contact was effectively foreclosed.
3. Neither *Hidden Figures* nor the NASA biography cites Langley publications that might be relevant to the claims of KJ's impact even though she was not listed as a coauthor.
4. Neither *Hidden Figures* nor the NASA biography presents independent corroboration of any of the claims for KJ's importance to manned spaceflight in the form of discussions of KJ's work in NASA administrative or technical documents, oral history interviews of supervisors or colleagues, or newspaper or magazine articles that quote named NACA or NASA sources.

Given these four facts, *KJ's influence on the manned spaceflight program can be based only on published technical work with her name on it.* The only other route is to contest what I have called incontestable facts. The endnote discusses the possibilities.[5] Absent that, people who want to assess whether KJ had any impact on manned spaceflight have a simple task: Examine all the publications for which KJ was a coauthor for evidence that those publications provided important information to the STG or MSC that they did not already possess. A complete list of these publications is given in Appendix D with embedded links to URLs for downloading them from the NASA Technical Reports Server.[6]

1. KJ's role in the Mercury manned missions.

The relevant publication is Theodore H. Skopinski and Katherine G. Johnson, TN D-233, "Determination of azimuth angle at burnout for placing a satellite over a selected earth position." The paper was completed in November 1959 and published in September 1960. "TN" stands for "technical note."

Hidden Figures treats TN D-233 as a seminal document, essential for the STG and subsequently MSC to carry out the Mercury flights. Here is the key passage:

> In the final section of the Azimuth Angle research report she completed in 1959, Katherine had marched through the calculations for two different sample orbits, one following an eastward launch and the other a westward, as Glenn was scheduled to fly [*sic*]. *Once she had worked out the math for the test scenarios on her calculating machine, substituting the hypothetical numbers for variables in the system of equations, the Mission Planning and Analysis Division* [sic] *within the Space Task Group took her math and programmed it into their IBM 704.*[7][Italics added]

I have italicized the crucial sentence. It is demonstrably wrong.

Hal Beck's statement, consistent with Ken Young's commentary, is explicit:

> For Mercury mission planning, the launch trajectories for both the Mercury-Redstone and the Mercury-Atlas launch vehicles were generated using CO3E, the three-degrees-of-freedom program developed within the Mission Analysis Branch by John Shoosmith. The launch vehicle simulations in CO3E were from sources external to the STG; specifically, the Army Ballistic Missile Agency was the source for the Mercury-Redstone launch vehicle simulation and the Space Technologies Laboratory in Los Angeles was the source of the Mercury-Atlas launch vehicle simulation.
>
> The retro and entry trajectory data were also computed using CO3E. The trajectory data included the retro maneuver simulation and the impact target parameters. The entry trajectory data included aerodynamic forces, the spacecraft heating profile, and the trajectory event timeline. The

> programming of CO3E was underway months before even a draft of TN D-233 was available. Nothing in TN D-233 was used in CO3E's subsequent iterations.

This statement is falsifiable through documentation in NASA's archives, but the essence is not subject to dispute: TN D-233 calculated trajectories using the two-body model whereas all the Mercury flights used the mathematics of three-degrees-of-freedom trajectory integration.

"Two-body" mathematics expresses the relative motion of two bodies in space, ignoring external forces. Forest Ray Moulton had developed the basic mathematics for solving two-body problems in *An Introduction to Celestial Mechanics* published in 1902 and updated in 1914. As of 1959, some of the Germans who worked at Redstone Arsenal under Werner von Braun had been calculating two-body trajectories since 1936.

American aeronautical engineers had been calculating trajectories since the first Redstone missile launch in 1953 and had already moved beyond two-body mathematics to trajectory integration—the process of integrating the equations of motion of a spacecraft to determine its position and velocity as a function of time. The integration process takes into account specified external forces or perturbations acting on the spacecraft. In the Mission Analysis Branch, John Shoosmith was preparing a high-fidelity trajectory simulation in CO3E for the Mercury missions months before KJ had completed the draft of TN D-233.

What did TN D-233 mean for the manned spaceflight program? For Hal Beck and Ken Young, the algorithms that were later published in TN D-233 were useful for a parametric study of site-selection for Project Mercury's tracking network. Their understanding was that Skopinski had developed the algorithms specifically for that purpose. The analyses related to the site selection process had nothing to do with the launch, orbital, and entry trajectories in mission planning for the Mercury flights.

Ted Skopinski, the lead author, was a long-time colleague of both Beck and Young. He never even mentioned TN D-233 or its algorithms to either of them. *KJ is the only person at Langley or with the MSC who is known to have thought that TN D-233 was even relevant, let alone essential, to the software used for the Mercury missions*.[8]

Corroborating Evidence

The transcript of a 1998 interview of Stanley H. Cohn for the Johnson Space Center Oral History Project provides testimony that independently reinforces the positions of Beck and Young.[9]

Cohn was among the Canadians who worked for AVRO who were recruited for the STG in late 1958. Cohn's job was to lead mathematical support for the STG. He recalled that upon arriving at Langley in early 1959, "We were given a thick manual that had been prepared by the Research Center on how to calculate planetary orbits. So it was reliving some old astronomy that I never thought would have practical application."

His official duties "…meant calculating a large number of operational trajectories and orbits for all of the upcoming missions and dealing with problems of an uncertainty in the accuracy of the data and where the capsule might land."

He discusses visits in 1959 to Redstone Arsenal and to Convair, which was building the Atlas launch vehicle, to study their approaches to computing trajectories.

He says of the STG's first computer, "It was a Bendix G15, also an early computer, but it looked like a good one and we had lots of calculations to do and Langley wasn't able to keep up with the smaller kinds of problems for us."

All these statements are about activities completed or underway before even a draft of TN D-233 was available.

Claim 2. KJ's role in plotting the trajectory for Apollo 11.

Hidden Figures is elusive on this point. Shetterly writes of Apollo 11 that "…only after their landing matched the numbers of her equations… would she [KJ] be able to exhale," (245-46) which implied that "her equations" were being used for the mission. The NASA biography is explicit: "After Project Mercury, she joined the Space Mechanics Division, and calculated the trajectory for the 1969 Apollo 11 flight to the Moon…." (see Appendix A). KJ herself explicitly claimed that she helped compute the trajectory. Here is the transcript of an interview she gave to *The Historymakers* website on February 6, 2012:

> Interviewer: "Did you have—was there anything that you did that you think you were the most proud of doing?"
>
> Katherine Johnson: Oh, I was most proud of the trajectory to the moon because we had to compute the launch conditions from here, and then trace it around until it got to the moon, and you had to know how far the moon had moved in that length of time… And then when it came time for them to leave the moon, you had to reverse the calculations and say that he left moon, and he leaves over here. Then back at earth, you got to say how far has the earth rotated, you know. So you had, those were very

> intricate calculations, and I was very concerned about them. And we were right on target, of course, no problem, no problem.

This recollection has no documentary basis in any technical note, report, conference proceeding, or other product of Langley Research Center. It is not mentioned in "NASA Langley Research Center's Contributions to the Apollo Program" posted by Langley on its website. Her description of the process of calculating trajectories for a lunar mission bears no resemblance to the actual process, described by Beck in his commentary:

> The design and generation of the translunar trajectory for a lunar landing mission is not a simple operation. Translunar trajectory targeting and design requires a precisely accurate, high-fidelity simulation of the earth-moon system, the launch vehicle, spacecraft systems, and trajectory targeting techniques for all maneuvers.
>
> The lunar landing mission simulation for the Apollo lunar landings was developed within MPAD at Houston. The simulation was called the Apollo Reference Mission Program and was under development for years. It was used to generate the official reference missions for all Apollo lunar missions. *None* of the preparation for Apollo 11 (or any Apollo mission) was done at Langley, where Katherine continued to work.

Beck then gives the citation of the official reference mission for Apollo, available through the NASA history office.[10]

It is possible that KJ calculated basic numbers for a theoretical lunar mission for some unidentified Langley project. This is speculative; there is no evidence that she did even that. The central point is that it was impossible for anyone at Langley, with any level of technical expertise, to have calculated the complex set of trajectories actually used for Apollo 11.[11]

Claim 3. KJ's role in rendezvous for the lunar missions.

Here is *Hidden Figures*' statement of KJ's role:

> She considers her work on the lunar rendezvous, prescribing the precise time at which the lunar lander needed to leave the Moon's surface in order to coincide and dock with the orbiting command service module, to be her greatest contribution to the space program. (248)

The NASA biography is equally explicit:

> When asked to name her greatest contribution to space exploration, Johnson highlights the calculations that helped synchronize Project Apollo's Lunar Lander with the moon-orbiting Command and Service Module. (Appendix A)

No document with KJ's name on it has anything to do with rendezvous. One document involves lunar orbits: Harold A. Hamer and Katherine G. Johnson, TN D-5105

"Effect of gravitational-model selection on accuracy of lunar orbit determination from short data arcs," March 1969. The analysis in the paper was conducted on behalf of the unmanned Lunar Orbiter Missions that Langley led. Here is the opening of the summary of TN D-5105:

> The analysis was performed mainly to study the effects of varying the lunar gravitational model and data-arc length on the accuracy of orbit determination. A brief study was also made of the effect of model selection on accuracy of predicting pericynthion altitude. The results of the analysis are indicative of the accuracy of lunar orbit determination that may be expected with current gravitational models.

Simplifying the terminology, orbits for the Lunar Orbiter Missions were calculated using a lunar gravitational model developed by the Jet Propulsion Laboratory that employed 11 gravitational coefficients. Would the calculation of lunar orbits be significantly improved by using more than 11? The paper tested out models that used up to 21 coefficients using tracking data from Lunar Orbiter Missions I and III. The analysis concluded that the answer was "no." "Solving for a 21-coefficient representation for the lunar model did not yield better orbit-determination accuracy than solving for properly chosen 11-coefficient sets." (13) In fact, usably accurate results could be achieved using as few as four coefficients. TN D-5105 was a mathematically elegant demonstration that a potential way of improving the accuracy of calculating lunar orbits wasn't required. The Jet Propulsion Laboratory's existing model worked.

TN D-5105 had nothing to say about the time at which a lunar lander needed to lift off or anything else relevant to enabling successful lunar rendezvous. But neither did *Hidden Figures* have anything specific to say except for the passage quoted above asserting without evidence that KJ did those tasks plus a sentence in which Shetterly writes that "Katherine Johnson had confidence: she knew her numbers were right" (244). The latter could be interpreted as referring either to the lunar landing and liftoff or to the Apollo 11 mission as a whole. There is no information anywhere in *Hidden Figures* indicating what numbers those might have been or when they were calculated. Such numbers do not appear in any work for which she was a coauthor.

Claim 4. KJ's role in Apollo 13.

If the question is whether KJ's work had any effect on Apollo 13, the answer is consensually "no." All the claims for her contribution involve the creation of methods and materials for manual navigation using star sightings in cases when the automatic navigation equipment had failed. As Shetterly acknowledges in the Epilogue to the digital edition of *Hidden Figures*, debris from the ruptured Command and Service Module prevented the astronauts from using star sightings. The Apollo crew was forced to line up using the sun to execute the burn that put them on a return trajectory—the inspired idea of Ken Russell, the lead guidance officer in Mission Control.[12]

If the question is whether KJ did in fact participate in work that developed manual navigation procedures, the answer is "yes, but not the way that *Hidden Figures* portrays it." Here is the account in *Hidden Figures*:

> She and engineer Al Hamer collaborated on four reports between 1963 and 1969, some of them written to work out the all-important lunar orbits, others asking the question, What if? What if the computers went out? What if there was an electrical failure on board the spacecraft and the astronauts needed to navigate back home by the stars, like the mariners of a simpler age?" (234)

The passage is misleading in two respects. First, as discussed above, the one that discussed lunar orbits had no effect on anything involving lunar missions. Second, dating the other three reports to "between 1963 and 1969" is incorrect. Only one of the three reports dealing with "What if" failures was published in that time period. The other two appeared after Apollo 13, in October 1970 and September 1971 (see Appendix D). The remaining technical note, "Midcourse-guidance procedure with single position fix obtained from onboard optical measurements (TN D-4246), published in 1967, did indeed present a manual method for navigating in the event of a failure in the automatic equipment, but….

If the question is whether MSC had independently developed backup procedures for manual navigation in the event of equipment failure, including star charts, the unsurprising answer is "yes." It was one of the most obvious requirements for crew training since the outset of the manned spaceflight program. Backup procedures for manual navigation had been developed and practiced by the astronauts since the Mercury missions and had become increasingly sophisticated during Apollo.[13]

Star charts, another accomplishment often attributed to KJ, were prepared for every mission. Each had to be tailored to the specific date of the mission. They were prepared with help from the US Geographical Agency in St. Louis in collaboration with the MSC Flight Activities Officer. Ken Young identifies Robert Nute as the Flight Activities Officer for Apollo 13.

To summarize: *None of the four claims for KJ's impact on manned spaceflight has a basis in the published record of KJ's work nor is any of them substantiated by independent sources*. All are based solely on KJ's accounts of them. In each case, evidence demonstrates that STG and later MSC already possessed the knowledge and already was doing the things that would have formed the substance of KJ's contributions if her claims were correct.

Hal Beck and Ken Young agree that KJ did have one documentable accomplishment related to manned spaceflight: providing algorithms that were helpful in selecting sites for Project Mercury's tracking network. That contribution is not mentioned in either *Hidden Figures* or the NASA biography.[14]

The John Glenn Request Mystery

Katherine Johnson's account of John Glenn asking "the girl" to "check the numbers" is probably the most famous story in *Hidden Figures* and the one that Mercury veterans think is the most unbelievable. And yet *whether the story is true has no effect on the assessment of KJ's impact on manned spaceflight*. If it is false, it wouldn't detract from other accomplishments KJ might have had. If it is true, all it means is that KJ checked the numbers that MSC was going to use anyway and found that they were okay. Either way, the flight of Friendship 7 and the history of manned spaceflight would be unaffected. The truth of the story is irrelevant to the purpose of this document, which is to set the historical record straight about KJ's role in manned spaceflight. The truth is also unknowable—the people who could have clarified it are no longer alive.

All we know for sure is that, whatever the real story may be, the account in *Hidden Figures* and the NASA biography cannot possibly be true as told. The Beck and Young commentaries lay out several reasons that the story doesn't make sense, but one of those goes beyond the personality of John Glenn, the close relationship of the astronauts to the MSC mission planners, the improbable timing of the request, or any other speculative reasons.[15] The John Glenn story as told in both *Hidden Figures* and the NASA biography rests on the false premise that it was *possible* to use a Friden calculator to do what Glenn allegedly asked her to do—run the same numbers through the same equations that had been programmed into the computers. Hal Beck said it most succinctly to Margot Shetterly in his email response to her questions: "<u>You don't validate a high-fidelity simulation using a two-body solution – but rather the other way around,</u> i.e., you use an accurate simulation to check your approximate solution to see how adequate the approximation is." (Appendix B. Underline in the original).

Beck's point has two collateral facts behind it:

- The computerized trajectory algorithms in the CO3E software had been used successfully on several previous flights, and Glenn had to know that.[16]
- The computerized algorithms in the CO3E software were too complex to be checked with a Friden calculator, and Glenn had to know that too.

Whatever KJ may have thought she was doing during that day and a half of calculations that *Hidden Figures* describes, she could not possibly have been checking the trajectory computation for errors.

The Decision Not to Incorporate Feedback from Experts in Manned Spaceflight

The most conspicuous theme in Ken Young's commentary is that *Hidden Figures* shows no sign of ever having been checked by an expert in manned spaceflight and not much evidence of editorial scrutiny of any kind. He cites many outright errors to make his point.[17]

That so many mistakes would be found in an early draft of *Hidden Figures* is to be expected. A non-engineer writing about aerospace engineering makes mistakes—an inevitability that Catherine Cox and I experienced as coauthors of *Apollo*. The solution is to have the draft vetted by experts from the earliest draft to the final one. Perhaps Shetterly obtained such review of the material about Langley's history, but it is certain that she did not seek review from experts in manned spaceflight until very late in the book's preparation and that the feedback she got was not used for the published version.

The Acknowledgments section in *Hidden Figures* mentions just two such experts: "Harold Beck and Jerry Woodfill entertained my technical questions regarding the months leading up to John Glenn's orbital flight and the crisis of Apollo 13, respectively." (269) Jerry Woodfill had been the lead engineer on the Apollo Spacecraft's Caution and Warning System. Shetterly interviewed Woodfill on April 26, 2016, the same week she emailed Hal Beck with questions. *Hidden Figures* contains no information about any feedback Woodfill provided about Apollo 13, and Woodfill cannot tell us himself because he died in 2022. However, he certainly knew, as did everyone involved with Apollo, that the crew of Apollo 13 aligned the spacecraft using the sun, not star charts, and that backup manual navigation procedures had been part of flight operations since the Mercury missions.

There was no shortage of experts who would have been able and willing to have vetted early drafts. When Shetterly started her research, many people in the original STG were still alive and living in the Houston area. Many were still alive when the final draft was ready in 2016. But she did not show draft to any of them.

Even Hal Beck did not see any actual text from the book. He responded to an email from Shetterly containing specific questions. Both her email and Beck's long, detailed response are given in full in Appendix B. His response pointed out numerous factual errors in her account. Either Shetterly decided not to incorporate any of that information into the published text or the publisher decided not to make changes that Shetterly requested.

Beck got the impression that there hadn't been enough time to incorporate his material before the book's publication date in September, just four months later. This is not consistent with my experience as an author of nonfiction books. Publishers today have much more flexibility in making changes than in the days when a late change meant resetting pages of type. To take just one example, the copy editing for the 832-page book

The Bell Curve that I coauthored with Richard J. Herrnstein generated at least a dozen substantial changes and many dozens of minor ones that were incorporated into the published book during the four months before publication. That's an extreme example of what a publisher can do, but less extreme late changes are commonplace. Publishers routinely accommodate late changes, especially when the changes correct errors of fact in a nonfiction book. Perhaps the author or the publisher (HarperCollins) will clarify why changes weren't made in the case of *Hidden Figures.*

How Did It All Get Started?

If the material in this document is correct and the edifice of achievements in manned spaceflight attributed to KJ is without foundation, it is natural to wonder how it all got started. Margot Shetterly didn't do it. As Hal Beck takes pains to point out, the Internet was filled with false information about KJ's achievements when Shetterly began her research for *Hidden Figures.*

When I agreed to post Hal Beck's and Ken Young's commentaries, I assumed that we were looking at KJ's war stories that got better and better as the years passed, as war stories tend to do. I now have another theory of the case. *I emphasize that it is speculative*; no more than my attempt to devise a plausible explanation that is consistent with the known facts.

At the center of my theory is KJ's conversion of the algorithms and analyses supporting the design of the Mercury Space Flight Network into a formal technical note, TN D-233, over a period from sometime in 1959 to its publication in September 1960. My hypothesis is that *what happened during the preparation of TN D-233 was truly momentous—not for manned spaceflight, but for Katherine Johnson.*

The hypothesis was prompted by Shetterly's description of that period. It deserves quotation at length:

> "Let me do it," Katherine said to Ted Skopinski…. Sitting in the emptier office, she plunged into the analysis…. She conferred with Ted Skopinski, consulted her textbooks, and did her own plotting. Over the months of 1959, the thirty-four-page end product took shape: twenty-two principal equations, nine error equations, two launch case studies, three reference texts (including Forest Ray Moulton's 1914 book), two tables with sample calculations, and three pages of charts….
>
> Katherine's and Ted Skopinski's Azimuth Angle report was the work of the Flight Research Group, the responsibility of their branch chief, Henry Pearson, and while Ted Skopinski was increasingly out of sight, spending time over at the STG offices on the East Side, the report, still unfinished, was not out of Henry Pearson's mind.

> "Katherine should finish the report," Skopinski said to Pearson. "She's done most of the work anyway." Henry Pearson had the reputation of being less than supportive of the advancement of female employees, but whether it was circumstance, the triumph of hard work over bias, or an incorrectly deserved reputation, it was on his watch that Katherine put the finishing touches on her first research report on the Friday after Thanksgiving 1959. "Determination of Azimuth Angle at Burnout for Placing a Satellite over a Selected earth Position" went through ten months of editorial meetings, analysis, recommendations, and revisions before publication in September 1960—the first report to come out of Langley's Aerospace Mechanics Division (or its predecessor, the Flight Research Division) by a female author. Stepped on, turned out, pulled apart, and subjected to every stress test the editorial committees could throw at it, Katherine's road map would help lead NASA to the day when the balance of the space race was tipped in favor of the United States. (190–92)

To Hal Beck and Ken Young, TN D-233 was just one of many parametric studies that went into the design of the Mercury tracking network. To John Shoosmith, it was irrelevant to his programming of the CO3E trajectory software. But TN D-233 was momentous in KJ's eyes, and understandably so. A woman in pre-feminism America, a black in the segregated South, KJ was no longer just a math aide, a junior partner, but the person responsible for completing the job. It was not just any job, but one demanding advanced mathematics and one that in her mind was essential to putting Americans into space. And she pulled it off, not only completing the paper but getting it through NACA's notoriously grueling review process. It was an impressive personal accomplishment, and she was right to see it that way. She was mistaken to think that TN D-233 was an important accomplishment in manned spaceflight—but she did, for reasons that cannot be reconstructed now.

TN D-233 did not slowly take on inflated importance to KJ as she reached old age. She saw it as vitally important from the beginning. Contemporaneous evidence can be found in two newspaper articles about KJ's role in the manned spacecraft program cited in *Hidden Figures*. The first is an article apparently published soon after Alan Shepard's flight in a major black newspaper of that era, the *New York Amsterdam News*. Shetterly quotes it in *Hidden Figures*:

> They [unnamed people at NASA] are loud in their praise of a young West Virginia-born Negro girl who has prepared a science paper that was not only a key document in the flight of Commander Shepard into outer space but which will actually become "THE" key document if and when we are able to put an astronaut into orbit.[18] [Capitalization in the original]

The source for the quote could not have been Henry Pearson, Ted Skopinski, or anyone in the Mission Analysis Branch. None of them saw TN D-233 that way. Someone else from Langley described the paper as "'THE' key document." Whether the source was KJ herself or a confidant to whom she had described TN D-233, the article is consistent with someone who was convinced of her work's importance.

The second contemporaneous source is an article in a black weekly newspaper, the *Pittsburgh Courier*, printed under the headline "Lady Mathematician Played Key Role in the Glenn Space Flight" and with the subhead "The Story of Katherine Johnson." The date was March 10, 1962, 18 days after the flight of MA-6. In *Hidden Figures*, Shetterly summarized the section of the article dealing with KJ's role in MA-6 this way:

> The newspaper recounted the lady mathematician's background and accomplishments with pride, detailing the report that sent Glenn's rocket cone whizzing through the sky. Katherine accepted the recognition graciously: all in a day's work. (225)

Here is the full text of the section that Shetterly summarized:

> Mrs. Johnson is credited with helping to devise the highly complex tracking system which enables scientist to predict...within TWO miles, the location of Lieut. Col. Glenn's rocket cone upon his return to earth after three orbits around the world.
>
> She is co-author … September, 1960 … of the NASA Technical Note, D-233. Subject: "Determination of Azimuth Angle at Burnout for Placing a Satellite Over a Selected Earth Position."
>
> BROKEN DOWN into plain, understandable English, it means that Mrs. Johnson co-authored the paper which tracked the rocket cone upon its re-entry into the earth's atmosphere.
>
> Mrs. Johnson is listed as a top security mathematician at Langley Field, Va., where she lives with her talented daughter and Artillery captain husband.
>
> It is said that Mrs. Johnson spent nearly six months making the calculations which eventually produced the formula mentioned above. [Ellipses and capitalization in the original]

It is the only known contemporaneous account of KJ's role in MA-6. According to her autobiography, the reporter called her to request an interview, which she granted.[19] The article, errors and all, is notable for what it *doesn't* include. It does not mention the day and a half she had spent doing calculations three days before the launch. It does not mention that John Glenn had requested that she check the numbers.

Why didn't KJ mention John Glenn to the *Pittsburgh Courier* reporter (it is highly unlikely the newspaper would have omitted such a newsworthy tidbit)? I am speculating that she was still entirely focused on TN D-233 as her contribution and *at that time* did not think that Glenn had asked her to "check the numbers." Rather, someone in Henry Pearson's branch had asked KJ to see how a two-body solution using parameters taken from the Mission Analysis Branch's official mission planning document for MA-6 would compare with the solution of the high-fidelity trajectory parameters. She worked intensively for a day and a half, just as *Hidden Figures* reports, and came up with results that corresponded closely to the more accurate ones.

This is the "most likely scenario" that Hal Beck describes in his commentary. He notes that it was not uncommon during the Mercury project for engineers to compare two-body results (which could be calculated using a Friden) to the results of high-fidelity simulations. The purpose wasn't to validate the high-fidelity simulations, but to assess the accuracy of two-body theoretical solutions against real-world data. In this scenario, the identification of John Glenn as the source of the request was a later invention.

Two subsequent published interviews of KJ that I have been able to find lend support to this scenario. In a newspaper interview in 1977, KJ is quoted saying "it was our group" that calculated the trajectory for Al Shepard's flight and TN D-233 is cited by name.[20] The article, written four years after the end of the Apollo missions when KJ was 58 years old, does not mention the John Glenn request or any post-Mercury contributions to manned spaceflight.

A 2008 interview of KJ, conducted by a staff member at Langley on the occasion of KJ's ninetieth birthday, reports that she calculated the trajectory of Alan Shepard's sub-orbital flight and implies that she did so for MA-6. In this interview KJ does mention checking the numbers for MA-6:

> By the time John Glenn was to go up to orbit the earth, NASA had gone to computers. "You could do much more, much faster on computer," Johnson says. "But when they went to computers, they called over and said, 'tell her to check and see if the computer trajectory they had calculated was correct.' So I checked it and it was correct."

Her wording is consistent with a request to see how a how a two-body solution would match up with the software's results. There's still no mention that John Glenn made the request and no mention of any post-Mercury contributions to manned spaceflight.

We thus know with a high level of confidence that by the time of Alan Shepard's flight KJ was already convinced that the work she was doing on TN D-233 was vital to the success of the Mercury flights and that she continued to believe it. By the time of the 2008 interview, she had long since received credit for that accomplishment in the press, beginning with the articles in *The New York Amsterdam News* and *The Pittsburgh Courier* cited in *Hidden Figures*. "Over time," as Shetterly writes, "articles began to appear in the peninsula's *Daily Press* and in the *Richmond Times-Dispatch*, and Katherine's name became a necessary entry in any book detailing the accomplishments of black or female (or black female) scientists and engineers."[21] (249)

Where and when were the claims about the calculating trajectory of Apollo 11, the liftoff of the Lunar Module for Apollo 11, and the role in rescuing the crew of Apollo 13 added to the Katherine Johnson story? As far as I have been able to discover, only after 2008. In 2011, when KJ was 92, she told a television interviewer that the call to check the numbers came directly from John Glenn.[22] In 2012, she said she was most proud having calculated the trajectory for Apollo 11. Margot Shetterly's four interviews with KJ occurred from December 2010 to September 2013, during which she also took credit for calculating the liftoff of the Lunar Module on Apollo 11 and providing support to Apollo 13.

The evolution in KJ's accounts over the years leads to another hypothesis, also speculative but falsifiable: *KJ's alleged post-Mercury contributions to manned spaceflight are late inventions after she turned 90.* It is falsifiable because my inventory of interviews of KJ is surely incomplete. More remain to be found, either online, in the NASA archives, or among KJ's own collection of articles written about her, presumably still in the hands of her family.[23] And if the John Glenn story had become widespread many years before John Glenn died in 2016, surely someone asked him about it. I could not find evidence that anyone did, but it may exist.[24] The discovery of earlier references to the post-Mercury claims could disprove my hypothesis and tell us more about the evolution of the story. A good working strategy for anyone who wants to dig deeper would be to determine the nature of the evidence that led President Obama to award KJ the Presidential Medal of Freedom in 2015.

As for why none of the people who were in a position to know the truth spoke up, we already have answers. As Ken Young said in his initial email to me in December 2016, the MSC veterans in Houston had been trying to decide what to do since the Presidential Medal of Freedom had been announced in 2015. They finally decided to keep quiet. One of the reasons was that KJ was alive and in her late nineties. No one wanted to spoil it for her—a very human and appropriate reason to keep quiet. Another reason was that discrediting the claims made for KJ's contributions would attract accusations of racism and sexism that could easily get national publicity—an unpleasant prospect.

For reporters, the Katherine Johnson story was "too good to check," as journalists like to say, and they did not check it. After all, by the time *Hidden Figures* was published, the Administrator of NASA was on record saying of KJ that "…she's one of the greatest minds ever to grace our agency or our country" and that "Katherine's legacy is a big part of the reason that my fellow astronauts and I were able to get to space." NASA's Deputy Administrator had said "She literally wrote the textbook on rocket science" and "At NASA, we are proud to stand on Katherine Johnson's shoulders." What's to check?

The story was also insulated from challenge by a peculiarity that has interfered with dispassionate discussions of black accomplishments for the last half century. I think Shetterly's observations on this score are pertinent:

> That even Katherine Johnson's remarkable achievements can't quite match some of the myths that have grown up around her is a sign of the strength of the vacuum caused by the long absence of African Americans from mainstream history. For too long, history has imposed a binary condition on its black citizens: either nameless or renowned, menial or exceptional, passive recipients of the forces of history or superheroes who acquire mythic status not just because of their deeds but because of their scarcity. The power of the history of NASA's black computers is that even the Firsts weren't the Onlies. (250)

At the beginning, Katherine Johnson and her fellow computers were close to being the Onlies. They were soon joined by thousands of others who surmounted the barriers facing African Americans and women in the 1950s, but KJ had been one of those at the tip of the spear.

Did Katherine Johnson deserve all the accolades she received? If measured by her contributions to manned spaceflight, no. But in terms of the inspiration she imparted to young people, especially minorities, to follow their dreams of a career in science or technology, yes. In terms of the example she set—her dedication to her work, perseverance, ability, and gracious personality, all of which she exhibited in the face of difficulties that are hard to comprehend seventy years later—the answer is again "yes."

Her story and that of her fellow black female computers is part of the history of an epic American accomplishment, the triumph of Civil Rights Movement from World War II to 1964. It needed to be told, and I, along with Hal Beck and Ken Young, are glad that Margot Shetterly told it. We just hope that the fictional elements of Katherine Johnson's career do not permanently misinform the history of another epic American accomplishment, the triumph of manned spaceflight from 1958 to 1972.

Appendix A

NASA Biography of Katherine Johnson

The following is a verbatim reproduction of the principal biography of Katherine Johnson posted on the NASA website. It was last updated on August 6, 2017. Katherine Johnson subsequently died on February 24, 2020. Underlined text relates to the discussion in this document. The biography is unattributed. It shares wording with a shorter biography elsewhere on the NASA website that is attributed to Margot Shetterly.

Katherine Coleman Goble Johnson (1918–) is an African-American mathematician who made valuable contributions to critical aeronautics and space programs of the NACA and NASA. Overcoming the constraints of segregation and gender bias, she progressed from mathematical tasks, such as computing experimental flight and ground-test data using a mechanical Frieden calculator for the NACA, to the application of spacecraft trajectories and spacecraft control calculations for NASA. Her life, 33-year career, and contributions are discussed in the best-selling 2016 book "Hidden Figures" by Margot Lee Shetterly and the Academy-Award nominated motion picture of the same name. Her story has become widely known and is a stimulus for the interests of young people in science, technology, engineering, and mathematics (STEM) activities across the nation.

Katherine Johnson was born in White Sulphur Springs, West Virginia, and quickly advanced through high school because of her intense interest and demonstrated expertise in mathematics. She attended West Virginia State College where she graduated with highest honors in 1937 with a bachelor of science degree in mathematics and French, and took a job teaching at a black public school in Virginia. When West Virginia decided to quietly integrate its graduate schools in 1939, she was one of the first three African-Americans selected to desegregate West Virginia State College. After the first session, however, she decided to leave school and start a family with her husband James F. Goble. When their three daughters got older, she returned to teaching.

She learned that the NACA Langley Aeronautical Laboratory was hiring a group of African-American mathematicians with teaching experience to perform mathematical calculations that transformed raw data that had been obtained using instrumentation into final engineering parameters. She began her career at Langley in the segregated West Computing section in the summer of 1953 under the supervision of fellow West Virginian Dorothy Vaughan. The pool of women mathematicians performing data reduction calculations were known as "computers." Just two weeks into Katherine's tenure in the office, Dorothy Vaughan assigned her to a project in the Maneuver Loads Branch of the

Flight Research Division, where her position soon became permanent. She spent the next four years analyzing data from flight tests, and worked on the investigation of a plane crash caused by an encounter with wake turbulence. She was assertive, asking to be included in editorial meetings (where no women had gone before). It was during this time that her husband James died of cancer in December 1956.

The launch of the Soviet satellite Sputnik in October 1957 changed aerospace history—and Katherine Johnson's life. In 1957, Johnson provided some of the descriptive material for a 1958 document "Notes on Space Technology," a compendium of a series of 1958 lectures given to staff members by engineers in the Flight Research Division and the Pilotless Aircraft Research Division (PARD). Engineers from those groups formed the core of the STG, NASA's first official foray into space research, and Katherine, who had worked with many of them since coming to Langley, "came along with the program" as the NACA became NASA later that year. While not a member of the STG, she developed an interest in calculating trajectories of spacecraft and satellites.

She experienced a highlight of her life when she married her second husband, Colonel James A. Johnson, in 1959.

In 1960, Johnson and engineer Ted Skopinski coauthored a report entitled "Determination of Azimuth Angle at Burnout for Placing a Satellite Over a Selected Earth Position," using basic "two-body" equations for an orbital spaceflight in which the landing position of the spacecraft is specified. Such equations could be solved using a Frieden [*sic*] calculator. It was the first time a woman in the Division had received credit as an author of a research report. She also was coauthor of a report in 1962 on the orbital behavior of the first communications satellite, Echo I (a 100-ft-diameter inflatable balloon). That effort was a pioneering contribution because it was the first satellite whose orbit was affected by solar pressure.

When interviewed for the book "Hidden Figures," Johnson discussed her activities in Project Mercury and the Apollo missions. She recalled doing trajectory analysis for Alan Shepard's May 1961 Mercury mission, America's first human suborbital spaceflight. She also remembered how, in 1962, as NASA prepared for the orbital mission of John Glenn, the complexity of the orbital flight had required the construction of a worldwide communications network, linking tracking stations around the world to IBM computers in Washington, DC, Cape Canaveral, and Bermuda. The network provided tracking and communications of Glenn's spacecraft from blast off to splashdown. According to Johnson, Glenn asked engineers to "get the girl"—Katherine Johnson—to run the same numbers through the same equations that had been programmed into the computers, but by hand, on her desktop mechanical calculating machine. "If she says they're good," she remembers the astronaut saying, "then I'm ready to go." Glenn's flight was a success, and marked a turning point in the competition between the United States and the Soviet Union in space.

After Project Mercury, she joined the Space Mechanics Division, and calculated the trajectory for the 1969 Apollo 11 flight to the Moon, and computed backup navigational charts for astronauts in case of electronic failures. In 1970, Apollo 13's aborted mission to the Moon made use of her earlier research on backup parameters and charts, enabling the crew to safely return to Earth four days later. Later in her career, as a member of the Flight Dynamics and Control Division, she worked on the Space Shuttle program, the Earth Resources Satellite, and plans for a mission to Mars. Her final projects before retirement included analysis of guidance and control of large flexible structures.

When asked to name her greatest contribution to space exploration, Johnson highlights the calculations that helped synchronize Project Apollo's Lunar Lander with the moon-orbiting Command and Service Module. She authored or coauthored 13 research reports during her career.

Katherine Johnson retired in 1986. Her legacy includes an extraordinary social impact as a pioneer in space science and computing that may be seen both from the honors she has received and the number of times her story is presented as a role model to aspiring young people. Since 1979 (before she retired from NASA), Johnson's biography has had a place in lists of African-Americans in science and technology. In 2015, President Barack Obama awarded Johnson the Presidential Medal of Freedom, citing her as a pioneering example of African-American women in science, technology, engineering, and mathematics (STEM). In 2016, NASA dedicated a new Katherine G. Johnson Computational Research Facility at the Langley Research Center. Dr. Johnson was included in the list of "BBC 100 Women", a list of 100 inspiring and influential women from around the globe. Her awards include the Astronomical Society of the Pacific's Arthur B.C. Walker II Award (2016); a NASA Silver Snoopy award (2016); an Honorary Doctorate of Science from Old Dominion University (2010); an Honorary Doctor of Science by the Capitol College, Laurel, Maryland (2010); the West Virginia State College Outstanding Alumnus of the Year (1999); and an Honorary Doctor of Laws, from SUNY Farmingdale (1998).

Katherine Johnson and her husband reside in Newport News, Virginia, and have two daughters: Joylette, and Katherine. A third daughter, Constance is deceased. Katherine Johnson is now 98 years old.

Last Updated: Aug 6, 2017

Editor: Eric Vitug

Appendix B

Email Exchange Between Margot Shetterly and Hal Beck

Hal Beck writes that "Serious dialog between Margot Shetterly and me began in April of 2016. She came upon my name knowing that I was a co-worker of Katherine in the early days of mission planning for Mercury flights. Margot sent questions related to Katherine's role in the mission planning and I provided a factual response to her questions." The most important exchange between Shetterly and Beck is shown in full and unedited below. All italics, underlines, quotation marks, underlines, and errata are in the original.

From: Margot Lee Shetterly
Sent: Sunday, May 1, 2016
To: Harold Beck
Subject: MA-6 calculations

Hal-- One of Katherine Johnson's big moments came when she coauthored the "Azimuth Angle" report with Ted Skopinski, and another when she was asked to check the output of the computer prior to John Glenn's orbital flight MA-6.

I was able to track down the "Calculated Preflight Trajectory Data for Mercury-Atlas Mission 6"-- this is Project Mercury Working paper 217. Most of the document pages are number runs (attaching here the first 40 pages so you can see what it looks like).

Here are my assumptions:
(1) This trajectory data is based at least in part on the orbital equations set out in Katherine and Skopinski's Azimuth angle report;
(2) This data was calculated using one of the Goddard IBM 7090s, programmed with the trajectory equations from the report, and any other equations that other groups were working on that would have been necessary for guidance and tracking during the flight (although in the original 1959 report, it appears they used an IBM 704 to crunch the numbers).
(3) Input data for the "test" is set out on page 1-1 in Section 1.1, "Description of Test", and those are the input parameters used to generate the computer run in this working paper.
(4) When Katherine Johnson was asked to check the numbers, she was given the same input and equations that were being fed into the computer, and required to calculate all numbers by hand, using her Friden (or Monroe or Marchant).

(5) Katherine's check of MA-6 was at the tail end of her involvement with MA-6, after that, most of the mission planning became the full-time job of the Houston-based math aides (Mary Shep Burton, Katherine Osgood et al)

Here are my questions:

(1) When would Katherine Johnson have performed this check?

--How close to launch?

--What input parameters was she given to do the check, and who would they have come from?

(2) She remembers being in the office (1244, upstairs from the Hangar which I think had just been renamed the Aero Space Mechanics Division) and a phone call came in from John Glenn to one of the engineers who was there in the office at the time (You? William Aiken? John Mayer? I believe this was before the group had moved to Houston, though three years after the Space Task Group had set up offices on the East side). She remembers overhearing a conversation, the gist of which was that the engineer in question was being asked to "get the girl to do it"—i.e., ask your (human) computer to double check the output that has come out of the IBM, as a part of the preflight checklist. One thing I have read in many of the oral histories is that the computers were not completely reliable in the beginning. I've also read in more than one place that the astronauts were particularly distrustful of computers (there was an interesting section on this in the book Digital Apollo).

(3) Katherine remembers it having taken her "a day and a half", to do the hand check of the computer run, does that square with what you remember?

Margot

From: Harold Beck
To: Margot Shetterly
Subject: Re MA-6 calculations

The following notes are in specific response to the email that you sent yesterday. There are nine major items addressing: the attachment, Working Paper 217; a response to your assumptions; and answers to your questions.

(1) Relative to the attachment, Working Paper 217: "Working Paper 217, Project Mercury Calculated Preflight Trajectory Data for Mercury-Atlas Mission 6 (MA-6)", was part of the preflight documentation that was generated in support of MA-6. It was part of a typical "reference trajectory" documenting the "final" results of the mission planning and analysis that was done in the months prior to the mission launch date (for MA-6 the launch date was Feb 20, 1962). Such a set of documentation was done to support each flight. It was used to define the nominal mission plan, including the launch window, orbit inclination and altitude, orbit lighting conditions, the crew timeline, maneuver sequences, spacecraft attitude timeline, etc. The nominal profile was also used for all sorts of contingency planning (abort planning and alternate mission planning). The official "reference trajectory" was also used to configure the world-wide network for a specific mission, e.g., ship placement, etc. Within NASA it was the official and primary roadmap for mission operations. The reference trajectory, related analyses and trajectory studies were the official responsibility of the Mission Analysis Branch (John Mayer's group) of the Space Task Group; the data was of course under strict configuration control. This particular document was the responsibility of Clay Hicks, who was project engineer for MA-6 (note the signature page). The document was approved for distribution by Robert Gilruth (for this particular document Paul Purser signed for Gilruth).

The software program used in the "precise" trajectory simulation for the MA-6 trajectory was called CO3E which was developed in 1959 in the Mission Analysis Branch by John Shoosmith. The following is a description of the CO3E development and utilization.

The development of Mercury Orbital Mechanics Tools – CO3E (history of development)

An early software project within the Branch was the development of a detailed mission simulation program to be used in planning all of the essential flight information, including the ground track, lighting, tracking coverage, spacecraft attitude profile, landing site locations, retrofire time/attitude, etc.

In April '59, John Shoosmith joined the Space Task Group and was assigned to the Mathematical Analysis Section of the Mission Analysis Branch. John was one of the exceptional engineers who had come down to Langley from A.V. Roe, Canada.

John began the development of a primary tool to be used by the trajectory and mission planning analysts. He is credited with the early development of the C03E program that was used for Mercury mission planning and analysis. The CO3E software was initially developed on the IBM 704 at Langley, but the program would be used for years within MPAD. Soon after the start of the CO3E project, John was promoted to a management position and Wilber Boykin took over the program and later revised it for the IBM 7094 computer.

> *Sidenote of interest: For those interested from an historical perspective, here's a reference for documentation for the CO3E program: "Revised Three Degree of Freedom Particle Trajectory Program CO3E for the IBM 7094 Computer - NASA Technical Note TN D-3463; Boykin, Wilbur R. - NASA. The document was published in 1966 and is available on Amazon.com*

Parallel to the CO3E program development, Charlie Allen was developing orbital analysis programs for the Bendix G-15. These programs were used in trajectory studies to calculate parameters for elliptic orbits, e.g., altitude, velocity, flight path angle, apogee radius, perigee radius, and other parameters. The programs were useful in validating results from the primary C03E trajectory program.

After developing the computer programs required to support Project Mercury, the Branch was ready for the mission planning tasks. As time went on the C03E program had to be augmented with a number of output-parameter options. Mercury spacecraft characteristics were incorporated to provide the capability to calculate accurate ground track data, tracking acquisition data, retrofire times/attitude, landing area data, and other ancillary information. The program was later used by the Mission Planning and Analysis Division of MSC for many years. It was primary for Mercury and was used extensively for Gemini.

The very important math aide group under the most capable management of Mary Shep Burton was responsible for the preparation of the reference mission documentation and the quality control of the related planning products. Mary Shep's team included Shirley Hunt (Hinson) and Cathy Osgood. (They later moved to Houston and worked in the organization for many years). All three frequently went to the Cape and supported the realtime operations for the Mercury flights and generated the post-flight reports. The post-flight reports were a measure of mission success, documenting any off-nominal system performance, etc.

(2) Relative to assumption 1: *This trajectory data is based at least in part on the orbital equations set out in Katherine and Skopinski's Azimuth angle report.*

Response: As stated earlier, the primary trajectory tool, the workhorse for the Branch, was the CO3E program developed initially by John Shoosmith. CO3E was a high-fidelity trajectory program that integrated the spacecraft equations of motion taking into account external perturbations. CO3E was used for all the Mercury flights.

The Skopinski algorithm was a two-body orbital mechanics solution. The equations were "closed form" and did not require an integration engine and were readily solved using the Friden calculator. It's important to note that the two-body solution was most frequently used in orbit mechanics studies. It was most convenient for parametric analyses – and required little computer resources. The two-body solution provided reasonably accurate results and was easily calculated. When the Mission Analysis Branch moved to the STG, we had an IBM 1620 and two-body studies were a natural for the smaller computer. The CO3E required the IBM 704/7094. We also used the Friden calculators extensively for quick-look studies.

(3) Relative to assumption 2: *This data was calculated using one of the Goddard IBM 7090s, programmed with the trajectory equations from the report, and any other equations that other groups were working on that would have been necessary for guidance and tracking during the flight (although in the original 1959 report, it appears they used an IBM 704 to crunch the numbers).*

Response: The CO3E software was initially developed at Langley within the STG on the IBM 704 by a Branch engineer, John Shoosmith. It was later installed on the IBM 7094. The branch engineers used CO3E extensively for mission planning and analyses, especially for higher fidelity simulations. The Goddard computers were used in near-real-time for orbit determination. During Mercury, the Control Center at the Cape did not have computers. During the missions, all support calculations were done using the Goddard computer resources.

(4) Relative to assumption 3. *Input data for the "test" is set out on page 1-1 in Section 1.1, "Description of Test", and those are the input parameters used to generate the computer run in this working paper.*

Response: Section 1.1 provides the orbit insertion state vector - or the cut-off conditions from the Mercury-Atlas launch trajectory. One could take this state vector and propagate it and obtain the resulting orbit. The fidelity of the propagation would depend upon the software simulation – it could be a two-body sim or a more accurate numerical integration simulation.

(5) Relative to assumption 4: *When Katherine Johnson was asked to check the numbers, she was given the same input and equations that were being fed into the computer, and required to calculate all numbers by hand, using her Friden (or Monroe or Marchant).*

Response: as stated above, Section 1.1 provides the orbit insertion state vector or the cut-off conditions from the Mercury-Atlas 6 launch trajectory. Katherine was probably given the input (insertion parameters) from the working paper, but she did not use the equations of motion in the CO3E software spec ("*given the same input and equations*"). She used the input conditions for the two-body simulation to calculate the basic orbit parameters. The results would be approximate but would be reasonably close especially if you are only propagating for a few orbits. Sidenote: In general, <u>you don't validate a high-fidelity simulation using a two-body solution – but rather the other way around,</u> i.e., you use an accurate simulation to check your approximate solution to see how adequate the approximation is.

(6) Relative to assumption 5. *Katherine's check of MA-6 was at the tail end of her involvement with MA-6, after that, most of the mission planning became the full-time job of the Houston-based math aides (Mary Shep Burton, Osgood et al)*

Response: The launch date for MA-6 was Feb 20, 1962 - a couple of months prior to the Branch move to Houston. The detailed planning for MA-6 was done in the months prior to the launch date (late in '61 and early '62). Clay Hicks was the project engineer and was responsible for the generation of the nominal trajectory and for all the ancillary data. Again, CO3E was the primary software tool. The work was certainly not an individual's responsibility but rather a team activity. Carl Huss, John Mayer, Ted Skopinski, and other engineers were all involved - and indeed the math aide group played a most important role in data reduction, ancillary data generation, data validation and documentation. The Mission Analysis Branch worked the problem from the conceptual profile definition up through real-time support at the Cape. Branch members (including Mayer and Huss) spent a great deal of time at the Cape supporting the mission, real-time and with postflight analyses and postflight documentation.

Question: what is meant by *"… the tail end of her involvement with MA-6"?*

(7) Relative to Question 1: *When would Katherine Johnson have performed this check?*

--How close to launch?

--What input parameters was she given to do the check, and who would they have come from? Answer: If she used the input insertion vector from the Working Paper 217 (and I guess that this is a good assumption) then she must have done the calculations no sooner than early January 1962. The working paper was published On December 28, 1961.The launch date for MA-6 was Feb 20, 1962. A possible scenario: someone in Pearson's organization probably had access to the classified document, Working Paper 217, and provided Katherine with the input parameters for use in her calculations. Perhaps someone like Bill Aiken or Henry Pearson just asked her to do the computations as a matter of interest (to see how well the two-body solution would compare??)

(8) Relative to question 2: "…. *and a phone call came in from John Glenn to one of the engineers who was there in the office at the time (You? William Aiken? John Mayer? …. she remembers overhearing a conversation, the gist of which was that the engineer in question was being asked to "get the girl to do it"-- i.e., ask your (human) computer to double check the output that has come out of the IBM…. "*

Answer: Question 2 is really a challenge!

Part 1: I'm not sure who got the phone call. I assume it was around early January '62. Skopinski, Mayer and I had previously transferred to the STG, and we were preparing for the move to Houston in a couple of months. The call could have come in to Henry Pearson or perhaps Bill Aiken – I'm not sure though when Bill left Pearson's organization to take a position in Washington?

Part 2. I doubt very seriously that John Glenn called Pearson and asked for validation of the official NASA Operational Flight Profile. If for any reason he had a question or an issue, he would naturally have gone to Gilruth, Kraft, John Mayer, Carl Huss, or Clay Hicks. The Space Task Group was a relatively small team at that time – and everyone worked together with absolute open communication. John Glenn's office was down the hall from Mayer's office. Within the Space Task Group there was a formal process for the validation of software and the data used in operations – there was a high confidence level – even in the early days.

In my years working with the flight crew, I have only experienced unbounded trust by the flight crew guys in the competence of the mission control team and in the flight planners. *Perhaps* (?) some of the astronauts later on did question computers but if they did so, they were definitely in the wrong business. The success of all the missions was absolutely tied to computer capability and software validation – and that is true to this day! Just look at the complexity and reliability of the onboard computers! With what I know about John Glenn it seems totally out of character to make such a call. I think the most likely scenario is the one mentioned above: someone in Pearson's organization probably had access to the classified document, Working Paper 217, and provided Katherine with the input parameters for use in her two-body calculations. Perhaps someone like Bill Aiken or Henry Pearson just asked her to do the computations as a matter of interest (to see how well the two-body solution would compare??). But without a doubt, the two-body solution **would never** be used to validate a high-fidelity trajectory simulation! [in those days, we did often compare two-body results to fidelity simulations in software assessments]

(9) Relative to question 3. *Katherine remembers it having taken her "a day and a half", to do the hand check of the computer run, does that square with what you remember?*

Answer: That's certainly a reasonable amount of time for the task. Katherine was quite familiar with the two-body equations. Setting up the spreadsheet in preparation for the computation was a bit time consuming but Katherine was one of the best when it came to the Friden operation. She could outperform almost everyone in the organization. (Incidentally, one of her top competitors was Bill Aiken, one of the senior engineers – he was a whiz indeed). The number of calculations of course depends upon the chosen "time steps" or granularity of the solution. It should be noted that the Friden computation is not actually a "hand check of the computer run". There are levels of accuracy in trajectory propagation: the two-body is one level (and represents an approximation) and the numerical integration is the second level. But indeed, there is no true mathematical model to predict the "actual" position of a spacecraft – there are uncertainties in upper atmosphere densities, physical characteristics of the spacecraft, etc. That opens the door to a discussion on orbit determination, earth modelling, etc.—for another day.

Appendix C

Timeline for the Creation of the Manned Spaceflight Program

Hal Beck assembled the following timeline of major events within NASA during the early phase of Space Program development that may help put events described in Hidden Figures into perspective.

NASA's Predecessor. Though today's National Aeronautics and Space Administration (NASA) was established in 1958, its historical roots reach back much farther. In 1915, twelve years after the Wright Brothers' flight, the US Congress created the National Advisory Committee for Aeronautics (for some reason, always called "the NACA" with the letters spelled out, never pronounced "naka," while NASA is always pronounced "nasa"). At that time, the airplane was in its infancy and much had to be done to transform it into a practical and versatile vehicle. The NACA's mission was "to supervise and direct the scientific study of the problems of flight with a view to their practical solution." The NACA would perform basic research that provided practical solutions to serious problems facing the aircraft industry and the military air services.

The authors of the NACA's charter had left open the possibility of an independent laboratory. The NACA pointed out in its first Annual Report for 1915 that civil aviation research would be in order when the Great War ended. And, even before the war's conclusion, plans were afoot to acquire a laboratory. The best option seemed to be collaboration in the development of a new US Army airfield, across the river from Norfolk, Virginia. The military facility was named after Samuel Pierpont Langley, former secretary of the Smithsonian; the NACA facility was named the Langley Memorial Aeronautical Laboratory. Much later, it became Langley Research Center.

NASA is formally established. On July 29 1958, President Eisenhower signed the National Aeronautics and Space Act of 1958 establishing the National Aeronautics and Space Administration (NASA). NASA was formally opened for business on October 1, 1958. NACA was no more.

First open discussion of a manned ballistic satellite. Only three days after Eisenhower signed the Space Act, Robert Gilruth presented preliminary plans for a manned ballistic satellite; his remarks amounted to the first open discussion of the technical aspects of what was soon to become Project Mercury.

The Beginning of the Space Task Group. In the fall of 1958, after the establishment of NASA and after the acceptance of the preliminary plan for Project Mercury, Gilruth began to put together a more formal organization for the implementation of the manned satellite project that became the STG. The STG would be initially be located at Langley, but STG management would report directly to Abe Silverstein in Washington, the head of all space projects at headquarters.

The transfer of key Langley personnel to the STG. In November 1958, Gilruth arranged for t[1]he transfer of 35 Langley personnel to the STG. These people formed the nucleus of the new manned space program (Mercury), supplemented by ten additional engineers from the Lewis Research Center at Cleveland. The STG was located on the east side of Langley Field; Langley Research facilities were primarily located on the west side.

Langley Research Center support to the STG. Besides absorbing the loss of talented personnel to the Space Task Group, which exploded in size from the original nucleus of 35 people in November 1958 to about 350 people in July 1959 (over half of whom came from Langley), Langley also took on much of the direct responsibility for getting Mercury off the ground.

Growth of the STG: Over the next few years, the STG grew and quickly became fully operational. Project Mercury became official on November 26, 1958. Within a few months, NASA began to conduct the first test flights of the program; the first flight was Little Joe 1, launched from Wallops Island on August 21, 1959.

Schedule for Project Mercury. Between August of 1959 and May of 1963, Project Mercury launched twenty unmanned test flights and six manned missions. Of the six manned missions, two were Mercury-Redstone suborbital missions and four were Mercury-Atlas orbital missions. The manned missions spanned a two-year period from May 1961 until May of 1963. The first manned mission was MR-3 launched on May 5,1961. It was the first United States manned spaceflight, piloted by astronaut Alan Shepard. MR-3 was a 15-minute suborbital flight.

Mission planning for Project Mercury. All official mission planning for the Mercury missions was the sole responsibility of the Mission Analysis Branch of the Space Task Group. The branch chief was John Mayer. That organization later became the Mission Planning and Analysis Division (MPAD) within the Manned Spacecraft Center (MSC) at Houston.

Mission Control for the early Mercury missions. NASA's Mercury Control Center (MCC) at Cape Canaveral was the United States' first mission control center for both unmanned and manned space programs. Big Joe 1 launched on September 9, 1959, was the first Mercury mission controlled from the MCC. Later, all the Mercury-Redstone and Mercury-Atlas missions, the unmanned Gemini 1 and Gemini 2 missions, and the manned Gemini 3 mission were controlled from there. The first manned flight controlled from the MCC (Cape) was Alan Shepard’s flight, Mercury-Redstone 3, which lifted off on May 5, 1961.

The Manned Spacecraft Center is established in Houston. In May 1961, after President Kennedy set the national goal of landing men on the moon by the end of the decade, it became clear to the NASA administrator, James E. Webb, that Gilruth would need a larger organization and facilities to administer US manned space programs. A site selection team was formed to select a location for the new NASA facility. On September 19, 1961, Webb announced that the new NASA center would be built near Houston, Texas.

The Manned Spacecraft Center. On November 1, 1961, the Space Task Group was officially redesignated the Manned Spacecraft Center (MSC).

The original STG moves to Houston. In early 1962, the STG moved from Langley to Houston. The entire organization occupied temporary facilities while the MSC was being built at Clear Lake.

Appendix D

Publications Coauthored by Katherine G. Johnson from 1960 to 1972

Retrieved by Charles Murray from ntrs/nasa.gov, August 4, 2023.

Theodore H. Skopinski and Katherine G. Johnson. Determination of azimuth angle at burnout for placing a satellite over a selected earth position. TN D-233. September 1960

Gertrude C. Westrick and Katherine G Johnson. "The orbital behavior of the Echo I satellite and its rocket casing during the first 500 days. TN D-1366. 1962. June 1962. [Katherine Johnson is listed as the lead author on the NTRS website but as the second author on the PDF of the original paper]

White, Jack A., and Katherine G. Johnson. "Approximate solutions for slight-path angle of a reentry vehicle in the upper atmosphere." TN D-2379. July 1964. [Katherine Johnson is listed as the lead author on the NTRS website but as second author on the PDF of the original paper]

Blackshear, W.T. and Katherine G. Johnson. A study of solar-system geometric parameters for use as interplanetary navigation aids. TN D-2890. July 1965.

W.T. Blackshear, H.A. Hammer, K.G. Johnson. Midcourse-guidance procedure with single position fix obtained from onboard optical measurements. TN D-4246. December 1967.

Harold A. Hamer and Katherine G. Johnson. "Harold A. Hamer and Katherine G. Johnson. "Effect of gravitational-model selection on accuracy of lunar orbit determination from short data arcs." TN D-5105. March 1969.

Harold A. Hamer and Katherine G. Johnson. "An approach guidance method using a single onboard optical measurement." TN D-5963. October 1970.

Harold A. Hamer and Katherine G. Johnson. Midcourse and approach guidance requirements for simplified onboard control of moon to earth trajectories. TN D-6343. July 1971.

Harold A. Hamer and Katherine G. Johnson. Fixed-angle translunar guidance procedures using onboard optical measurements. TN D-6461. September 1971.

Harold A. Hamer and Katherine G. Johnson. Simplified interplanetary guidance procedures using onboard optical measurements. TN D-6752. May 1972.

Notes

[1] There is no point in critiquing the historicity of the film *Hidden Figures*. Several scenes are wholly invented and are not based on the book *Hidden Figures* or any other source.

[2] There is a list of Apollo reports available in the National Archives and Records Administration. I did not try to compile a roster of all the websites that contain such reports but finding them should not be a daunting task. The final flight plan for Apollo 11, all 340 pages of it, may be of special interest in view of KJ's claim that she calculated the trajectories for Apollo 11.

[3] I do not specifically reference KJ's autobiography, published in 2021, a year after KJ's death, under the title *My Remarkable Journey: A Memoir*. The title page lists Katherine Johnson as the author "with Joylette Hylick and Katherine Moore [KJ's two surviving daughters] and with Lisa Frazier Page." KJ's descriptions of her contributions are effectively the same as the descriptions in *Hidden Figures* with two exceptions. She claims to have assisted in the Apollo missions after Apollo 11 (without specifying how), and she disclaims any role in Apollo 13—not because debris prevented the astronauts from using her star charts, but because an astronaut (Leland Melvin) had told her that "the view of the stars from Earth is different from the eye level view in space. The stars are indistinguishable when you're flying among them, he told me. Thus the information in the study was not useful to them." (211) His wording must have been garbled in the retelling.

[4] Scenes in the film *Hidden Figures* depicting such personal contacts are inventions without foundation.

[5] Regarding the first "incontestable fact," it could be argued that just because the exclusive *responsibility* for planning and conducting the flights rested with the STG and then MSC doesn't necessarily mean that they did all the work, as testified by the tasks that the STG delegated to Research Division personnel in the earliest months of the STG's existence. Did STG or MSC ever do it again? If it did, such requests should be documentable by examining the Langley and MSC archives. But there's no point in such an investigation unless you think both Hal Beck and Ken Young are lying. Beck was working with John Mayer, Clay Hicks, Ted Skopinski, and the other founders of the STG's Mission Analysis Branch from the time he arrived at Langley in 1959. Ken Young joined in the middle of Mercury, just after Scott Carpenter's flight. Both men were present and at the center of mission planning for every subsequent Mercury, Gemini, and Apollo mission. Both state unequivocally that Langley in general and KJ specifically was completely uninvolved in mission planning for those flights. If you think they are being too adamant, you must understand how ridiculous it sounds to both Beck and Young that MPAD'S engineers, mathematicians, and programmers—collectively the world's unrivaled experts in planning manned spaceflights—were awaiting important information from a math aide at Langley so that they could get on with their work.

Contesting the second "incontestable fact," that KJ had no professional interactions with people outside Langley except during the first few months after the STG was organized, is going to be extremely difficult. Shetterly does not claim that any such interactions took place. KJ never visited the MSC in Houston. Hal Beck knew her well when he was at the desk next to her, but he didn't have any professional interactions with her after he joined the STG in early 1961. Ken Young had never heard of her until the events leading up to the award of the Presidential Medal of Freedom in 2015. The same was probably true of all the members of MPAD who had not been working at Langley when the STG was formed.

The third "incontestable fact," that neither *Hidden Figures* nor the NASA biography cites Langley publications that might be relevant to the claims of KJ's impact even though she was not a coauthor, is certainly true of the texts of *Hidden Figures* and the NASA biography. It also appears to be true based all the papers published by Langley from 1959–1972. My review of those included in the NASA Technical

Reports Server (ntrs.nasa.gov) did not identify any related to trajectories and lunar rendezvous for which KJ was not a coauthor.

Contesting the fourth "incontestable fact" has potential if one broadens the search for independent corroboration from the content of *Hidden Figures* and the NASA biography to the potential corroboration that might still be out there. My examination of *Hidden Figures* identified only three contemporaneous quotes about KJ's activities. Two of them are from the articles in black newspapers that I discuss in the concluding section of this postscript. Neither quotes any source by name. The third consists of a caption to a photograph of KJ: "Mathematician Mrs. Katherine Johnson is shown analyzing lunar trajectories and computing trip time to the moon and return to earth by a space vehicle, Aero-Space Mechanics Division, Langley Research Center, Langley Field, Virginia." Hers is one of six photographs portraying African Americans working in aerospace occupations. The page is in a US Department of Labor booklet commemorating the hundredth anniversary of the Emancipation Proclamation, *America Is for Everyone*, published in 1963. The booklet contains no text related to the six photographs; only the captions.

But my search was not even close to complete. The amount of media attention given to the Mercury, Gemini, and Apollo programs was enormous. I went through the potentially relevant oral history interviews online at the Johnson Space Center Oral History website without finding KJ mentioned, but its interviews began in 1997, after many of the most important people at Langley in the 1950s had died. NASA's Washington history office has transcripts of hundreds of other interviews conducted earlier (Catherine Cox and I accessed them during the research on *Apollo*). They include interviews with John Mayer, who headed mission planning from Mercury through Apollo, Bill Tindall, another key figure in mission planning from Mercury onward; and presumably all the other members of the STG, including one-time colleagues of KJ such as Carl Huss and Ted Skopinski. It is quite possible that interviews with Henry Pearson, KJ's boss, and other members of Langley's Maneuver Loads Branch are among them. Presumably those interviews are still at NASA's Washington or Johnson Space Center history offices, but I have not been able to identify online access to information about them.

[6] These searches yield 21 TNs and conference papers or proceedings over KJ's entire career. KJ was the second or third author on all these papers. For unknown reasons, the NTSR citations for two papers (TN D-1366 and TN D-2379) list KJ as lead author when she is shown as second author on the PDF of the original paper. If you want to replicate this list, note that you must conduct two searches to catch all KJ's citations, one for "Katherine G. Johnson" and another for "Johnson, K.G." Note also that the search on "Johnson, K.G." retrieves four citations for a Kenneth G. Johnson.

[7] Regarding the two uses of "[*sic*]": 1) As Ken Young noted, the underlined text. "…one following an eastward launch and the other a <u>westward, as Glenn was scheduled to fly</u>," is nonsensical. No launch in the history of Cape Canaveral has ever been westward, for obvious reasons. 2) At the time of MA-6, the Mission Planning and Analysis Division was still called the Mission Analysis Branch.

[8] As Hal Beck discussed, sources other than *Hidden Figures* have credited KJ with a role in calculating trajectories for the Apollo missions (see, for example, the statement by NASA Deputy Administrator Dava Newman that Beck quotes from the ceremony awarding KJ the Presidential Medal of Freedom). *Hidden Figures* does not make this claim directly and I know of no evidence that Newman or others could call upon to support it.

[9] For additional description of the work on trajectories, including programming trajectory equations before TN D-233 was even in draft form, see the Oral History interview with Claiborne Hicks.

[10] MSC Internal Note 69-FM-186. "Revision 1 to the Spacecraft Operational Trajectory for Mission G (Apollo 11), Volume I Operational Mission Profile, Launched July 16, 1969." Mission Planning and Analysis Division, Manned Spacecraft Center, Houston Texas.

[11] KJ was the coauthor of a TN that did deal with re-entry: Jack A. White and Katherine G. Johnson, "Approximate solutions for flight-path angle of a reentry vehicle in the upper atmosphere," TN D-2379, July 1964. As the title indicates, the paper was not intended to do more than produce approximations. The substance of the paper consisted of two equations derived from the equations of motion. "Solutions obtained from numerical integration of the nonlinear reentry equations are used to evaluate how well the derived equations approximate the true value of flight-path angle." To put it another way, the TN was evaluating how well its approximations worked by comparing them to more complex solutions, not proposing their approximations as a superior way to determine flight-path angles. This paper is not cited in *Hidden Figures.* It is also one of the two papers that list Katherine Johnson as lead author in the NTRS citation but as the second author in the published TN.

[12] Charles Murray and Catherine Bly Cox, *Apollo*, 2004 ed., p. 421.

[13] Such a procedure was used during Apollo 12 after the guidance system was knocked offline by lightning during the launch. Ibid., p. 370.

[14] Both *Hidden Figures* and the NASA biography discuss the need to develop a tracking network but neither connects it with the contribution of TN D-233.

[15] I have thought of a reason that "the story doesn't make sense" that I have not seen elsewhere. John Glenn was a United States Senator from Ohio for twenty-four years, winning four state-wide campaigns and making countless speeches to black audiences in Cleveland, Akron, Cincinnati, and other Ohio cities with large black populations. It doesn't make sense that a Democratic politician never mentioned to an audience of African American voters that he trusted a black woman's expertise on the most momentous day of his life.

[16] The film *Hidden Figures* provides a dramatic hook for Glenn's request: On the day of the launch, it is discovered that the computer calculations don't match the previous day's calculations. It is a Hollywood invention.

[17] Most of the factual errors that Ken Young identified were easily checked (e.g., that Glenn could not possibly have been scheduled for a westward launch; the date of Titov's flight). In one instance when Shetterly and Young disagreed, however, regarding the duration of a lunar orbit, Shetterly cited a source for her figure of 90 minutes—Richard Orloff, *Apollo by the Numbers: A Statistical Reference*, NASA SP-2000-4029. Ken Young scoffed at 90 minutes, saying that the time was "closer to every 120 minutes." I downloaded Orloff's book. His text does not have a general statement about the duration of lunar orbits, but for several of the lunar missions he provides the number of orbits and the precise elapsed time for those orbits, making it easy to calculate the mean lunar orbit time for that mission. They ranged from 117–120 minutes. Searches on "90 minutes" and "ninety minutes" for the Orloff book turned up only two results, neither of which applied to lunar orbits. Making things still more confusing, the text of *Hidden Figures* is "circling the Moon every ninety minutes." (245) The endnote associated with that number references the text as "circling the Moon every fifty-nine minutes." (314)

[18] The citation given in *Hidden Figures* (315) is James Hicks, "Negroes in Key Roles in US Race for Space: Four Tan Yanks on Firing Team," *New York Amsterdam News*, February 8, 1958. The date must be wrong. The quotation indicates that Shepard's flight had already occurred but that an orbital flight was still

uncertain, which would place the article sometime soon after May 5, 1961. I was unable to find the full article online.

[19] Katherine Johnson et al., *My Remarkable Journey: A Memoir*, 2021, p.166.

[20] Roberta Nicholls, "NASA Mathematician's Motto: Never Be Afraid to Go Higher," *Daily Press* (Newport News, VA), 27 February 1977.

[21] Shetterly does not give citations for these articles. I have been unable to locate them online.

[22] WHRO Public Media, "What Matters – Katherine Johnson: NASA Pioneer and 'Computer.'" 25 February 2011. www.youtube.com/watch?v=r8gJqKyIGhE&t=8s.

[23] The WHRO Public Media interview includes a pre-filmed biography with screen images of the 1977 *Daily Press* article, a photograph of KJ in a book that I could not identify, a photograph of a flag carried on a space shuttle mission and awarded to KJ, and a stack of handwritten fan letters to KJ dating back at least to the 1980s.

[24] A search of John Glenn interviews on YouTube did not yield any mentions of a problem with the trajectory of the flight nor any questions about a request that the computer program be checked by anyone. The most likely spot for such a question or such a comment by Glenn was a video interview conducted at the John Glenn School of Public Affairs on 1 February 2011. Other likely places to have found such material are NASA, "50th Anniversary: John Glenn and Friendship 7." 13 February 2012. and Retro Space HD, "Friendship 7 – John Glenn Orbital Flight Mercury-Atlas 6. 1962. By far the most exhaustive book-length treatment of MA-6 is Colin Burgess, *Friendship 7: The Epic Orbital Flight of John H. Glenn, Jr*., 2015. It contains no mention of problems with the trajectory software in the run-up to the flight.