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BILL TINDALL, MASTER INTEGRATOR OF GEMINI AND APOLLO

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Howard Wilson "Bill" Tindall Jr. is credited by many who worked in the Gemini and Apollo Programs with playing a key role in leading the development of flight techniques used to design and fly the Gemini and Apollo missions. Tindall had a talent for bringing order to complex projects and was a master at guiding emotional and contentious technical discussions in meetings toward a decision. Tindall communicated technical issues in a simple and understandable manner to personnel representing a variety of technical disciplines, including engineers, program managers, astronauts, scientists, and computer programmers. His Apollo era memos, called "Tindallgrams," are treasured by many Apollo veterans.

INTRODUCTION

Howard Wilson "Bill" Tindall Jr. was regarded so highly by Mission Control Flight Director Gene Kranz that he asked Tindall to sit next to him during the Apollo 11 lunar landing, even though Tindall did not have a job to perform in Mission Control.[1] Tindall was a hero to many engineers who worked on Mercury, Gemini, and Apollo. Hal Beck described him as "exceptional and unique in his contributions, and he was one of a kind." [2] Tindall was the first person named an honorary Mission Control Flight Director. NASA Gemini and Apollo veteran Ken Young described Bill Tindall as "The master integrator of the Gemini and Apollo Programs." Young also reports that Chris Kraft and Glynn Lunney claimed frequently that the contributions of Bill Tindall were key to a successful lunar landing program. Apollo 15 astronaut Dave Scott believed that Bill Tindall's efforts were crucial to improving the working relationships and communication within the Apollo Program after the AS-204 pad fire that killed Grissom, White, and Chaffee.[3]

Bill Tindall not only contributed to the innovation of new technology, but he was also a leader in determining the best way to use new technology. He worked on the flight operations side of human spaceflight, in a process referred to as "plan, train, fly." Tindall was a leader of people who innovated the processes, plans, software tools, flight rules, and procedures that governed how technology was used to fly the Mercury, Gemini, and Apollo missions.

A 1966 conference paper on Gemini mission planning co-authored by Bill Tindall identifies four steps in the mission planning process.[4] These are:

1) Mission design requirements that influence the design of the spacecraft and launch vehicle.

2) Design reference missions used to define spacecraft and launch vehicle requirements.

3) Nominal and contingency mission plans for each flight, along with mission logic and flight rules used in Mission Control.

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4) Real-time mission re-planning during a flight if circumstances require it.

Bill Tindall (Figure 1) was like the conductor of an orchestra who performed the work necessary to accomplish steps 1 through 4.

In the 1960s, as in the 21st century, effective leadership, teamwork, and communication is required to successfully develop and fly spacecraft. Spaceflight is not just about solving engineering problems, but about using people to solve engineering problems. This human aspect of spaceflight, either crewed or robotic, must be addressed for flight programs to succeed. What can be learned from Bill Tindall's leadership and communication style in regard to this vital aspect of space flight? Why was he so highly regarded?

Figure 1. Bill Tindall in 1965. NASA photograph.

This paper uses published sources, interview transcripts, the Tindallgrams, and comments provided to the author by Gemini and Apollo veterans to provide insight into Bill Tindall's leadership. This is one of a series of papers intended to document the contributions of key leaders and engineers to NASA's human flight program.[5-10]

EDUCATION AND U.S. NAVY SERVICE OF BILL TINDALL

Howard Wilson "Bill" Tindall, Jr. was born in 1925 in New York City and his family moved to Scituate, Massachusetts when he was a teenager. While in high school he played the French horn, and, in a small swing band, the trumpet. He was class president for two years, and was active in band, orchestra, glee club, dramatics, and yearbook. His mother observed that he had some ability in math but was not an outstanding student and thought that engineers only drove trains.[11]

After graduating from high school in 1943, he enlisted in the U.S. Navy. He attended Tufts in 1943 and 1944 in the Navy V-12 officer training program and earned two years' worth of college credits.[12] Tindall didn't like studying while other men were seeing action in the Pacific and wanted to flunk out and be sent to boot camp. His parents told him the Navy needed leaders, and so he stayed in the V-12 program.[11] He finally got to the Pacific and served as a radar officer and assistant engineer on the U.S. Navy destroyer USS Frank Knox. At this time Tindall became interested in mathematics and engineering. Tindall had trouble remembering dates in history, but he discovered that he could remember equations. After the war ended, he participated in the occupation of Japan.[12]

Upon leaving the Navy as an Ensign, Tindall decided to become an engineer. He attended Brown University on the GI Bill and covered four semesters of class work in a year and a half (February 1947 to September 1948). In 1948 he graduated with a degree in mechanical engineering.[12-17]

NACA AND EARLY WORK AT NASA

Before graduating from Brown University, Tindall was not sure what his next step would be. However, he found a brochure about the National Advisory Committee for Aeronautics (NACA)

Langley Research Center in the university placement office. Although Tindall had not expressed a previous interest in aeronautics, he applied for a job at Langley, and started there in October of 1948.[12] His early career at NACA, in the Instrument Research Division, focused on developing wind tunnel instrumentation for testing aircraft. While at Langley, he also was the stage manager for an amateur theater group where he met his future wife. Jane Smith's hobby was painting, so she served as the scene designer at the same theater. Jane and Bill married and had four children. Until Tindall became busy with space projects at Langley, he enjoyed sailing and wood working.[17]

In 1959, after NACA became NASA, Tindall worked on orbit determination for Project Echo, a passive communications satellite experiment. Like many other engineers at Langley, spaceflight was new to Tindall and he found himself learning two subjects he had not studied before; orbital mechanics and the development of computer software that could solve orbital mechanics problems. Whether engineers were right out of college or had a lot of experience, everyone had to figure out how to do spaceflight.[12-15, 17, 18]

PROJECT MERCURY

Bill Tindall moved from Project Echo to the Flight Operations Division of the Space Task Group on May 28, 1961.[19] Project Mercury required a world-wide communications network to handle voice, data, and commanding. Data from tracking stations spread across the globe was sent first to the Computing and Communications center at the NASA Goddard Space Flight Center in Maryland where computer processing of data and orbit determination was performed, and then sent electronically to the Mercury Control Center at Cape Canaveral. Leadership of Mercury computer programming was performed from NASA/Langley by Bill Tindall and J. J. Donegan of the Tracking and Ground Instrumentation Unit (TAGIU).[19-22] Tindall worked closely with NASA/Goddard and IBM personnel who developed the software for the computers at Goddard. Tindall had a talent for designing software flow charts.[16] In his book *Highways Into Space*, Glynn Lunney says Tindall worked to simplify the operations concept for Mercury, which consisted of the control center in Florida, the tracking stations around the world each staffed by a small team of flight controllers, and the computation facility at NASA/Goddard in Maryland.[23] This world-wide network later became known as the Manned Spaceflight Network, or MSFN.

In the Space Task Group, Tindall served as the deputy to Mission Analysis Branch Chief John Mayer.[16] Cathy Osgood remembered that Mayer was collecting talented people (whether he needed them at the moment or not) in preparation for future work on Gemini and Apollo.[20, 24] In his book *Failure Is Not An Option*, Gene Kranz describes John Mayer and Bill Tindall as a perfectly balanced pair of leaders who under any other set of circumstances probably would not have met. John Mayer, the branch chief, was adept at finding answers to questions when no answers were apparent. He was aloof on first acquaintance and had the appearance of an accountant working for the Internal Revenue Service. Bill Tindall, the deputy branch chief, was easy going and youthful in spirit and manner, gregarious and short tempered, extroverted and mercurial, but quick to recover after an emotional outburst. The Mayer/Tindall partnership would continue after the Space Task Group moved to Houston and the Mission Analysis Branch became the Mission Planning and Analysis Division (MPAD).[1] During Mercury, it was estimated that the Mission Analysis Branch spent about 90% of their effort planning for contingencies as compared to nominal mission planning. It was a practice that Mayer and Tindall would continue during Gemini and Apollo.[22, 25]

Glynn Lunney and his wife Marilyn got to know Bill and Jane Tindall after the Lunneys moved to Langley. Tindall grew up sailing off Cape Cod and while employed at Langley he was refurbishing a 34-foot sailboat in his barn. In his book *Highways Into Space*, Lunney describes Tindall as fascinated with new challenges of mission planning that Project Mercury had to overcome. Tindall was good at mentoring and teaching the younger engineers orbital mechanics.[23]

PROJECT GEMINI

In 1961, after joining the Space Task Group, Tindall began working on development of a mission plan to perform orbital rendezvous of two spacecraft.[16] Previous work at Langley, conducted by John Houbolt and his team (Hewitt Phillips, John Eggleston, Arthur Vogeley, Max Kurbjun, John Bird, Clint Brown, Bill Michael, John Dodgen, William Mace) on orbital rendezvous was of a theoretical and academic nature and was sufficient for supporting the advocacy of the Lunar Orbit Rendezvous (LOR) profile.[26, 27] However, an actual rendezvous performance during a space mission required a considerable amount of trajectory design, mission planning, and software development. This involved taking the results of theoretical studies on rendezvous performed at Langley and combining it with mission planning experience from Mercury and the results from more applied rendezvous studies.

Tindall assembled a small team within the Mission Analysis Branch to begin this work. They worked on various trajectory studies and software tool development tasks and met weekly. Tindall published the analysis results, much of it informal, as “Rendezvous Notes.” These notes became required reading for new engineers.[16, 20]

One of the engineers in Tindall’s rendezvous working group was Edgar Lineberry. This was the beginning of a partnership that would continue through Gemini and Apollo and into Space Shuttle development in the 1970s. Lineberry was the quiet and thoughtful genius of orbital mechanics, while Tindall was the skilled executive and communicator who convinced people that Lineberry’s ideas for trajectories and software represented the best approach.[9]

In February of 1962 Tindall requested that all Gemini computer programming, data processing, and orbit determination be performed at the new Mission Control Center in Houston. Tindall believed this would be a more efficient way to support the rendezvous missions flown by Gemini, than separating computer processing and flight operations between two locations as during the Mercury mission.[16]

In the spring of 1962, Tindall and other members of the Space Task Group moved to Houston to the newly formed Manned Spacecraft Center (MSC).[†] Until the new buildings were built at MSC, the Mission Analysis Branch was housed in leased office space in the Houston Petroleum Center just off the Gulf Freeway (I-45). After the move to Houston, Tindall made the rendezvous planning process more formal. The meetings on Gemini rendezvous and trajectory design that Tindall chaired eventually evolved into the Gemini Trajectory and Orbits (T&O) Panel (part of the Gemini Project Office), led by Tindall.[16, 19] Chris Kraft referred to Tindall as “my rendezvous expert.”[28]

In May of 1962 NASA created the Flight Operations Division, and John Mayer and Bill Tindall were appointed Assistant Chief and Deputy Assistant Chief for Mission Planning, respectively.[19] In November 1963 NASA/MSC management created the Mission Planning and Analysis Division (MPAD), with John Mayer as Chief and Bill Tindall as Deputy Chief. Cathy Osgood observed that Tindall preferred being a deputy, a position which gave him the authority he needed to get things done, while limiting his administrative and management tasks.[20] John Mayer, the MPAD chief, handled management and administrative duties as well as most of the Apollo mission planning, while Tindall, his deputy, handled Gemini mission planning.[29]

[†] The NASA Manned Spacecraft Center (MSC) was renamed the Lyndon B. Johnson Space Center (JSC) in 1973.

In 1963 and 1964, Tindall also served as acting head of the Rendezvous Analysis Branch. He applied his talent for designing software flow charts, honed during Project Mercury, to the conception of rendezvous mission planning software needed for Gemini.[16] Cathy Osgood recalled that one day Tindall placed a blueprint sized sheet of paper on software developer Bill Reini's desk, and told him to code it. It was a flowchart for what would become the rendezvous profile software that would be used for mission design.[20] Tindall took a step-by-step approach to defining what the crew and Mission Control had to do to accomplish a rendezvous from launch through docking. He would later use this same step-by-step approach when Chief of Apollo Data Priority Coordination. Tindall's rendezvous work included overseeing the development of orbit determination software and the Analytic Ephemeris Generator, both used for Gemini in Mission Control.[9]

Soon after astronaut Buzz Aldrin arrived in Houston in the latter half of 1963, Tindall learned that Aldrin's PhD dissertation concerned rendezvous.[30] Tindall promptly included Aldrin in the rendezvous planning effort.[20] In his 1973 book *Return to Earth*, Aldrin wrote that Tindall had a sense of humor, was respected, knew what he had to do, and led teams that beat the problems to death. Tindall was a likeable expediter and was thorough and decisive. Furthermore, he kept everyone informed of what was going on through his clear and precise memos that eventually came to be called Tindallgrams. Tindall's Gemini T&O Panel examined all contingencies that could occur during rendezvous, all the details of the computers, the ground support required, and other matters concerning rendezvous.[31] When Tindall passed away in 1995, Buzz Aldrin remembered Tindall's Gemini Trajectories and Orbits Panel meetings:

> "The Gemini Trajectories and Orbits Panel is where it started and it carried on into Apollo. There was a period when that meeting was suspended and so many of us in mission planning felt lost for a period of several months until that panel was reinstituted with a memo in typical Tindall fashion, entitled 'T&O Rides Again.' Everyone sensed a relief because they knew mission planning was in good hands again." [15]

One significant task of the Trajectories and Orbits Panel was the selection of a trajectory profile for the first Gemini rendezvous and docking with the Agena upper stage. Bill Tindall, Edgar Lineberry, and Glynn Lunney proposed the tangential concept, one they had studied since their Space Task Group days in conjunction with James Rose of NASA/Langley. Buzz Aldrin and Paul Kramer proposed a concentric rendezvous, while a third proposed rendezvous profile was a first apogee or direct rendezvous. In June of 1964 Tindall and the Trajectory and Orbits Panel would recommend the concentric profile (which was later renamed the coelliptic profile).[32]

Tindall was concerned not just with rendezvous, but with trajectory control and mission planning for the ascent, orbit, and re-entry phases of flight. This included development of rendezvous launch window software tools and ascent insertion targeting. In his book *Forever Young*, astronaut John Young recounts Tindall's involvement in the backup retro burn discussion before the flight of Gemini III in March of 1965,[33] a period which Tindall also discussed in a conference paper he co-authored in 1966.[4]

During Gemini missions, Tindall was present in the Flight Dynamics Staff Support Room, along with other MPAD personnel, to support the flights.[17] One example of Tindall's involvement during a flight occurred when Gemini V deployed a Radar Evaluation Pod (REP) from the adapter module. The plan was for Gemini V to separate from it, then track it with the on-board radar and perform a rendezvous, to practice for the planned Gemini VI rendezvous and docking with an Agena upper stage. After deployment, the crew tracked the REP with the radar, then a fuel cell problem forced the crew to shut off the radar to conserve power. Mission Control then canceled the rendezvous. To gain some rendezvous experience despite the canceled rendezvous with the REP, Bill Tindall and Buzz Aldrin conceived the idea of performing the Mission Control targeted portion of a rendezvous with a phantom target spacecraft. Apogee adjust, phasing adjust, plane change, and coelliptic burns were targeted by Rendezvous Analysis Branch personnel in the Auxiliary Computer Room. The targeting data was given to Mission Control and the crew performed the burns. Post flight analysis proved that the Gemini V phantom rendezvous, proposed by Bill Tindall and Buzz Aldrin, was a success.[16, 29, 34, 35, 36]

Bill Tindall passed away in 1995, before the JSC Oral History Project began in 1996, however, an interview transcript with Bill Tindall from 1966 was discovered during research in 2019 on the Gemini IV station-keeping failure. [29, 37] The interview was conducted during research for the official NASA history of Project Gemini, *On the Shoulders of Titans*, and provides insight into the trajectory design and mission planning issues that Tindall was concerned with during Gemini and illustrates Tindall's understanding of engineering detail and flight performance. Although Tindall is famous for his Apollo era Tindallgrams, he mentioned to the interviewers that he had four volumes of memos he wrote during Gemini.

In the January 1966 issue of *Brown Alumni Monthly*, Tindall wrote that he found "this work awfully exciting and interesting. In many ways it is just like a hobby. I am really lucky to have been allowed to do this job." [12] Later, in *Managing the Moon Program*, Tindall made the following observation on delegation.

> "Another thing that I think was extraordinary, and this was throughout the whole manned-space flight program, was how things were delegated down. I mean, NASA responsibilities were delegated to the people and they, who didn't know how to do these things, were expected to go find out how to do it and do it. And that is what they did. It was just so much fun to watch these young people take on these terribly challenging jobs and do them." [18]

Tindall put into practice a key leadership skill; delegation. Those to whom responsibility was delegated had to prove to management that they had the right answer to the problem.

APOLLO PROGRAM

Bill Tindall turned his attention to Apollo in 1966. By this time, he was already a proven leader with a sophisticated understanding of mission planning and software development, having provided leadership in those areas during Mercury and Gemini.

Introducing Discipline into Apollo On-Board Software Development

On-board flight computer software for the Apollo Command Service Module (CSM) computer and primary Lunar Module (LM) computer was developed by the Massachusetts Institute of Technology Instrumentation Laboratory (MIT IL).[‡]

In 1966, Apollo program management was concerned that MIT IL was not delivering CSM and LM software on time to simulators at the Cape and MSC, and to North American and Grumman. The Assistant Director for Flight Operations, Chris Kraft, sent Bill Tindall to MIT IL in Cambridge, MA to get things moving. Kraft also set up a configuration control board for CSM and LM software; no changes would be made unless he signed off on them. Kraft told Tindall that MIT IL had one month to get things moving.[28] By 1966 Tindall already had much experience in ground software development for Mercury and Gemini.

[‡] The MIT Instrumentation Laboratory was renamed The Charles Stark Draper Laboratory in 1970.

The CSM and LM computers did not have enough memory for all the software functions that people wanted. Software development, testing, and deliveries to other organizations in the Apollo Program was behind schedule. The challenges faced by MIT IL were typical of large software projects. MIT IL had a culture that was informal, academic, and innovative; they were good at problem solving. However, MIT IL was not optimized to manage rapid software development.

Tindall began traveling to Boston to meet with MIT IL to review software development, identify problems, and offer solutions and process changes.[38-41] At first Tindall's observations and ideas were not well received, but after two or three trips, Tindall's inputs were appreciated by MIT IL personnel who liked his personality and leadership style.[14] MIT IL engineer Malcolm Johnston describes Tindall's work in the introduction to a collection of Tindallgrams he compiled.

> "In 1966, Apollo Spacecraft Program Manager George Low made Tindall responsible for all guidance and navigation computer software development by the Massachusetts Institute of Technology. Bill quickly grasped the key issues and clearly characterized the associated pros and cons, sometimes painfully for us, but his humor, friendliness, and ever-constructive manner endeared him to all of us." [42, §]

Within a month of the assignment, MIT IL had implemented changes that set time critical on-board software development in motion. Tindall's work resulted in three Black Friday meetings held on May 13, 1966, January 13, 1967, and August 28, 1967. These meetings determined what software functions to delete so that the software for the CSM and LM would fit in the limited memory of the on-board computers. Meetings were emotional due to disagreement over what software functions could be considered not mandatory and therefore eliminated from the software. Tindall frequently urged, "better is the enemy of good enough," in his efforts to eliminate the "bells and whistles" so that the software would fit in the available computer memory. Problems with software development were overcome, thanks in large part to Bill Tindall's leadership.[14]

Apollo Mission Techniques Meetings

On August 3, 1967, Bill Tindall was appointed Chief of Apollo Data Priority Coordination. Tindall's new role was announced in a memo by George M. Low, the Manager of the Apollo Spacecraft Program Office.[43] The memo stated in part:

> "In this assignment he will coordinate all MSC and contractor efforts in developing the techniques and procedures for the operational utilization of the trajectory control systems involved in manned Apollo missions. …. Specifically, his job is to determine the operational rules and procedures for properly utilizing the Apollo system capabilities and constraints and to evaluate their accuracies; to establish the criteria for system selection during various phases of the mission; and to establish the proper spacecraft and ground displays and use of these displays. His responsibility will include the utilization of the spacecraft propulsion, guidance, and control systems, as well as the associated support from the MSFN and Mission Control Center." [44]

Tindall was to report directly to the Manager of the Apollo Spacecraft Program and was to be on loan from his position as Deputy Chief of MPAD in the Flight Operations Directorate. The title Chief of Apollo Data Priority Coordination is a poor indicator of the importance of his role, or the broad influence Tindall had over how the Apollo missions would be flown, and perhaps for this

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[§] In *Managing the Moon Program*, Tindall states he was working for Apollo Spacecraft Program Office Manager Joe Shea when he worked on the Apollo on-board software.[18] George Low did not become Manager of the Apollo Spacecraft Program Office until 1967, but Tindall began traveling to MIT IL in 1966. Charles Fishman also discusses this minor time discrepancy in his book *One Giant Leap*, in the chapter titled "The Man Who Saved Apollo." Much of the chapter concerns Bill Tindall.[14]

reason, the key role he played was not visible to the public or the news media. However, Chris Kraft was to later state that no one had contributed more to the success of Apollo than Bill Tindall.[45]

The name "Data Priority" originated from an issue that was identified early in planning for Apollo; what sources of navigation data should be used, and how should that choice be made during the mission? [23] The Mission Techniques meetings determined how to control the trajectory once mission objectives, the trajectory, and the crew timeline had been defined.[¶] The trajectory was controlled through crew and ground operation of the Guidance, Navigation, and Control (GNC) system, as well as the propulsion systems, under the assumption that there may be degraded systems performance or failures. Many of the issues discussed in the Mission Techniques meetings concerned contingency planning, causing Tindall to later call himself a "professional pessimist".[18] These issues included defining astronaut and Mission Control procedures for cross-checking and monitoring spacecraft systems performance, and procedures for degraded performance or failures, and determining just how well systems have to perform. This task was made more complex due to the use of two crewed spacecraft, the Command Service Module and the Lunar Module.[18, 46]

In 1995, Buzz Aldrin described Tindall's role in the Mission Techniques meetings.

> "He had a brilliant way of analyzing things and the leadership that gathered diverse points of view with the utmost fairness. He listened to all points of view and then made and carried out astute decisions." [15]

At the start of a meeting, Tindall made sure everyone in the room understood what the objective of the meeting was. Then he facilitated discussions and navigated emotional arguments to find a consensus even when data was incomplete or conflicting, making some reluctant to make a decision. These decisions, which were official due to Tindall's position, unified subsequent work to be done, and helped people identify additional work that had to be performed. If some were not happy with the outcome of a discussion and the resulting decision, it still gave them a target to aim at when addressing their concern in other forums and management channels. Early decision making served as a point of departure and forced engineers in various organizations to check and re-check supporting data and numbers used in software and procedures, both in on-board and ground computers.[46] A factor for the success of the Mission Techniques meetings was that people were not afraid to stand up and speak out about a concern, even though they might be embarrassed later by the outcome of the discussion. Tindall considered people who found problems but did not speak up about them to be the "worst kind of person to have around." [18] In his book *Never Panic Early*, Apollo 13 crew member Fred Haise states that Tindall was a master facilitator of meetings and kept order. He could pull every nugget of information from the brains of the meeting attendees, including those attendees that were shy about speaking up.[47] Astronaut Dave Scott wrote that the Mission Techniques forum permitted information and ideas to be freely exchanged by various participants in the program. Tindall had a unique ability to get people talking so that hardware and software was integrated across the program. The Mission Techniques meetings were lively discussions where decisions and commitments were made.[3]

In his 1970 paper "Techniques of Controlling the Trajectory" Tindall described the challenge of the effort and the benefit of the Apollo Mission Techniques meetings.

> "The meetings were regularly attended by experts involved in all facets of trajectory control – systems, computer, and operations people, including the crew. Our discussions not only resulted in agreement among everyone as to how we planned to do the job and why, but also inevitably educated everyone as to precisely how the systems themselves work, down to the last detail. A characteristic of Apollo you could not help noting was just how

[¶] Tindall referred to the meetings he led as "Mission Techniques" in his Tindallgrams.

> great the lack of detailed and absolute comprehension are on a program of this magnitude. There is a basic communication problem for which I can offer no solution. To do our job, we needed a level of detailed understanding of the functioning of systems and software far greater than was generally available. Through our meetings, however, we forced this understanding. It was not easy, but we got it sorted out eventually – together." [46]

Much later, the Mission Techniques meetings would be renamed Flight Techniques. During the Space Shuttle Program, these meetings were chaired by a Mission Control Flight Director. Insight into the nature and importance of this type of meeting is provided by Space Shuttle Flight Director Paul Dye in his book *Shuttle, Houston: My Life in the Center Seat of Mission Control*.

> "Another key element of learning was going to meetings – sure this sounds boring, but meetings were where flight techniques, rules, and procedures were ironed out – as well as where vehicle problems and changes were hashed out and argued over by program management, engineering, and the flight ops team. Meetings were where young flight controllers learned to understand logical argument supported by data – always supported by data! It was where they learned to sell their ideas to colleagues who were looking for any weakness in risk analysis and logical thought." [48]

Apollo 16 astronaut Ken Mattingly described the Mission Techniques meetings as follows.

> "These meetings would go on sometimes two days, and they would be eight in the morning until eight in the evening, whatever it took. Room filled with people. Not always a lot of decorum. Bill was after answers. It was nowhere near as a collegial environment as you see in some organizations today. But they were after what was right, and everybody was passionate about. Everybody was young so they were kind of brash and there wasn't a lot of patience anywhere. So some of those meetings were very, very colorful. Some of the characters were colorful. At the end of this, you were just inundated with all of this stuff you've heard." [49]

While the Mission Techniques meetings could be emotional and contentious, MIT IL engineer Malcom Johnston observed:

> "Those of us who took part in those meetings and other interactions with Bill will always appreciate another aspect of his contribution ... he made it a lot of fun!" [42]

One valuable result of the Mission Techniques meetings was that it gave Mission Control personnel and the crew (astronauts) an understanding of both what they were to do, and how and when they were to do it. This enabled Mission Control and the crew to effectively and efficiently train once simulations began, because all the details had been worked out.[46] In *Managing the Moon Program*, Tindall stated that the extraordinary amount of high-fidelity simulations that were conducted for training was a great contributor to minimizing risk during Apollo.[18] Mission Techniques meetings also led to the discovery of deficiencies in mission plans, as well as deficiencies in onboard and ground software and procedures, revealing that some changes had to be made in trajectory planning.[46]

As Chief of Apollo Data Priority Coordination, Tindall was involved in many decisions concerning mission planning, such as the 1968 decision to send Apollo 8 to the Moon.[1, 28, 50, 51] To prepare for Apollo 11, much of Tindall's attention was devoted to LM descent, surface activities, and LM ascent.[50]

Tindall documented the discussions and decisions made in the Mission Techniques meetings in his memos, known as Tindallgrams.[52] Tindall's method of writing memos was not new to him since he wrote them throughout Project Gemini.[29]

Apollo 11 Lunar Landing and Honorary Flight Director

Bill Tindall planned to watch the Apollo 11 lunar landing from the viewing room behind Mission Control. Gene Kranz, at the Flight Director console in the Mission Control room, looked behind him through the glass at the people in the crowded viewing room.

He saw Tindall and motioned for him to join him at the Flight Director Console. At first, Tindall declined, but then came into the Mission Control room, sat down near Kranz, and plugged his headset into the console, Kranz allowing him to sit close enough so that he could observe the displays on the console. In *Apollo*, Murray and Cox wrote that it was an honor that Tindall would never forget.[1, 36]

Kranz states in his book *Failure is Not An Option* that Tindall was made the first honorary Flight Director at a beer party after the Apollo 11 mission had ended (see the Appendix of this paper).[1]

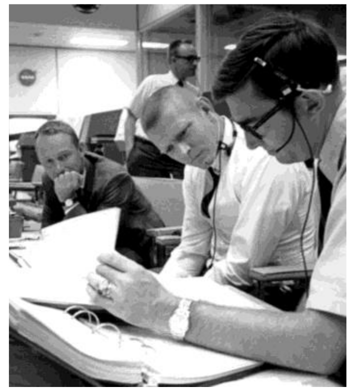

Figure 2. Bill Tindall (left) and Gene Kranz in Mission Control during Apollo 11. NASA image s69-44155 via www.honeysucklecreek.net.

Apollo 12 Landing Near Surveyor III

After the Apollo 11 landing there was some question concerning exactly where the Lunar Module had landed. For Apollo 12, NASA management wanted to make a pinpoint landing near the Surveyor III spacecraft that landed on the Ocean of Storms in April of 1967. Soon after the completion of the Apollo 11 mission Tindall convened Mission Techniques meetings to define the techniques needed to control the descent trajectory and achieve a landing close enough to Surveyor III to permit the crew to walk over to it. Several problems had to be solved, and Andrew Baird covers how Tindall led the resolution of those problems in his 2007 *Quest* magazine article "How to Land Next to a Surveyor." [6, 13] Kranz stated in his book that Tindall, "was in the middle as the developer of the technique." [1] Emil Schiesser developed the powered descent guidance target biasing technique, and Alan Wylie used the Lear filter (developed by Dr. William M. Lear) during powered descent to obtain the data needed for the Apollo 12 crew to execute the Noun 69 command to bias the guidance target.[6]

Bill Tindall After Apollo 12

On January 29, 1970, Tindall was named Acting Deputy Director of Flight Operations, and was named permanently to the position on March 13, 1970. On April 28, 1972, he was named Director of Flight Operations.[19] Divisions within Flight Operations included Flight Control (Mission Control), Computation and Analysis, Landing and Recovery, Mission Planning and Analysis (MPAD), and Flight Support.

SPACE SHUTTLE

Before the Apollo Program ended, Tindall was already involved in planning for the Space Shuttle. He presented his thoughts on the Space Shuttle in a January 1973 AIAA conference paper titled, "A Cursory Look at Shuttle Flight Operations." [53]

In January of 1974 Tindall became Director of the new Data Systems and Analysis Directorate (DSAD) where he oversaw shuttle avionics development,[54] a new directorate resulting from a re-organization that combined the Flight Crew Operations and Flight Operations Directorates.[55] DSAD was responsible for institutional and programmatic data systems and analysis, as well as the on-board flight software for the Space Shuttle. Divisions within DSAD that reported to Tindall included the Ground Data Systems, Institutional Data Systems, Mission Planning and Analysis (MPAD), Spacecraft Software, and Flight Simulation.[56] The Spacecraft Software Division was concerned with development of the flight software for the Space Shuttle. Tindall continued as Director of DSAD until his retirement from NASA in September of 1979.[57]

POST NASA CAREER

Bill Tindall served as a consultant to NASA concerning unmanned deep space probes and worked at the Federal Aviation Administration on a new air traffic control system. He passed away on November 20, 1995, in Orleans, Massachusetts.[15]

OBSERVATIONS ON BILL TINDALL AS A LEADER

Bill Tindall, like a lot of people who worked on Apollo, was humble about it. He told the authors of *Apollo, the Race to the Moon* that he didn't do anything himself. Perhaps in his mind he got other people to do what needed to be done, but it was Tindall who brought out the best in them. [36]

One key to Bill Tindall's success as a leader is that he was having fun. In the 1989 Apollo oral history workshop that was documented in *Managing the Moon Program*, he summed up his Apollo experience as follows.

> "I remember through my career, I never worried about the next, or any promotion at all. In fact, I was just having a really good time, really, really good time. And I guess the organization we were in encouraged that. …. But the thing that was so outstanding, you just hope that the young engineers and scientists that we are talking to here have a chance to be, to get into an organization, I don't know whether it has to be a project like Apollo, but an organization like we had that really delegated the jobs as tough or tougher than you could do and just said go on out there and figure out how you can do it because it was so doggone much fun." [18]

More insight into Bill Tindall's leadership style and personality can be gained from the memories of those who worked with or for him.

Ken Young – MPAD Engineer

Ken Young remembered that he once asked Bill Tindall if he was afraid of making the wrong decision. Tindall said "no," and then explained that he made decisions based on the arguments and evidence presented to him. If he made the wrong decision, people would be lined up outside his office to tell him about it.

Cathy Osgood – MPAD Engineer

Cathy Osgood stated that Tindall was a "free spirit and a troubleshooter. He got a lot done." [20] Osgood described Tindall's approach as follows.

> "So he started holding these rendezvous meetings, or weekly meetings, turned into what was—I think he first called it the data priority, and we had something called a T&O Panel, Trajectory and Orbit Panel… Then that later became the Flight Techniques, which still goes on today. But that type of work was done not as one branch doing it, but as this one talented individual coordinating other talented people to get the job done… And he was

> one that would—he'd just dive right into a knotty problem, and when he just barely got that under control, he was into the next one. Like the onboard software was just stumbling along, and he decided that that was his next project… He called it a big bag of worms. He just got into it. [Laughter] It was really fascinating to be in that sort of a situation." [20]

Don Eyles – MIT IL Software Developer

In his book, *Sundance and Luminary,* MIT Instrumentation Laboratory Lunar Module software developer Don Eyles described the key to Bill Tindall's effectiveness as his personality, "lucid, affable, unselfish." Tindall had a way of learning about complex issues and communicating his understanding in a clear manner to engineers and managers that represented a variety of organizations and engineering disciplines. He was generous and pleasant to work with and for. He exhibited these personality traits in a stressful work environment that would overwhelm many people.[58]

Gene Kranz – Flight Director

Flight Director Gene Kranz liked Bill Tindall since he knew what he believed and was clear on where he stood on an issue, being unafraid of getting emotional.[36] Bill Tindall in turn admired Gene Kranz for his ability to pay attention to multiple issues. Tindall told the authors of *Apollo, the Race to the Moon* that Kranz seemed to have two different minds. He could keep track of all the communications over the voice loops in Mission Control, think of what had to be done, and lead the team.[36]

Gene Kranz observed that Tindall was a genius at focusing on issues and getting people from different teams to work together to solve them. He used his friendly nature and sense of humor to encourage people to work together. Even though Gene Kranz and Bill Tindall had different technical backgrounds, the two had several things in common. Both were emotional about their work, they were both optimistic, and they both gave the people working for them unconditional support.[1]

Glynn Lunney – Flight Director

Glynn Lunney described Tindall as "brilliant, enthusiastic, and energetic" and possessing an infectious enthusiasm. He was able to understand and discuss the various viewpoints on a topic. Tindall broke down complex issues by systematically addressing issues in each mission phase (ascent, orbit, rendezvous, descent). This made the issues easier to understand and made it easier to eventually identify workable solutions. Lunney compared Tindall to a judge in a court room, as he orchestrated the vigorous arguments between organizations. Tindall's good people skills enabled him to turn down a bad or unsupported idea without offending the person promoting that idea. He was able to change his mind on an issue if presented with compelling evidence, or he could strengthen his own views based on evidence brought to him.[23]

In the book *GO, FLIGHT!* and in a 2017 conversation, Glynn Lunney pointed out the value of Bill Tindall's approach to problem solving through teamwork by comparing the Gemini experience with rendezvous and space walks (Extra Vehicular Activity, or EVA).[59, 60] Tindall led the development of rendezvous flight techniques and mission planning through the Trajectories and Orbits Panel, which he chaired. Tindall's approach to leading rendezvous flight techniques development involved multiple organizations with different responsibilities and skills working together to identify and solve problems. Much of the success of Gemini rendezvous is owed to the patient refinement of nominal and contingency flight techniques over several years of study. Trajectories could be developed through computer simulation. Glynn Lunney claimed that Bill Tindall did leadership the right way, insisting that all the discussions be held openly, that everyone be kept informed, and that he understand the different skill sets and engineering disciplines required to successfully solve problems and plan the mission.[60]

Lunney then contrasted Tindall's approach to Gemini rendezvous development to EVA development techniques performed during Gemini. The development of EVA techniques was handled within the Flight Crew Operations organization (specifically by the crew assigned to fly a Gemini mission) and their support personnel. Unlike rendezvous, EVA planning was not performed by a multi-disciplinary team under an effective leader. There was no one person that led EVA techniques development for all missions, therefore lessons learned were not effectively shared from one mission to the next. EVA also involved human performance in a pressurized space suit while performing tasks in zero gravity. At that time human factors could not be simulated on a computer, and engineers and managers outside of Flight Crew Operations were reluctant to get involved. The first EVA, performed on Gemini IV, was relatively simple, and gave some a false sense that EVA would be easy. EVAs performed on Gemini missions IX, X, and XI proved to be challenging since simple tasks were harder than expected.[60, 61] The Gemini XII EVA was more successful, due in part to astronaut Buzz Aldrin's use of underwater training, improved restraints, tethers, and handholds, and the methodical approach Aldrin used in planning and executing simple tasks that could be measured accurately in terms of workload.[61]

Fewer challenges were encountered with rendezvous than with EVA and Glynn Lunney believed this was due to the one leader, Bill Tindall, who was responsible for rendezvous technique development for all missions, and the teams of engineers representing different organizations, together performing all work, debates, and decisions in an open, visible way that was communicated to everyone. This is in contrast to the Flight Crew Operations approach to EVA, where leadership, astronauts, and engineers involved in EVA development changed with each mission.[23, 59, 60]

Jerry Bell – MPAD Engineer

NASA engineer Jerry Bell, who worked in MPAD from the 1960s through the 1980s, described three memories of Bill Tindall which he said, "shows the measure of the man and why he commanded the great respect he earned from all." [62]

During Apollo, Bell was assigned to give a presentation at the Powered Descent Abort Data Priority meeting concerning the rendezvous strategy and techniques for LM rendezvous with the CSM and CSM rescue of the LM. However, the lighting constraints during the terminal phase of rendezvous had not been determined and therefore were not included in the presentation, at which Tindall expressed his anger. The next morning, Bell and other engineers met in Tindall's office to discuss terminal phase lighting constraints. Tindall discussed the issue with the engineers, and identified what work needed to be done to define the constraints, and who would do it. He did not express any of the anger that he did the day before, it was as if the confrontation at the meeting had never happened. Tindall was short tempered, but quick to recover after an emotional outburst, as Gene Kranz noticed in his book *Failure is Not an Option*.[1] Jerry Bell and the other engineers learned an important lesson that day from Bill Tindall. No matter how busy, or how challenging the schedule, they must take the initiative to investigate a topic and bring it to management's attention. Waiting for someone else to do it or waiting for management to direct someone to do it was not acceptable. This lesson impacted how Jerry Bell approached future assignments.[62]

The second encounter occurred in the mid-1970s during development of the Space Shuttle. At this time, Tindall was Director of Data Systems and Analysis, and MPAD was one of the divisions that reported to Tindall. Jerry Bell and other MPAD and Remote Manipulator System (RMS, the robotic arm) personnel were trying to convince senior NASA management that Reaction Control System jet plume impingement presented a real risk to the successful capture of target spacecraft with the Space Shuttle RMS.[63] However, there was little evidence to support the concern, making some suspicious of it. Jerry Bell gave a presentation to senior management on the concern, and actions were assigned to investigate and find supporting data. After the meeting Bill Tindall called

Jerry Bell and told him that his presentation was "on the money." [62] Tindall showed his appreciation for good work, and engineers in turn respected him and were loyal to him.

Bell's third example was the most memorable. He gave a presentation on launch windows for a shuttle mission that would deploy a Tracking and Data Relay Satellite (TDRS) with an Inertial Upper Stage (IUS). In addition to NASA/JSC personnel, the audience included representatives of NASA/Marshall, the Department of Defense, TRW, Boeing, and Western Union. Tindall was so impressed with Bell's presentation that he wrote a memo to MPAD Chief Ron Berry complimenting Bell on the quality of his presentation. Berry gave a copy of the memo to Jerry Bell, and it became his most treasured item from his NASA career.[62] Tindall took the time to reach out and officially recognize people for a job well done, even though he was in upper-level management and had a demanding schedule.

THE TINDALLGRAMS

What made the Apollo Mission Techniques meetings even more valuable were the "Tindallgrams," the memos that Tindall dictated to summarize meeting discussions and outcomes, Tindall's thoughts on the issues, and hallway conversations on the topics. They were trying to figure out how to fly the vehicle, what the flight rules should be, what the on-board and ground software should do, and Tindallgrams conveyed this important information, connecting people in different organizations and rapidly informing them.

Tindall used his memos to communicate with a broad audience that was eager to learn more about how the Apollo vehicles worked and would be flown, what decisions were being made, and the rationale and backstory behind those decisions. The Tindallgrams were passed around and copied, as a written record they reached a broader audience than just those who had attended the most recent Apollo Mission Techniques meeting.

Historian Andrew Baird estimated that Bill Tindall wrote or dictated over 1,100 memos from 1964 to 1970 concerning Gemini and Apollo.[64] Originally, he wrote his own memos, but beginning with Project Gemini he dictated the memos to his secretary, Patsy Saur. Saur insisted that Tindall not write his memos himself, since she did not want to lose her dictation skills. At first, Tindall would write a draft, then read it to Patsy Saur, but he soon abandoned drafting for straight dictation, he simply spoke. Saur typed the memos, made copies, and put them in the internal mail for distribution. Tindall's secretaries during the Gemini and Apollo era in MPAD (1964-1970) were Patsy Saur, Corinne Morrison, Patricia Jones, and Joanne Sanchez. From 1970 to 1979 they were Martha W. Taylor, Barbara J. Perkins, and Judy S. Wyatt.

In his book *Sundance and Luminary*, MIT IL engineer Don Eyles described the Tindallgrams as follows.

> "… he raised issues that needed to be considered by the wider community, shared his hopes and misgivings, stroked the enterprising, cajoled the reluctant, reported the status of long running deliberations; and when conclusions were reached, disseminated them, perhaps to reopen the case later on new evidence." [58]

Eyles explained that the value of the Tindallgrams was that they provided big picture context to engineers who were focused on details and described the Tindallgrams as "pure candy." Tindallgrams were copied and passed around. Tindall's written communications gave him a lot of leverage when the resolution of issues was debated in various forums.[58]

Apollo 16 astronaut Ken Mattingly had this to say of the Tindallgrams in a 2001 oral history.

> "And he could summarize these complex technical and human issues and put it down in a readable style that—I mean, people waited for the next Tindallgram. That was like waiting for the newspaper in the morning. They looked forward to it." [49]

People who had in-boxes that were always full, were on distribution for more memos and documents than they could read and were invited to more meetings than they had time to attend, made a point to always read Tindallgrams and attend meetings chaired by Bill Tindall.

Memo Style

The Tindallgrams were written on an official U.S. Government memo form, but the style and content of the memos was not controlled by a template, as much communication in today's NASA and corporations is. Tindall's memos were a refreshing change from the terse, formal, and bureaucratic style that engineers and managers were used to. Tindall was a recognized and respected leader with above average communication skills. He had editorial freedom to communicate in a way that was informative, engaging, and effective, even though his communication style was not the typical form associated with NASA and aerospace contractors. Tindall communicated in complete sentences and paragraphs, not bullet points. Tindallgrams were written like he talked, as if the reader were listening to him face-to-face. His personality came across in the memos. Sometimes Tindall published more than one memo a day. For example, there are four Tindallgrams dated October 29, 1969.

Tindall's memos were concise, straightforward, well written, and sometimes witty.[45] Dave Scott noted that while some Tindallgrams had a chatty and amusing tone, they were also clear, informative, and succinct. The closing of Tindallgrams often included phrases that invited people to offer a differing opinion or add additional information. Tindall used humor aimed at himself and other people to lighten up the atmosphere in a stressed-out work environment.[3] He maintained his sense of humor even under all the pressure of the years 1966-1969. Some memo titles were humorous, and the first paragraph usually had some humor in it to introduce the reader to the topic. Occasionally he made witty references to politicians or entertainers, such as a speech given by President Lyndon Johnson, or a reference to comedian Don Ameche. Tindall understood that some people did not like to read long memos, and he used self-deprecating humor to get them to read his memos.

Some example quotes from Tindallgrams follow.

> "This March l meeting conflicted with the President's speech but a few of us dedicated jokers pressed on as follows." [65]
>
> "I just reread that last paragraph and it sounds like I'm still asleep. Does it make sense to you?" [66]
>
> "As part of F/G Torture Week, we spent Thursday, January 30 on the rendezvous." [67]
>
> "I always start out these MIT newsletters with the hope they will be short enough that you'll be willing to read 'em." ….. "Wasn't very short was it, or interesting either, but I'll be darned if I'll throw it away after getting it to this stage." [68]
>
> "I made an announcement during the F Operations Review which was absolutely flat-out wrong." [69]
>
> " 'The time has come' the walrus said, 'to talk of many things.' This classic quotation apparently now applies to the Apollo 13 lunar orbit mission techniques and this walrus is suggesting Tuesday, September 23." [70]
>
> "Why are you still sitting here reading this stupid thing when there is all that important work to be done!" [71]

> "I blundered into something the other day - which is probably none of my business but is interesting, so I thought I would bring your attention to it." [72]

Astronaut Dave Scott observed that the underlying message of the Tindallgrams was completely earnest, even when the tone of the summaries was light-hearted.[3]

Content of the Tindallgrams

Tindall wrote memos on important topics from meetings and did not rely solely on the meeting minutes to preserve the record of discussions. He easily switched back and forth between technical detail and commentary on leadership and management. Tindall understood the technical issues well enough to write about them and explain them to engineers, managers, and astronauts. The memos show his familiarity with crew procedures, Mission Control procedures, flight rules, on-board computer functionality, and mission planning.

In some cases, Tindall wrote a memo to prepare readers for a discussion to be held at an upcoming meeting. He provided background on previous technical discussions. Tindallgrams also informed people of important and late breaking developments. Tindall used his memos to keep people informed of changes that impacted analysis that was underway, crew procedures, simulations, mission planning, and Mission Control procedures. He was particularly concerned with decisions made without an understanding of the negative impact on other aspects of mission planning or operation of vehicle systems.

Tindall not only shared his own opinions, but those of various people and organizations, including the crew. He wrote about phone and hallway discussions, quoted important items verbatim from memos written by other engineers, discussions that occurred in meetings other than Mission Techniques, and identified and recommended informative memos written by other people. Tindall listened to the crew and tried to see things from their perspective, then communicated the astronaut's perspective to a wider audience. He would state a proposed change to a crew procedure and then ask if anyone had an objection.

Tindallgrams identified who was given action items, who was working on what, and who was the contact for various issues. Summaries were provided of analysis results and status of work in progress. The memos contained lists of open items to be discussed at upcoming meetings, questions remained to be answered, and answers to questions that were raised in meetings. Tindall identified what decisions were made and explained what factors drove the decisions. Then he stated what people and organizations were doing in response to those decisions. Tindall often asked for input on what else should be done, what other issues needed to be worked, and what he himself needed to do. His memos defined what was important, reminded people of what the principal objectives were, and established boundaries for decision making. Tindall wanted to make sure people understood the priorities for software development, but he did not dwell on defining priorities.

Tindall used his memos to get people thinking about how to solve problems, calling out details and problems that certain individuals needed to pay attention to. People were assigned to give presentations on topics to give the broader engineering and operations community the opportunity to review the topic and make comments. Tindall was skilled at identifying where confusion existed concerning issues under debate and sought to provide clarity to aid in decision making. He established special forums, called panels, for topics that required attention. Tindall would write a charter defining what the panel was to do, and who the panel members were.

Tindall used his Tindallgrams to share personal observations. He stated what was bothering him and identified things that were painful to people, such as process changes. He did not hesitate to admit that a particular development effort was terrible. He understood people's frustrations and was honest with his own frustration. Tindall identified what impressed him and what did not. He wrote about challenges, communicated his expectations, and commented on expectations he considered to be unrealistic. Tindall admitted that he did not understand or know everything, and admitted both his mistakes, and his contributions to confusion. Even in the face of serious budget, schedule, personnel, and engineering challenges, Tindall pointed out the good things that both civil servants and contractors had done to address the challenges. He gave credit to people for the hard work they did.

CONCLUSION

Bill Tindall was highly respected as a leader and an engineer who made key contributions to the success of the Mercury, Gemini, and Apollo Programs. Tindall had the soft skills to not only manage schedules, priorities, and task assignments, but to effectively lead people. Meetings led by Tindall were not boring, but informative, decisive, and occasionally entertaining. As a leader, Bill Tindall could inspire, communicate complex engineering topics to a broad audience, and get people to change their minds. Tindall had a talent for making sense out of complex problems where no solution was obvious, simplifying it, and getting people to work together to devise solutions. His people skills and written communication via the Tindallgrams made people in a large program feel informed and included. Bill Tindall enjoyed his work at NASA, and he had fun doing it.

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APPENDIX: FLIGHT OPERATIONS DIRECTORATE PROCLAMATION

In recognition of his contributions to NASA's human space flight programs, Bill Tindall was the first person made an honorary Mission Control Flight Director at the NASA/Johnson Space Center. Tindall took the name Grey Flight. As of 2023, only five honorary Flight Directors have been named. The following proclamation was issued when Tindall was named an honorary Flight Director, and it hung on his office wall at NASA.

> Whereas, Howard W. Tindall, Jr., has been instrumental in the leadership of Flight Operations and Data Systems & Analysis, and
>
> Whereas, his leadership and guidance have contributed greatly to all U.S. manned spaceflight programs from Mercury to Shuttle, and
>
> Whereas, his capable leadership of the Data Priority provided critical techniques so vital to the successful completion of man's first lunar landing mission, and
>
> Whereas, the Flight Operations Directorate wishes to pay tribute to one who has demonstrated outstanding leadership and support to the successful execution of Flight Operations, now therefore be it
>
> Resolved, by the Flight Operations Directorate, that this proclamation stand in recognition of the services rendered by Howard W. Tindall, Jr., and be it further
>
> Resolved, that on behalf of the personnel of Flight Operations, he be named to the position of Flight Director.

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