# SYSTEM SAFETY IN EARLY MANNED SPACE PROGRAM: A CASE STUDY OF NASA AND PROJECT MERCURY

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## ABSTRACT

This case study provides a review of National Aeronautics and Space Administration's (NASA's) involvement in system safety during research and evolution from air breathing to exo-atmospheric capable flight systems culminating in the successful Project Mercury. Although NASA has been philosophically committed to the principals of system safety, this case study points out that budget and manpower constraints—as well as a variety of internal and external pressures—can jeopardize even a well-designed system safety program. This study begins with a review of the evolution and early years of NASA's rise as a project lead agency and ends with the lessons learned from Project Mercury.

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## INTRODUCTION

The concept of system safety is well known today but there are valuable lessons to be learned in examining the historical roadmap of aeronautical safety methodologies, specifically system safety programs, which have evolved from origins within and around the aviation industry. The value in this review is to better understand what programs and processes have been successfully employed and more importantly how to preserve the benefits of those expensive lessons learned. Hopefully this effort will help to identify some of the best practices that have evolved over the past century and produce a basis for system safety program managers to emulate in all applications.

## METHODOLOGY

The term case study can have more than one meaning that includes the description of a particular organization or a research methodology. According to Bromley (1990), it is a "systematic inquiry into an event or a set of related events which aims to describe and explain the phenomenon of interest" (p. 302). Yin defines the scope of case study research as an empirical inquiry that investigates a contemporary phenomenon within its real-life context (Yin, 2002). The unit of analysis for this study is the National Aeronautics and Space Administration (NASA), specifically the early years of the manned space program. This study is focused on an exploration and description of NASA's use of system safety during the early years of the man in space program and not in formulating any specific propositions.

### The Beginning

The first four decades of powered flight proved that a piecemeal, rearview mirror approach to safety is ineffective and expensive. Early airplane pioneers such as the Wright Brothers, Samuel P. Langley, Glenn Curtiss, and others practiced the fly-fix-fly approach to safety. Although aircraft performance improved dramatically during these early years, so too did the military accident rate. The U.S. Army Air Service reported in 1921 "that the Air Service desires to perfect preventive accident measures to the fullest possible may be readily appreciated from the fact that during the calendar year 1920, 51 officers and enlisted men of the Air Service lost their lives in airplane accidents, [and] 312 airplanes were damaged or destroyed" (p. 25).

This early expression of concern was soon translated into the first practical steps toward a formal accident prevention program. In December 1925, Major Henry "Hap" Arnold identified the need for a systematic approach to aircraft maintenance. Military leadership stressed a systematic discipline, which focused on a proactive effort, seeking to identify hazards, analyze them for risk, and then to control them as known quantities. The focus of this approach is to establish an acceptable level of safety, designed into the system as a whole before production or operation. This approach then seeks to identify and evaluate hazards before an incident or accident causes a loss—anything less is arguably a gamble. The current definition of system safety seeks to optimize all aspects of safety within constraints of effectiveness, time, and cost throughout all phases of the system life cycle. The significance of the emphasis on all phases of the system life cycle will become apparent in the following history of NASA.

An interesting case study presents itself while examining these early years of system safety practice. The marked contrast between what was available and what was employed, in terms of system safety management and engineering, is so striking that it calls for a more in- depth look. As with any program, gaining acceptance and support with subsequent administrations almost always requires an effort to convince the new management team that the old management team knew what they were doing. Egos and narcissism are plentiful in the aviation industry; the humorous quip, "You can tell a pilot – you just can't tell him much" is true even among those who manage pilots, and the systems they fly.

**NACA History**

In the 1920s and 1930s, the National Advisory Committee for Aeronautics (NACA) was demonstrating worldwide leadership in aeronautical sciences. They concentrated their research in aerodynamics and aerodynamic loads, with lesser attention to sub-systems and components such as structures and power plants. During this era, NACA worked closely with the military services in joint projects that were its contractual lifeblood. Even as late as 1939, NACA was a relatively small organization with an annual budget of $4.6 million and a total workforce of approximately 500 people, of which slightly over one-half were researchers (Swenson, Grimwood, & Alexander, 1966).

In 1941, Jerome C. Hunsaker, head of the Department of Aeronautical Engineering at the Massachusetts Institute of Technology (MIT) and a member of the Main Committee of NACA, assumed the NACA chairmanship. As the U.S. geared its industrial might for war, NACA watched as Germany and the United Kingdom led aviation in areas such as jet propulsion and high-speed flight. Going into the war years, the majority of NACA's research effort was oriented toward improving current designs or quick fixes to military aircraft already in production (Hunsaker, 1956). This organizational culture would follow NACA into the next decade.

After the close of WW II, the cold-war years continued to place demands for research, acquisition, and the fielding of new systems.

> By 1946, NACA had grown to approximately 6,800 personnel with an annual budget of $40 million. Chairman Hunsaker and others on the Main Committee felt that NACA's principal mission should be research into the fundamentals of aeronautics, however, the aircraft industry continued to rely on NACA as a problem-solving agency. The pressure and culture for quick fixes prevailed within the agency as the United States entered the conflict in Korea—war justified the need for expediency in solving various performance challenges and resulting system problems. (Hunsaker, 1956, pp. 267-268)

Closer inspection reveals that at this time in aviation industry's history, the valuable lessons learned in the previous decade had not proliferated broadly into the overall aviation industry culture.

The windfall discovery of extensive German aeronautical research programs after WW II compelled both the Army Air Force (AAF) and NACA to propose airplane research programs to Congress. For the AAF, struggling to achieve independence from the U.S. Army, the proposed new role was founded on justification that no other agency could do its flight research and development. The AAF's safety program development since the earliest days of aviation lends credibility to that position. The mission was also a logical one for NACA as an extension of the research roles they had established in aeronautical systems development.

In 1946, a team was assembled at Muroc Army Air Field, California [present day Edwards Air Force Base (AFB)] to begin the effort between the AAF, NACA, and research project manufacturer Bell Aircraft. Major General Albert Boyd, commander of Wright Field Flight Test Division and later the Flight Test Unit at Edwards AFB, reflecting on the success of the X-1 research vehicle, said of the accomplishment, "[This work stands] as a monumental tribute to both the USAF and the NACA, since the sonic barrier monster was not only completely licked, but a blow-by-blow account of its defeat was recorded for future use" (Air Force-NACA Conference, 1948).

President Harry S. Truman recognized the partnership's accomplishments and presented the Collier Trophy for significant contributions in aerospace research to United States Air Force (USAF) Captain Chuck Yeager, Mr. Larry Bell of Bell Aircraft, and John Stack of NACA.

The methodologies employed during the research conducted at Edwards AFB, including the work of the U.S. Navy (USN) and NACA on the Douglas Aircraft Company D-558, affected the designs of future military aircraft, which profited from the system acquisition approach employed by the military services. Follow-on tests of improved versions of the X-1 and a new design, the X-2, methodically tested the outer regions of supersonic flight in an effort to better understand hypersonic flight, which had to be mastered to escape the bounds of earth. Proven designs found their way into future aircraft systems. More reliable systems translated to lower mishap rates and by the early 1950s the entire aviation industry (commercial and military) were profiting from this research. Incorporating a proven acquisition process with system safety engineering at the basis, the military services and NACA were moving forward on a new experimental aircraft that would employ a rocket propulsion system capable of flying to nearly 400,000 feet—the upper boundaries of the atmosphere where the traditional knowledge of aerodynamics were almost unrecognizable (Swenson et al., 1996)

The assault that took place on the upper regions of the atmosphere was arguably second only to the Wright Brothers conquering of sustained flight just 50 years previous. In 1952, Robert Woods of Bell Aircraft Corporation began efforts to promote manned space flight by urging the U.S. to analyze the basic problems of space flight. He further recommended research into a suitable test vehicle for space flight. Unfortunately, the urgency and resources for such an endeavor were simply not available at that time.

By March 1954, however, the combined efforts of the USAF, USN and NACA's laboratories at Langley, Ames, and the High Speed Flight Station at Edwards AFB produced contracts to study the concept and ready the studies for hypersonic flight. Using a cradle-to-grave approach, the first feasibility studies were used to identify all major hazards in detail and initiate means to either eliminate or reduce the severity of those known threats. Recognizing there were regions of flight that could not be duplicated in wind tunnels, the test program established goals that recognized materials and technology limitations, while leaving enough flexibility to modify the program as they discovered new facts. NACA Langley requested that boundaries to the development be established, calling for a flight research tool to be used to obtain the maximum amount of data for the development of follow-on systems in a three-year time limit. This was a brute force effort on its part to obtain flight information as soon as possible (Stillwell, 1964).

History highlights a culture of expediency pervading within NACA and its successor NASA. This could be as a result of the motivating factors during WW II and the Korean War that provided contracts to NACA for quick fixes. Additionally, their use of unmanned test vehicles launched to gather test points had been successful but lacked the motivation or oversight of those who manage human lives. In the interest of time, higher risks can be accepted during unmanned test flights in a fly-fix-fly approach to testing, however the paradigm might be a difficult one to break when attempting to reduce the overall system risk in later human endeavors. Clearly, NACA's focus was test data.

It is difficult to prove, but certainly noteworthy, that it appears the NACA research engineers were willing to accept more risk than those who would fly the aircraft. In the design of the X-15, NACA:

> Emphasized that the airplane should not become encumbered with systems or components not essential to flight research. These requirements were tempered by knowledge that a three-year development schedule would leave little or no time to perfect systems and subsystems before first flight. (Stillwell, 1964, p. 3)

With Department of Defense (DoD) oversight, a Memorandum of Understanding was signed between the military services and NACA establishing guidelines for the program, with lines of authority and control. Establishing these fundamental understandings among the various agencies "had no small effect on the successful pursuit of the research. In essence, it states briefly that each partner agrees to carry out the task it is best qualified for" (Stillwell, 1964, p. 5).

The USAF Aeronautical Systems Division (formerly the Wright Air Development Center) provided a shepherding role during concept development. In December 1954, an agreement between the military services and NACA was accepted with operational arrangements similar to those in the X-1 and other experimental flight tests conducted at Edwards AFB. The USAF was responsible for finding a contractor and supervising design and construction; both the USAF and the USN would fund the project. Technical direction would come from NACA.

The Los Angeles Division of North American Aviation, Inc. (NAA) won the design based on past performance and safety records. (NAA had already demonstrated system safety approaches in development of other systems and Los Angeles was the aerospace Mecca of system safety engineers.) Although NACA studies had possible solutions for major technological concerns, the basic challenge of how to build an airplane capable of Mach 6 speeds flying to 250,000 feet was not precisely defined and the aerodynamic information necessary was incomplete or simply not available. Throughout this phase, the DoD program managers were continually forced to provide a reconciliation of differing viewpoints as each partner in the project had different objectives. The X-15 was to become the product of one year of study, one year of design and one year of construction. These types of broad milestones are frequently used in the early phase of system safety planning groups.

The preliminary hazard identification effort during the design concept phase did not limit safety concerns to only the X-15 pilot. The potential danger to the B-52 crew (stage 1 propulsion system) also had to be considered, as an explosion of the X-15 during separation and initiation of self-powered flight could be a serious threat to the launch vehicle. For this reason, safe operation of the X-15 (stage 2 propulsion systems) became a primary objective. Reaction Motors Inc. (soon to become a division of the Thiokol Chemical Corporation) was chosen for the task. Reaction Motors had designed and built many rocket engines for X-series research projects and, in over 384 flights, had never had a catastrophic engine failure. The technical specifications for the X-15's XLR-99 engine outlined that:

> Any single malfunction in either engine or propulsion system should not create a condition which would be hazardous to the pilot. [Engineers set about an exacting design philosophy]... endeavoring to prevent malfunctions... [by designing] the engine so that the conditions following any malfunctions would be controlled before they became hazardous. (Stillwell, 1964, p. 5)

The result of these efforts was a 96% reliability rate, a figure that shames other missile engines in this era. This is the essence of system safety philosophy in the concept and design phases, clearly demonstrating its practice within the military services, NAA, and the rocket motor division of the Thiokol Corporation in 1954.

A vibrant product improvement and development program continued throughout the operational life cycle of the X-15. In 1956 the aerodynamic design was established, while NAA pushed the limits of available materials with heat resistant Inconel-X to complete the structural design. In 1958 the introduction of new fabrication techniques happened, while the development-test program during the years 1959 to 1964 produced many examples of product improvement during the operational phase of use.

Using a system approach to design and acquisition does not guarantee a risk-free program without unexpected surprises. However, the frequency, severity, and total cost of such an event should be a calculated risk—not a gamble—accepted by someone at the appropriate level of decision making. The X-15 project had a few surprises. One aircraft broke in half on landing. A more spectacular event occurred during ground tests of the XLR-99 engine when the engine violently exploded due to a sub-component failure. This mishap would most certainly have cost test pilot Scott Crossfield his life had this occurred in-flight, however the controlled environment in which the test was conducted (land based) combined with the cockpit design, aircraft structure, and the life support systems built into the design allowed him to survive (Stillwell, 1964).

The flight test program progressed from flight to flight on foundations of discovery. Since testing involved venturing into the unknown, operational considerations required an answer to every possible issue. What-if questions involved many man-hours of fault tree analysis before allowing a pilot to potentially face such a critical event in flight. Analog and then digital computers were used to simulate flights on the ground, thus allowing pilots and engineers to work literally side by side as they test-flew a mission on the ground before any actual flight attempt. The operational margin of safety was the governing issue of the program. Each flight became an extrapolation of previous experience to more stringent parameters.

The significant accomplishments of the X-15 program are often compared to those of the unmanned efforts in space exploration during this era. The advantages or disadvantages of human versus automated machine are often at the center of the debate and continue to this day. However, the success rate at achieving research objectives over a five-year period, covering 120 flights with a 92% mission success rate certainly speaks highly of the reliability designed into the X-15 program. Was it the man in the cockpit or the men on the ground and the value they placed in human life aboard the research vehicle that contributed to the success of this project? Did the fact that the Flight Controller, responsible for the coordination and control of the complete mission, and one of the experienced test pilots, insure the tough issues were resolved with an err toward conservativeness? How were these conflicting positions resolved when the cultural differences between the various organizations represented in the research project gridlocked in a heated debate? Were system safety processes responsible for the differences noted between this and other programs outside of DoD management? These and other behind-the-scenes issues are outside the scope of this study; however, the strong commitment to safety of those in leadership positions far outweigh less formal processes left to resolve differences on their own. Clear-cut guidance from above is essential when the tough questions surface, as they inevitably do.

The successes of the X-planes programs, managed by the collaborative effort of the military services and employing system safety processes, even though it was still an evolving process, boosted the prestige of NACA as a research agency. The reputation for thorough aeronautical research that NACA quietly built in the interwar period of the 1920s and 1930s continued to grow until the organization transformed into a new space agency, almost overnight, when President Eisenhower signed the Space Act on July 29, 1958 (National Aeronautics and Space Act of 1958).

**USAF Leadership into Space**

The X-15 operated in what was termed the near-space equivalent. (Its pilots wore astronaut wings and dealt with re-entry issues much more demanding than a capsule re-entry from space into the earth's atmosphere.). However, the expediency felt by some to simply place a man into orbit around the earth compelled research engineers to seek other solutions to the goal as winged craft were taking too much time to accomplish that objective.

In one camp, aerodynamicists were working on a hypersonic research aircraft with delta wings to handle the heat of atmospheric re-entry using a program managed by the USAF. The other camp was reviewing how to quickly modify an Intercontinental Ballistic Missile (ICBM) launch vehicle (also managed by the USAF) to propel a ballistic capsule system, irreverently referred to as man in a can, into low Earth orbit. The capsule method was nothing more than an extension of re-entry vehicles used in the development of ICBMs. The limiting factor for adding a man was payload capabilities of existing launch vehicles and the weight of the capsule with its life support systems. Reliable missile technology did not currently exist with an ability to lift the heavier (winged) hypersonic-glide vehicle into orbit. For this reason, industrial firms were mainly investigating the ballistic capsule option as the quickest solution to orbiting a manned vehicle even though winged craft were already operationally testing the lower regions of space. In late 1956, NACA agreed in principle with the USAF Air Research Development Command (ARDC) to cooperate on the manned glide rocket research system. By January 1957, the NACA Ames group reported conclusions that a rocket-powered vehicle for efficient hypersonic flight was feasible. A minority report from a NACA Langley aerodynamicist in the Flight Research Instrument Research and Pilotless Aircraft Research Division (PARD), recommended a spherical capsule be considered for global flight before a glide rocket. There was little interest expressed in work on this proposal within the main body of NACA at this time (Swenson et al., 1966).

NACA study groups continued the investigation of manned glide rocket concepts. A 1957 study on the Preliminary Investigation of a New Research Airplane for Exploring the Problems of Efficient Hypersonic Flight (NACA) supported a raised-top, flat-bottom glider configuration. Soon thereafter, on October 4, 1957, the opening bell of the space race sounded. The U.S.S.R. had launched a satellite into earth's orbit and altered our nation's attitude about space exploration.

Even though the official position of the Eisenhower Administration was a no race policy, a new urgency was adopted and efforts to expedite space exploration were accelerated. On October 15, 1957, representatives from the various NACA laboratories met at the Ames center in an effort to resolve conflicts in aerodynamic thinking. Dubbed the Round Three Conference, the meeting produced the fundamental concept for the X-20 project. A small contingent returned to Langley convinced that maximum concentration of effort to achieve manned orbital flight as quickly as possible meant use of the ballistic-capsule approach. Dr. Maxime A. Faget, speaking to the entire conference, declared that NACA had misplaced its research emphasis on the hypersonic-glide option and should work on orbiting a man as fast as possible (Swenson et al., 1966).

In December 1957, Lieutenant General Donald L. Putt, USAF Deputy Chief of Staff for Development, moved to establish a directorate-level program for aeronautics within the USAF. The effort was quickly opposed by the Secretary of Defense, who was not supportive of any military services venturing into astronautics despite their ongoing research efforts. The newly appointed DoD Director of Guided Missiles accused the USAF with trying to grab the limelight and establish a position. It is interesting to note the

Secretary of Defense, a political appointee of President and retired General Dwight D. Eisenhower, would fail to recognize the value added from the DoD's own acquisition program and chide the USAF for continuing to do what President Truman had spoken so highly of in the effort to break the sound barrier. It appears the politics of space exploration had overridden common sense.

The directorate idea was shelved and USAF Headquarters (HQ) ordered the ARDC to prepare a comprehensive review of the astronautics program, including estimates of funding and space technology projections over the next five years. ARDC had already been working on a 15-year plan for USAF research and development in astronautics and quickly reduced its finding down to a 5-year plan. General Putt wrote to NACA Director Hugh L. Dryden on January 31, 1958, formally inviting NACA to participate with the USAF in both the boost-glide research airplane (the Dyna-Soar) and a manned one-orbit flight in a vehicle capable only of a satellite orbit.

> Dryden informed General Putt that NACA was working on their design for a manned space capsule and would "coordinate" with the USAF later when they completed their studies. By this date, NACA had already developed its own goals of managing manned space exploration and was beginning to spread its wings. (Swenson et al., 1966, p. 74)

Behind the scenes, NACA HQ administrators saw an opportunity for the agency to broaden their activities by moving into astronautics. Some managers within NACA wanted to leave behind its principal role in research projects and expand into system development and flight operations, despite having only been a participant in such programs with no managing experience. Seeking a leadership role in the uncertain world of contracts, full-scale flight operations and public relations, NACA fixed their sights on a broad-based national space program with a principal objective to demonstrate the practicality of manned space flight. During the ten months between the first Sputnik launch and the establishment of a manned space program under a newly designated agency, NACA leadership continued to ensure their current role in traditional research and consultation while at the same time unleashing an ambitious team of engineers scattered throughout the NACA establishment to allow themselves to take a dominant role in the nation's new objective in space (Swenson et al., 1966). The DoD was slowly abdicating its ability to positively influence the nation's space efforts. At least five years of successful system safety management was soon to be pushed aside as project management of space exploration was handed over to a new entrant into the big leagues of government contracts, public relations and Congressional oversight.

President Eisenhower's stated U.S. policy held that space activities should be conducted solely for peaceful purposes. The objectives of guided missile projects of the time reflected this policy. In a letter to Soviet Premier Nikolai Bulganin, dated January 12, 1958, the President stated;

> Outer space should be used only for peaceful purposes... Can we not stop the production of such weapons which would use or, more accurately, misuse, outer space, now for the first time opening up as a field for man's exploration? Should not outer space be dedicated to the peaceful uses of mankind and denied to the purposes of war? (Eisenhower letter to Nikolai Bulganin, 1958)

By April 1958, members of Congress would introduce a total of 29 bills and resolutions calling for re-organization of the nation's space efforts. The Senate Preparedness Investigating Committee under Senator Lyndon B Johnson summarized its findings with recommendations to establish an independent space agency. During these times of transition, the military services dutifully continued their planning of space programs using proven system acquisition practices in the hope of securing their role in future space programs and with the knowledge that a newly formed organization would take several months if not years to take the reigns currently held by the various research program managers within the armed services.

**NACA Covets a Leadership Role**

Consistent with Eisenhower's peaceful space policy, the Advanced Research Projects Agency (ARPA) of the DoD had been used as an interim oversight agency pending establishment of a new civilian-controlled aerospace management organization. Top-level management of these programs shifted from the DoD to a completely new organization in short order. President Eisenhower ordered an 18-member Presidential Scientific Advisory Committee (PSAC), chaired by James R. Killian, Jr., President of MIT, for advice on these matters. Eisenhower's directions to this committee were to draw up two documents: (a) a broad policy statement justifying government-financed astronautical ventures and (b) a recommendation for organizing a national space program. The early PSAC work was dubbed the Killian Committee and was divided into two subcommittees. One subcommittee was charged to develop policy and was headed by Edward H. Purcell, a physicist and executive vice-president of Bell Telephone Laboratories; the other subcommittee developed an organizational structure and was led by Harvard University physicist James B. Fisk. (Swenson et al., 1966).

Two physicists, one a corporate leader and the other an academic, developed the policy and organizational structure of a neophyte flight research, development, and operations organization charged with conquering this new flight environment called space. The organizational work was completed first and the subcommittee produced a crucial report to the PSAC in February 1958. A new agency built around NACA would be created to manage a comprehensive national program in astronautics, emphasizing peaceful, civilian-controlled research and development. The PSAC report, titled Introduction to Outer Space, was published in March, and stated, "the compelling urge of man to explore and to discover, the defense objective, national prestige, and new opportunities for scientific observation and experiment are four factors which give importance, urgency, and inevitability to the advancement of space technology" (PSAC, 1958, p. 2).

The President's intense conviction that space should be primarily reserved for scientific exploration, not military exploitation, called for the establishment of a "National Aeronautical and Space Agency...which would absorb NACA and assume responsibility for all space activities...except... those projects primarily associated with military requirements" (Swenson et al., 1966, p. 84). A single executive and a 17-member advisory board called for extension of the NACA Main Committee concept with a centralized authority that would "have not only research but development, managerial, and flight operational responsibilities" (Swenson et al., 1966, p. 83). This was a significant executive decision that launched a loosely woven group of research scientists and engineers into a national agency, unlike its NACA predecessor, with extensive authority for contracting research and development projects. The USAF and USN lost management control of the research programs into outer space and would take a subordinate advisory or support role in non-atmospheric flight operations. Would the valuable experience in flight test and research program management be transferred as well?

**NACA's Focus**

In addition to their contract work to date, engineers at all NACA installations had been stepping up research in materials and aerodynamics preparing for large-scale development and operational activities. The primary purpose of NACA's work to this point in its history had always been to improve the performance of piloted aircraft. Different philosophies existed within the various NACA labs and not everyone was convinced that the agency's best interests lay in managing programs and carrying out satellite launchings. Many of the more focused research engineers endorsed the official NACA HQ position that, "with respect to space it neither wanted not expected more than its historic niche in government-financed science and engineering...it should remain essentially a producer of data for use by others" (Swenson et al., 1966, p. 77). The prevailing attitude within the Ames Research Center about the prospect of managing programs was exceedingly distasteful. The Ames engineers enjoyed the quasi-academic focus on research, the outside-of-the-box thinking it was noted for and the freedom from political pressures. This same attitude did not exist at the other two labs or at the High Speed Flight Station at Edwards AFB. The years of direct participation with USAF/USN and research aircraft manufacturers provided Walter Williams and his staff at the Flight Station a rather clear operational orientation. The NACA Lewis and Langley staffs apparently understood the magnitude of the effort, but seemingly minimized it as they only stated it would be quite a challenge to manage a program versus simply advising the military or industrial providers. Most of NACA did approve of the scientific measures provided by President Eisenhower to Congress espousing their ideas.

In the various NACA Flight Research facilities at Langley, Wallops Island, and Lewis, there were engineers who had experience in operational issues while developing airfoils, however, they had always turned those research findings over to DoD management. Now, enticed by the prospect of national prominence, vast amounts of government funding, and the surge of emotions delivered by the Soviet's first-in-space achievements, it is easily recognizable why an ambitious group of research engineers seized the opportunity to put their expertise to work.

**Man in a Can Prevails**

In the months following the Soviet satellite launchings, NACA's attention to spacecraft design accelerated as they realized their nose-cone research for ICBMs was applicable and transferable to manned vehicles as well. While still working with the USAF on plans for a manned orbital project in March 1958, they had in fact been given official sanction to provide work they had already been accomplishing. Thus the Langley engineers had found a clever way to perform early development work for their own ambitious enterprise—Project Mercury.

The primary advocate behind much of this activity was Dr. Faget, head of the Performance Aerodynamics Branch in PARD, who embodied the traditional Langley research culture that preferred to test aerodynamic theories on instrumented free-flight vehicles versus wind tunnel testing. Dr. Faget was on record favoring the quickest solution to space, the capsule option, while NACA Ames was avidly pushing the semi-lifting body concept, without the responsibility to build the vehicle or manage the program.

The choice between the semi-lifting configuration (X-20 concept) favored by the Ames group and the capsule device really was an academic one to supporters of the capsule option. Accepting the assumption that a manned satellite should be placed into low-earth orbit as quickly as possible, the Atlas ICBM would have to serve as the launch vehicle for the relatively lighter capsule. The Atlas ICBM was undergoing a rigorous systematic review toward status as a reliable rocket (per military specifications) and it was the only launch vehicle near operational readiness. These questionable caveats limit the choices and build a paradigm around the option, which allegedly uses the simplest, quickest, and most dependable approach—ruling out the heavier, semi-lifting vehicle that would have required adding an extra stage to the Atlas rocket. Interestingly enough, Faget did not have detailed data on the Atlas' design performance; such information was highly classified and he lacked clearance.

While the engineers at NACA accelerated their designs, tests, and plans, and Congress received Eisenhower's space bill, the organizational transformation of NACA began. After the White House Advisory Committee on Government Organization recommended that a national civilian space program be built around NACA, Director Dryden and his subordinates in Washington began planning the revamping that would have to accompany the reorientation of NACA functions. On April 2, 1958, as part of his space message to Congress, Eisenhower instructed NACA and the DoD to review the projects then under ARPA to determine which should be transferred to the new civilian space agency (NASA, n.d.).

NACA and DoD representatives, in consultation with Bureau of the Budget officials, reached tentative agreements on the disposition of practically all the projects and facilities in question, with the notable exception of manned space flight. In accordance with Eisenhower's directive that NACA "describe the internal organization, management structure, staff, facilities, and funds which will be required" (Rosholt, 1966, p. 8), NACA set up an ad hoc committee on organization. The Space Act additionally called for a civilian-military liaison, appointed by the President, to ensure "full interchange of information and data acquired in NASA and Defense Department programs" (Swenson et al., 1966, p. 98).

The U.S. military systems management experiences of the past decade would not make the transition. The handoff from DoD management of flight research, especially in the area of system acquisition and safety, to the new national space exploration agency was not going to be a clean one. Ambitious research engineers, dividing their attention between their traditional roles in support of government projects and total management of their new enterprise, essentially failed to capture valuable lessons learned by the USAF and USN management of the activities at Edwards AFB. Political pressures within NASA to fulfill this new destiny forced many of those dissenting opinions to join the team that was now taking control of a program in support of a national objective. The pressure to think as the group thought must have been tremendous for those researchers and engineers who had been educated in the school of hard-knocks at the various military test facilities over the last decade. This was certainly not the last time that group-think would become problematic for the space agency.

**Quantitative System Safety Programs**

In 1958 while NACA engineers were maneuvering to take over research and development as the lead organization in the space race, the USAF was pressing ahead with the successful acquisition programs that had been evolving for the past five decades. The first quantitative system safety analysis effort to address hazard prevention in new designs was initiated with the X-20 Dyna-Soar program. Due to its design criteria to fly beyond the atmosphere, the X-20 was recognized to have unique emergency, rescue, and survival problems. Fulfilling a safety objective that states each person should be allowed to live and work under conditions in which hazards are known and controlled to an acceptable level of potential harm, system safety pioneers such as USAF Colonel George Ruff, of the Ballistics System Division, participated in initiating the first system safety programs required of prime contractors. (Roland & Moriarty, 1983) Unfortunately, NACA management did not learn this during their operational exposure at Edwards AFB. Predictably it was not transferred to their follow-on agency, NASA.

While safety experts struggled with hazards, politicians dealt with their own threats—the budget. That same year, the USAF attempted to invite NACA to join them in the man in space program on either the boost-glide (X-20) or the manned capsule (Mercury) projects. Director Hugh Dryden signed a formal agreement on the boost-glide research while rejecting the offer to join in the capsule option, as they were working on their own designs. This somewhat disingenuous act was self-serving for NACA, and readily points to how the X-20 program was overcome by politics and leapfrogging national priorities. Without doubt, the X-20 program would have escorted system safety concepts into the exploration of outer space, just like those ballistic missile programs managed by DoD. The budget for the X-20 was restricted. Funding waned as the nation embraced the man in a can approach. Ultimately, in December 1963 Secretary of Defense Robert McNamara canceled the project and a majority of USAF/USN participation in the exploration of space (Swenson et al., 1966).

The military services never abandoned their commitment to system safety, and continued to use a system approach as ballistic missile development pressed ahead during the late 1950s and early 1960s. In July 1960, a system safety office was established at the USAF Ballistic Missile Division in Inglewood, California. In April of that year, the USAF had published the first system-wide safety specification titled BSD Exhibit 62-41 (Stephenson, 1991). The Naval Aviation Safety Center was the first to become active in promoting an inter-service system safety specification for aircraft, using BSD Exhibit 62-41 as a model. By 1962, system safety was identified as a contract deliverable item on military contracts and that same year Roger Lockwood held organizational meetings in the Los Angeles area of what would become the System Safety Society—a professional organization incorporated as an international, non-profit organization dedicated to the safety of systems, products, and services. (Stephenson, 1991). By 1964, The University of Southern California had developed a Master's degree program to support industry demands for these specialties. BSD Exhibit 62-41 was broadened in September 1963, as MIL-S-38130, which in 1969 became the model for MIL-STD-882, a standard that has been updated over the years and exists today (USAF, 2000).

**Project Management by Trial and Error**

The rapid growth of NASA from a research-support agency to that of primary agency and program management for space exploration points to a hazard in itself and offers hindsight into the executive decision to make such a bold move. Almost certainly there was no intent to abandon the successful programs and relationships forged by the USAF/USN and even NACA, but the reality of politics is that once you lose control of the purse strings you often lose input to the direction of a program. Almost immediately discussions between the managing NASA agency and the manufacturer of various components of the ballistic capsule option highlight the lack of understanding and commitment, from the top down, to maintain previously established DoD relationships with the contractors. Debates of semantics broke out and a numbers game was tagged to some of the developmental efforts to quantify various engineering decisions. Some complained that reliability was a slippery word, suggesting more than could be proven. Of course in other endeavors, including aviation and missile acquisition, it had already achieved a recognized discipline as an engineering practice

In mid-1959, well after design and development work on major systems of the Mercury capsule were well under way, a search for a means of predicting failures and increasing reliability was modestly undertaken by NASA's Space Task Group (STG) and McDonnell Aircraft Corporation (MAC) engineers. This paradigm was consistent among other groups working in support, which also had not used formal processes to achieve quality control in various systems and sub-systems. "Mathematical analyses of the word *reliability* both clarified its operational meaning and stirred resistance to [a] statistical approach to quality control" (Swenson et al., 1966, p. 178).

Aviation research and development in the 1950s had witnessed a remarkable growth in the application of statistical quality control to ensure the reliability of various systems. The science of operations analysis and the art of quality had emerged by the end of the 1950s as special vocations. Amazingly, in what can only be viewed as a narcissistic not-invented-here attitude, STG executive engineers overlooked DoD examples and studied new methods for more scientific management of efficiency provided by the automobile industry.

By 1959, when it was finally decided to organize engineering design information and data on component performance, the definition of critical parts had to be established. The STG and MAC worked to create that definition while analysis suffered. NASA HQ sought outside help and USAF systems engineers were used. They pointed to certain semantic problems in the primitive concepts being used for reliability analyses by NASA.

Amazingly, some of the debates centered on questions such as, what constitutes a system, and how should we define failure. An indication of a more mature process was the question, what indices or coefficients best measure overall system performance from subsystem data (Swenson et al., 1966, p. 179).

Indications of the level of resistance to these proven methodologies were the positions taken by some creative engineers who felt the features of reliability prediction were so subjective that many seriously questioned the validity and even the reliability of reliability predictions. One apologist in this field admitted, "Reliability engineering may seem to be more mysticism and black art than ...down-to-earth engineering. In particular, many engineers look on reliability prediction as a kind of space-age astrology in which failure rate tables have been substituted for the zodiac" (Swenson et al., 1966, p. 179).

Although a skeptical attitude did exist within STG, newly arrived Associate Administrator Richard E. Horner brought a staff of mathematicians and statisticians led by Nicholas E. Golovin, who transferred from the USAF to NASA some of the mathematical techniques lending quantitative support to demands for qualitative assurance. NASA HQ and the Langley laboratory worked at cross-purposes for nearly a year as reliability and safety were debated. NASA HQ worked aggressively to align the STG and MAC worked to change their methods. Increasing the level of reliability became a major goal during testing in 1960.

**Sorting Wheat from Chaff**

Statisticians, and actuaries, working with large and statistically significant amounts of data, have long been able to achieve excellent predictions (as witnessed in the insurance industry's successes) by defining reliability as probability. However, this has never provided the ability to predict what would happen in a specific instance. STG and MAC managers working a specific system or project ridiculed probability theory and continued to reference the numbers game, failing to accept the statistical value of such efforts. They felt that reliability could be demonstrated as ability. Harry Powell, the senior statistician at Space Technology Laboratories for the Atlas weapon system, elaborated on this debate while man-rating the Atlas rocket.

> If reliability is to be truly understood and controlled, then it must be thought of as a device, a physical property which behaves in accordance with certain physical laws. In order to insure that a device will have these physical properties it is necessary to consider it first as a design parameter. In other words, reliability is a property of the equipment, which must be designed into the equipment by the engineers. Reliability cannot be tested into a device and it cannot be inspected into a device; it can only be achieved if it is first designed into a device. Most design engineers are acutely aware that they are under several obligations—to meet schedules, to design their equipment with certain space and weight limitations, and to create a black box (a subsystem)

> which will give certain outputs when certain inputs are fed into it. It is imperative that they also be aware of their obligation to design a device which will in fact perform its required function under operation conditions whenever it is called upon to do so. (Swenson et al., 1966, p.180)

A generally accepted standard in probability theory states the reliability of a system is exactly equal to the product of the reliability of each of its subsystems in series. The obvious way to mitigate risk (a hazard with measured probability multiplied by severity) is to place two mission critical components in parallel to perform the same function. If one system fails, the other assumes the critical function. Redundancy is a favored technique used to ensure reliability.

The MAC production of the Mercury capsule was taking longer to build than forecast primarily as a result of limited system integration within the project. Fuzzy lines of authority and communications without the benefit of the sharing of intelligence across organizational lines of reporting among the various activities involved in the program were hindering an efficient process. Even with these strong indicators of a flawed acquisition management style, STG and MAC felt the basic dispute over safety versus success, or positive versus negative redundancy, could be settled only with actual flight test experience, that is, a fly-fix-fly approach.

A precaution for safety program managers is highlighted by this historical event. Even though safety programs are in place, a lack of standardization and commonality of purpose among line organizations will result in non-effective monitoring, evaluation, and eventually loss of control in safety efforts throughout an organization.

As Project Mercury matured, the costs of solutions to technological and training problems rose. NASA administrators appeared frequently before Congressional oversight committees and admitted their growing concern with manned space flight, as opposed to other space activities. T. K. Glennan requested a supplemental $23 million appropriation to the fiscal year 1960 NASA budget of $500.6 million and justified $19 million of that extra sum on the basis of the urgent technological demands of Project Mercury. "It would be no exaggeration to say that the immediate focus of the U.S. space program is upon this project" (Swenson et al., 1966, p. 180), stated Glennan, waving the national objective in front of those with the purse strings in hand.

In February 1960, at NASA HQ in Washington, a high-level debate over the meticulous versus the statistical approach to reliability was vigorously discussed between NASA HQ, STG, and MAC representatives. They met in conference to decide what weight to give the numbers game in a frank and confidential estimate of readiness. The Chief of Reliability, John C. French, defended STG's practical procedures against the theoretical approach of NASA HQ's Nicholas E. Golovin. Eugene Kunznick also outlined the particulars of the prime contractor's quality control measures, and delivered the third revision of MAC's reliability program. Walter Williams presented STG's latest views on operational flight safety, and STG generally endorsed MAC's reliability program review as its own. At the conclusion of the meeting, NASA HQ was not convinced with the efforts taken by STG and MAC.

> Reliability issues caused scheduling delays and raised eyebrows toward the end of June 1960, when the qualification flight tests had been postponed by at least six months. Capsule system testing needed a completely new process, including organization, procedures, and test equipment. The top technical managers of Project Mercury and STG began to recognize some of their flawed thinking regarding reliability and admitted that quality control and reliability testing had to be raised to a new level. This effort targeted not only man and machine but man-rating (ensuring the equipment is certified safe for humans) and machine-rating (ensuring the human can safety operate the machine) processes as well. (This is consistent with today's 5-M model, which addresses the man, machine, media, management and mission as part of the entire human performance equation in system approaches.) A NASA HQ internal note recorded some of the issues:
>
> One of the major problems facing Mercury management is the conflict between a real desire to meet schedules and the feeling of need for extensive ground tests. The MAC capsule systems tests are not meeting this need since they were not intended for this purpose and since the pressure of time sometimes forces bypassing of some details (to be caught later at the Cape). Further, there has not been time available (or taken) on the part of MAC to study and update the CST [Capsule System Test] procedures and SEDR's (sic) [Service Engineering Department Report]. It was concluded that a group (mostly MAC effort) should be set up to review and update the CST and SEDR procedures. It is also firm that no details will be bypassed in the Cape checkout without the express approval of STG management (Swenson et al., 1966, p. 258).

Risk management was evolving at NASA. At the highest level within NASA, Administrator Glennan and associates recognized that the opportunity to make significant changes in NASA's organization and procedures would not exist much longer. A report written by a consultant firm McKinsey and Company revealed that NASA's record in supervising out-of-house efforts was spotty. Their findings highlighted that NASA had neglected to manage certain basic prerequisites in their oversight of the various contractors. NASA had failed to provide comprehensive statements of work, sufficient funding, ill-defined tasks, and ineffective contractor supervision, as well as failing to provide properly focused technical responsibilities—a NACA strong suit in previous DoD programs. (A basic problem was NASA's tendency to establish two channels of supervision—one from HQ, the other from the field center.

**New Leadership**

January 1961 saw a change in the nation's administration and a change at NASA HQ. President-elect Kennedy commissioned an ad hoc committee on space, chaired by Jerome B. Wiesner. The press received the hastily prepared report with mixed reactions.

> Roscoe Drummond, a syndicated columnist... charged that no Kennedy representative had consulted NASA to study the workings of the agency nor had any Kennedy official read or listened to briefings that had been prepared for the new leaders by outgoing Administrator Glennan and his staff. (Swenson et al., 1966, p. 360)

The press was also highly critical of the political transition process, noting that Administrator Glennan had departed from Washington on Inauguration Day, January 20, 1961, with no one named as a successor. In accordance with Washington protocol, Hugh L. Dryden had resigned as well.

The report was tacitly adopted when President Kennedy appointed Jerome Wiesner Chairman of the PSAC for the new administration, although Aviation Week stated that President Kennedy had rejected the committee's advice and decided to accept the risk if the first manned shot failed (Hotz, 1961). This kind of executive decision with full knowledge of a formal risk analysis is certainly within bounds of a system safety program. However, Drummond further charged that no persons representing the Kennedy administration had read or been briefed regarding the workings of NASA as prepared by the outgoing Administrator. This coupled with a superficial review of the workings of such an immense project as Project Mercury is insufficient to adequately allow for an informed decision and absent these kinds of review, accepting risk at this point appears to be more politics than science.

An interesting sidebar to this political intrigue is that the Eisenhower administration's last budget recommendation for manned space flight research and development was to cut $190.1 million from NASA's fiscal 1962 $1.1 billion total budget. The Bureau of the Budget in January allowed a total NASA request of $919.5 million, only $114 million of which was earmarked for manned space flight, including Project Mercury. Some $584 million was requested for military astronautics within the DoD budget that same fiscal year. (Swenson et al., 1966)

On February 2, 1961, Senator Robert S. Kerr, chairman of the Senate Committee on Aeronautical and Space Sciences, presided over the confirmation hearings for a new NASA Administrator. James Edwin Webb, experienced businessman, lawyer, Director of the Bureau of the Budget, and Under Secretary of the Department of State from 1949 to 1951, who had also served as a director of MAC. Armed with a resume full of bureaucratic qualifications, Mr. Webb certainly had a technical challenge facing him. It was felt that even though his background was not that of a scientist, he was widely known in governmental and industrial circles for having worked with scientists and engineers. From history's recordings, one can feel safe in presuming that during Mr. Webb's stint at MAC he was not exposed to a comprehensive background in system safety management. The Senate confirmed Webb's nomination after he severed all his business connections with MAC.

Even as NASA struggled to launch unmanned test vehicles, it was apparent Project Mercury's ends were merely a means to the greater goal of landing on the Moon. The funding for Project Apollo was under review in Congress as U.S.S.R. Major Yuri Gagarin's flight provided a tremendous impetus to the desires of Americans to continue the race that was now officially a race. Congress appeared willing to appropriate more money than NASA could spend. Robert Seamans, third in command of NASA as Associate Administrator and general manager, actually had difficulty restraining the House space committee's demands for an all-out crash program for a lunar landing. President Kennedy, consistent with one of his campaign promises, reacted to the U.S.S.R.'s manned orbit of earth by saying, "We are behind...the news will be worse before it is better, and it will be some time before we catch up (Swenson et al., 1966, p. 336)."

On March 9, 1961, Representative Overton Brooks wrote to President Kennedy regarding reports in trade journals that the space program might turn toward military oversight. Representative Brooks was concerned the Wiesner report pointed to this as he was also aware of a special PSAC investigating committee of scientists led by Donald F. Hornig. This committee was conducting a top down review of the manned space program. In his letter, Brooks reminded President Kennedy of the spirit and intent of the 1958 Space Act which was to:

> Ensure that control of space research remain in civilian hands so that resulting information and technological applications would be open for the benefit of all enterprise, both private and public. [Further,] too much information would become classified if the military were preeminent in space research, development, and exploration. (Swenson et al., 1966, p. 325)

President Kennedy gave reassurance that NASA's conduct of space exploration would not be placed subordinate to the military. For better or worse the marriage of the neophyte NASA management team and space exploration was now consummated.

**Project Mercury Lessons Learned**

Project Mercury lasted 55 months, from authorization through Gordon Cooper's final MA-9 mission. The earliest planned orbital mission ran 22 months past its originally scheduled launch date and achieved its original objectives (placing a man in low-earth orbit) with John Glenn's MA-6 flight 40 months after formal project approval. From some perspectives this was a good record compared to advanced missile or aircraft development programs, however there were critics who denied the validity of such a comparison given the national priority and virtually limitless funds made available for Project Mercury.

On October 3-4, 1963, NASA and the Manned Spacecraft Center (MSC) held a gala affair in Houston, Texas, called the Mercury Summary Conference. They covered program management, mission performance, astronaut preparation, network operations, and the most recent successes of the MA-9 experiments. Much to NASA's chagrin, along with the official press releases came another document publicly released by four MSC engineers. They outlined procedures following delivery of the MA-9 capsule and necessary actions prior to launch. The authors spoke of quality assurance and component defects found by processes designed to prevent errant components from being installed in various systems. These inspections had produced approximately 720 system or component discrepancies; 536 attributed to faulty workmanship, in the MA-9 mission alone! The unofficial engineer's release stated:

> Thousands of man-hours were expended in testing, calibration, assembly, and installation of a variety of hardware that later failed to meet performance specifications or that malfunctioned during systems tests in a simulated space environment... [Unnecessary delays could have been avoided if] adequate attention to detail during manufacture or thorough inspection before delivery had been exercised. (Swenson et al., 1966, p. 507)

The history of Mercury spacecraft system acquisition presented a good object lesson in how not to manage a major program. The tone of the public relations coming from NASA was to attack the industry, failing to see their role in the oversight of those contractors. The Government Accounting Office was criticizing NASA and fueling attacks on the upcoming great *moondoggle*, as it was irreverently being called. NASA failed to recognize exactly what had gone wrong.

**Post Project Mercury Lessons Learned**

The effort to place man in orbit required 12 prime contractors, 75 major subcontractors, and approximately 7,200 sub-subcontractors. NASA employed approximately 650 workers from STG and 710 from MSC and, conservatively, 18,000 DoD personnel supporting each individual Project Mercury mission. The scope of managing the total manpower figure of approximately 2,020,528 highlights the difficulties facing project managers. Knowing what is known today about the management techniques employed by NASA in this conquest it certainly becomes easy to see why the program ran behind schedule and over budget.

Total cost estimates of Project Mercury, delivered in October 1963, show that Project Mercury "had cost $384,131,000 throughout the program, of which 37% went for the spacecraft, 33% for the tracking network, and 24% for launch vehicle procurement" (Swenson et al., 1966, p. 508). Flight operations, research and development costs made up the remainder. The co-mingling of Project Mercury and Project Gemini costs during 1962 and 1963 complicated the final cost accounting. It is generally agreed that through MA-9 NASA estimated the total costs of Project Mercury at roughly $400 million, not considering the hundreds of millions spent by DoD in space research with NACA/NASA contracts.

NASA engineers and physicians listed three primary lessons learned for manned space flight from their experience with Project Mercury. Their medical objectives had been fulfilled through demonstrations that human beings could function normally in space if adequately protected. The X-15 missions had also demonstrated most of this knowledge. The main medical problems to be addressed were simple personal hygiene in flight

Second, Project Mercury had also demonstrated that launch preparations were highly time consuming in an effort to ensure readiness and reliability of both the machines and men (the holistic system). NASA subsequently designed an automated digital system, Acceptance Checkout Equipment, to reduce human error in testing and the time required on the flight line.

Third, mission control requirements had grown to encompass real-time telemetry, tracking, computing, and data display systems. Two more controlling agencies came into being. One was the new Mission Control Center at Houston. The other was the Ground Operational Support Systems, both new organizations reflecting the degree of complex system integration and automation being installed for positive ground control of future space flights. (Swenson et al., 1966).

It appears that the most valuable lessons learned may have been listed in the other section of the report. In the internal reviews on improving their performance for succeeding programs, NASA management spoke of other valuable technological and managerial lessons from Project Mercury. In system design they had encountered problems with safety margins, redundancy, accessibility, interchangeability, and with materials whose behavior under unfamiliar environmental conditions had not been wholly predictable. Regarding qualification of systems and components, they believed there should be more analysis in an effort to make techniques conservative, complete, integrated, and functional. Fabrication and inspection standards carried over from development into manufacturing work should be made still more rigorous, detailed, current, and enforced. Engineers called for continuous upgrading of tests, inspections, and other validation procedures, particularly with respect to interface compatibilities between systems. In configuration control, NASA developers recognized weight control problems and their need to become more responsive and aware of leading indicators in the production and fabrication phases. The managers of Project Mercury now acknowledged, "that methods of management that had worked well enough in the first American manned space project would not suit Gemini and Apollo, already in motion" (Swenson et al., 1966, p. 509).

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