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Chapter 9

From Dealer of Death to Guardian of Life: Man-Rating the Gemini Titan II Launch Vehicle[*]

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Abstract

There is a significant difference between a launcher designed to kill and a launcher designed to protect lives. Performance requirements are different, design parameters are more stringent, and reliability standards are higher. The Air Force Titan II ICBM had to make this transition when it was selected as the launcher for the Gemini program. The Air Force was charged with the defense of the nation, and the Titan II was a proven, acceptably reliable launcher. Changes, it was feared, would add weight and could compromise reliability, hence the Air Force was reluctant to make any revisions.

In man-rating the Titan II, NASA faced technical and managerial problems. The technical issue that caused the greatest difficulty was "pogo," longitudinal shaking in the first stage. Unmanned launchers can accept more "pogo" than can manned launchers, and the Air Force had finally achieved a level acceptable for a nuclear missile. This, however, was significantly greater than what NASA felt it could subject astronauts to in flight. NASA's limit was +/– 0.25 g while the Air Force was willing to accept +/– 0.60 g. It took intervention by Air

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Force General Schriever to prod the Air Force and the contractor, the Martin Company, to resolve the problem. Fuel accumulators and oxidizer standpipes were added, and the goal was finally accomplished.

The elimination of "pogo" was not the only technical issue addressed. A malfunction detection system was installed to provide information to the pilots so corrective action could be taken. Redundant systems were added to assure there would be no launch failures. Tracking, hydraulic, and electrical systems were modified to improve reliability, and the inertial guidance system was replaced by a radio-controlled system. In the second stage, combustion instability had to be corrected (it was statistically stable but not sufficiently stable enough for man-rating) and propellant tanks were lengthened to provide a longer burn time.

The managerial issues included addressing the competing goals and requirements of NASA and the Air Force as well as issues with quality control on the part of the contractor. Costs for the modifications soared and had to be more tightly controlled, and NASA had to force stronger operational controls on the part of the manufacturer.

The changes worked—there were no failures of the Titan II booster during the complete program, and Gemini met program objectives. How this came to be is the focus of this chapter.

I. Introduction and the Problem

There is a significant difference between a launcher that is designed to kill people and a launcher that is designed to save lives, those of the astronauts and ground crews assigned to it. The performance requirements are different and the design parameters and reliability standards are higher and significantly more stringent for the manned launcher. When it came time for NASA to select a launcher for the two-man Gemini program, the only launchers available or even in the pipeline were military launchers—ICBMs. With the only launchers in existence being military, the launcher selected by NASA for its two-man Gemini program was the US Air Force Titan II, and that launcher had to make the transition from an intercontinental ballistic missile to a manned, orbital system.

The history of the Titan II is demonstrative of the type and pace of decision making that took place in the early space program:

June 1960	Contract awarded for the development of the Titan II as an ICBM
Fall 1961	Titan II selected to be the Gemini manned launcher
December 1961	First captive test firing of a Titan II
March 1962	First test launch of a Titan II—suborbital
April 1964	First orbital launch of the Titan II—the unmanned Gemini 1
March 1965	First crewed launch—Gemini 3

Table 9–1: History of the Titan II.

The Titan II was chosen to be a manned launcher for the Gemini program before its first test firing, and the first orbital flight of Titan II was the crewed Gemini 3 mission. Man-rating of the Titan II GLV took on extra significance given that its first orbital flight would contain a two-man crew. The steps and processes involved in making the change from an ICBM to a manned launcher follow.

The concern about the success of any one missile launch is much lower than that for any manned flight. The launching of a missile in anger would not have been an isolated event. A missile launching would have been the result of a detected Soviet attack directed at the United States. The US response would have been a salvo of missiles under the realistic assumption that, while some might self-destruct or be stopped by Soviet defenses, some would not and response success would be assured. With the Gemini launcher, missions were carried out with a single launcher sent aloft one at a time, each one carrying two astronauts. Each individual mission had to be a success.

The concept of man-rating is not a straightforward proposition. Astronaut safety is the central issue, so the question, "How safe is safe enough?" has to be asked and answered. The process is always one of compromise, trading off absolute safety against other mission objectives. For the launch system itself, standard statistical analyses can predict failure rates and a cost-effectiveness analysis can be performed to determine the optimal level of reliability. But, when the human element is introduced, a simple reliance on numbers goes out the window. Human lives are valuable in-and-of themselves, and because of the aura surrounding astronauts at that early stage of the space race, their lives took on an added significance. The loss of 235 lives on Malaysia Airlines Flight 370 in a Boeing 777-200ER in 2014 did not result in a call for the grounding of all 777 aircraft, but the loss of seven lives on the Space Shuttles *Challenger* and *Columbia* resulted in a suspension of crewed shuttle flights for two-and-a-half years after each disaster.

The loss of two lives on Gemini with the attendant delay in Gemini's schedule and, likely, Apollo's schedules would have precluded a landing on the Moon in the 1960s.

The Gemini program was the second of the three early United States space programs. Project Mercury placed a one-man spacecraft on orbit. The Saturn Project ultimately placed a three-man spacecraft in lunar orbit and on the surface of the Moon. Between the two programs was Project Gemini, during which ten, two-man spacecraft were launched in less than two years, rendezvous and docking were accomplished, and extravehicular activity techniques were perfected. Interestingly, Project Gemini was something of an afterthought. The actual design sequence of the first three US manned launcher programs was not Mercury-Gemini-Saturn as many have assumed but Mercury-Saturn-Gemini. Thus, in many ways Gemini was the most technologically modern of the three spacecraft.

Today, space travel is all but routine. In 2016, the Dawn spacecraft went into orbit around the dwarf planet Ceres, and New Horizons completed a fly-by of the Pluto-Charon system. Astronauts spent almost 86 hours performing useful work during EVAs at the $100 billion International Space Station on orbit and continuously occupied since November 2, 2000. SpaceX, a private company, successfully landed its reusable launcher and American astronaut Scott Kelly began his year-long stay in space. In 2015, there were 86 orbital launches and 20 major suborbital launches with only five failures in all with none of the failures crewed. And 2015 was a typically active year in space. In 1961, the year in which Project Gemini began to take shape, things were *very* different.

To understand the concerns about man-rating a launcher, it is necessary to clear our minds of what we now know to be true about spaceflight and launchers and return to an era before Yuri Gagarin's path-breaking flight—we have to transport ourselves back in time 55 years. (For perspective, a 50-year-old aerospace engineer today was *born* in the last few months of the Gemini program.) Fifty years ago, we were at the opening of the space age. We were also in the middle of the Cold War. The intersection of these two eras gave the United States the need to move quickly into manned spaceflight with whatever equipment was readily at hand. That meant that existing launch systems had to be employed, launchers designed to make one-way suborbital trips with a non-human, if not inhuman, cargo. The Atlas and Titan launchers were pressed into service.

NASA brought the Mercury astronauts to Cape Canaveral to observe the launch of an Atlas, the craft that was to take them into space. Just minutes after liftoff, the astronauts were treated to the opportunity to watch it explode. In fact, of the 118 launches of the early Atlas rockets, 48 ended in failure. The early Titan launcher was little better. Of its 110 launches, 21 were failures. To make matters worse, the vast majority of these Atlas and Titan launch attempts were to have been suborbital flights. If a launcher could not reliably even complete a suborbital flight, how could it be trusted with a multi-day flight with human cargo?

A comparison of the thrust of the three early launchers, along with the Saturn V launcher used in the Apollo lunar landing program as a point of interest, may be seen in Table 9–2.[1]

Redstone	78,000 lb thrust (single stage)
Atlas	300,000 lb thrust first stage
	67,000 lb "second/core" stage
Gemini Titan II	430,000 lb thrust first stage
	100,000 lb second stage
Saturn V	7,600,000 lb thrust first stage
	1,000,000 lb second stage
	225,000 lb third stage

Table 9–2: Early NASA Manned Launcher Thrust.

The Redstone/Jupiter rocket served as the launcher for the first two Mercury flights, both suborbital. The Redstone lacked the thrust required for orbital flight, so the stage-and-a-half Atlas launcher was used to complete the Mercury program. While the Atlas ICBM ultimately served well in launching the Mercury orbital manned flights, it simply was not strong enough for the much heavier Gemini capsule: The Atlas launcher could not place on orbit the Gemini spacecraft. For this task, NASA turned to the Titan family of boosters, specifically the Titan II, the launcher that was to become the most powerful launcher in the US arsenal at the time.

In 1962, the Titan launcher was the most powerful rocket available. The Titan family of launchers was commissioned by the Air Force to supplement the Atlas ICBM. The miniaturization—if it could be called that—of nuclear weapons was underway, but the W-53 weapon that was the mainstay of the US nuclear arsenal was still a 6,000 pound, 9 megaton weapon system that had to be delivered in a suborbital ballistic arc. The Titan I was a two-stage launcher with an LR-87-3 rocket motor burning RP-1 and liquid oxygen. While RP-1 was stable and could be stored at room temperature, the cryogenic liquid oxygen had to be loaded immediately prior to launch. This meant that the Titan I could not be launched immediately after the detection of a Soviet attack, rendering both it and the United States highly vulnerable. As a result, the development of the Titan II began even before the Titan I came on line.

As would be guessed, the Titan II was an upgraded version of the Titan I, the United States' first fully-satisfactory intercontinental ballistic missile. The Titan I used RP-1 as a fuel and liquid oxygen as the oxidizer. This meant that the oxidizer could not be loaded until immediately before flight, building a significant delay into the response time for a launching, not a plus for an ICBM designed to be a deterrent. For the Titan II, the rocket motor was modified, becoming the LR-87-7, to permit the use of Aerozine 50 (a 1:1 mixture of hydrazine and unsymmetrical dimethylhydrazine [UDMH]) as the fuel and dinitrogen tetroxide (N_2O_4) as the oxidizer. This fuel and oxidizer were both storable at normal temperatures, so a missile could be pre-fueled and launched almost immediately on call. In addition, the fuel and oxidizer were hypergolic, they ignited on contact, meaning that there was no need for an ignition system and that the engines could be started simply by opening the valves and bringing the fuel and oxidizer into contact. Finally, a launch delay, unless it were lengthy, would not require the off-loading and re-loading of the fuel and oxidizer, both saving time and enhancing safety. Again, the design purpose of the Titan II was to launch nuclear weapons on a suborbital path to designated targets around the world, with an immediate launch in response to an enemy attack being an extremely high priority.

II. The Man-Rating Process

Because the Titan II was designed to be a missile, a number of changes had to be made for it to be man-rated for the Gemini program and for crew safety to be assured. The equation that expresses the relationship is:

$$P_{CS} = R_{LV} + (1 - R_{LV})\, R_{MDS}$$

where:

P_{CS} = probability of crew survival

R_{LV} = reliability of the launch vehicle

R_{MDS} = reliability of the malfunction detection system

(See Endnote 2)

There were three classes of changes that had to be made to the military Titan II to adapt it for use as the Gemini launcher:

1. Changes required to adapt the launch vehicle to support the spacecraft.

2. Changes necessary to achieve an 87-nautical mile orbit along with enough additional thrust to achieve a 161-nautical mile apogee.
3. Changes or additions required specifically to man-rate the launcher.

To maximize crew survival, therefore, engineers had to take into account and consider the following:[2]

1. Component or system redundancy which can improve the reliability of the launch vehicle.
2. Analysis of launch vehicle failure modes followed by design of a reliable malfunction detection system or MDS.
3. Functional utilization of the crew as part of the malfunction detection system.
4. Emphasis in launch vehicle checkout on minimizing the possibility of launching a bad vehicle.
5. Test, countdown, and launch procedures that [would] lead to maximum probability of launching a good vehicle.
6. System simplification where possible to achieve reliability.

Understandably, the US Air Force was reluctant to make major changes to the Titan II. The mission of Air Force was and is the strategic protection of the United States through the projection of force, not primarily to put a man in space, and the Titan II was hoped to become a proven commodity that could be relied on if and when emergency situations arose. Changes to the launcher, it was feared would do three things: add weight, with a concomitant decrease in performance; compromise the type of reliability required of a weapons launcher; and add development time, leaving the United States more vulnerable to a Soviet attack in the meantime. On the other hand, an attractive feature of supporting NASA's effort was that the Air Force would then have a launcher it could use in its own, nascent manned space program which it called Blue Gemini.

Assembly of the Gemini Launch Vehicle (GLV) was done at Martin-Marietta's facility in Baltimore, Maryland. The factors in the decision to assemble the Titan II GLV in Baltimore were two-fold. First, missile production could continue unabated at the firm's Denver facility, and second, increased inspection and monitoring to assure quality control and astronaut safety could be performed on the manned launcher. An added benefit to Martin-Marietta was that the Baltimore facility remained in operation and escaped a planned shut-down.

The changes required in making the Titan II a satisfactory man-rated launcher were many and fell into two categories, technical and managerial. The goal was to improve pilot safety, and to do this reliability had to be improved by building in redundancies, preparing for potential malfunctions, providing crew with information about malfunctions in time for an abort decision to be made, and generally upgrading equipment, management, and construction. In all of this, the overriding issue was that the mission of the Air Force, and therefore of the Titan II missile, was strategic defense (bolstered by significant offensive capabilities), not a manned space program. The managerial issues included addressing the competing goals and requirements of NASA and the Air Force as well as issues with quality control on the part of the contractor.

As was the case with all early space programs, costs for the modifications soared and had to be more tightly controlled, and NASA had to force stronger operational controls on the part of the manufacturer. Broadly stated, the major issues were:

1. Address the issue of "pogo" or longitudinal oscillation in the first stage.
2. Replace inertial guidance with radio guidance.
3. Add redundancies to flight control and guidance systems.
4. Add a malfunction detection system.
5. Add redundancies to all electrical systems.
6. Eliminate combustion instability on the second stage.
7. Eliminate the retro and vernier rockets on the second stage.
8. Modify the adaptor sections between stages and between the second stage and the spacecraft.
9. Change the launch profile to "burn-until-empty."

(For a complete list of the significant changes made to the Titan II launcher to man-rate it, see Endnote 3.)

A discussion of the technical issues follows.

III. Modifications to the Titan II

1. Actions to mitigate the excessive longitudinal acceleration experienced during launch.

The issue that caused the greatest difficulty for the manned Gemini launcher was "pogo," longitudinal shaking caused by combustion instability. Too much "pogo" can destroy any launcher, but systems can manage some amount of "pogo" and function appropriately. Unmanned launchers such as ICBMs can withstand a greater amount of "pogo" than can manned launchers, and the Air Force, which had developed the Titan II booster, had finally arrived at a level that was acceptable for a nuclear missile.

On the first flight of the Titan II, "pogo" oscillation reached a maximum of 2.5 g's over a 30 second period, this in addition to the continuous acceleration of the launcher itself.[4] While this was too high even for the Air Force, the amount of "pogo" the Air Force was willing to accept was greater than NASA felt astronauts could be subjected to in flight. NASA's limit was +/– 0.25 g while the Air

Force was willing to accept +/– 0.60 g. It took intervention by Air Force General Bernard Schriever, widely considered to be the father of the US missile program, to prod the Air Force and the contractor, the Martin Company, to go back to the drawing board. The contractor began by experimenting with increased tank pressures, but the best results were achieved through the inclusion of fuel accumulators and oxidizer standpipes. On the first flight that included accumulators in the oxidizer feed lines, however, the peak oscillation reached 5 g's resulting in a premature shutdown of both engines and the concomitant loss of the mission. Six test flights later, however, the goal was accomplished.[5]

2. The inertial guidance system of the military Titan II was replaced with a radio-controlled guidance system. From set-it-and-forget-it to ongoing operational control.

A key change in the guidance system for the Gemini Titan II was that of added complexity and two-way, real-time communication between the spacecraft and Mission Control in both Houston and at Cape Kennedy as well as the Goddard Space Flight Center and the Blockhouse.

Guidance is managed by comparing actual in-flight performance with predicted performance. To accomplish this, NASA's contractors (Martin Co. and Aerospace Corp.) developed sophisticated simulation techniques, and the inertial guidance system was replaced by a radio-controlled system.

3. Redundancies were added to the flight control and guidance systems such that no single point of failure could jeopardize the mission.

Redundant systems were added to minimize the possibility of launch failure, to assure astronaut safety, and to increase the probability of mission success. Further, tracking, hydraulic, and electrical systems were modified to improve reliability.

Flight control systems were completely duplicated. The primary system was composed of a three-axis reference system, a radio guidance system, an auto pilot, rate gyros, and a hydraulic system for actuation. The secondary system was similar, comprised of the spacecraft's inertial guidance system, a second auto pilot, rate gyros, and an independent hydraulic system.

Flight control switchover could occur either automatically or manually. Automatic switchover occurred during Stage One of the launch when there was a loss of hydraulic pressure in the primary system, excessive turning rates in any of the three axes, or engine thrust chamber movement to a hard-over position.

Automatic switching was used during Stage One flight because at the point of maximum dynamic pressure (Max Q) there is less than one second between initiation of the problem and the structural breakup of the spacecraft. During Stage Two flight, dynamic pressures are significantly reduced, and response to a hard-over condition is less critical. As a result, there was no redundant hydraulic system on Stage Two. Electrical systems on the second stage, however, were duplicated.

Guidance improvement was an iterative process. As data were acquired from completed flights, changes to both guidance programs and systems were possible. One example is that of the pitch program. An analysis of the first three Gemini flights showed that the trajectories achieved during first stage operation were significantly higher than predicted. This was traced to slightly inaccurate vehicle thrust and specific impulse predictions for the launcher. When these predictions were revised in the calculations, launch profiles were much more accurate, reducing the magnitude of on-flight maneuvers with the attendant fuel requirement. Making this adjustment resulted in a 65-pound payload increase.

4. In conjunction with system redundancies, a malfunction detection and warning system was added, providing warning to both cabin and ground crews.

The malfunction detection system (MDS) was the center-point of pilot safety. Gemini pilots had to be aware of actual and potential malfunctions early enough to effect correction or to make an abort decision. As was central to all of Gemini's flight characteristics, the MDS was designed around the capabilities and decision-making time of the astronauts. The system combined both automatic and manual actuation to make maximum use of astronaut competence.

The value of the combined automatic/human-actuated abort system was described well by James Chamberlin (Project Director) and Andre Meyer:

> The Atlas is so instrumented that it will automatically abort the Mercury Spacecraft if any one of a number of malfunctions is sensed in the launch vehicle. The automatic abort modes in Mercury are very complicated and have caused the loss of complete spacecraft in the early development unmanned flights. In each instance, had a man been on board, he could have manually salvaged the system.
>
> In Gemini, a launch vehicle malfunction activates lights and gauges on the instrument panel and the astronauts exercise judgment as to the seriousness of the situation and the best procedure to follow during any special circumstances. With this sort of system, more than one cue can be used to verify an abort situation. Simulations reveal that in many cases, much reliance is placed on the audio-kinesthetic cues for this purpose. These cues are not only very reliable, but instill confidence in the pilots in the validity of the systems when they are checked by this means.[6]

The astronauts were jet fighter pilots and almost all were highly rated experimental aircraft test pilots. They were accustomed to making split-second decisions based on mental assessment and gut hunches. The manual aspect of the MDS allowed Gemini to take advantage of the pilots' experience.

The parameters displayed to the astronauts were:

1. Engine thrust chamber pressure for both stages.
2. Pressures on both oxidizer and both fuel tanks.
3. Excessive rates of yaw, pitch, and/or roll.
4. A switchover from the primary to the secondary flight control system.

These factors were selected for display to the astronauts based on an empirical assessment of the types and modes of failures, the probabilities of these failures occurring, the amount of time from initial problem to catastrophe, and the reaction times of astronauts at various stages of launch and orbital insertion. In cases of primary flight control or guidance failure, the Malfunction Detection System initiated a switchover to the relevant secondary system. In other cases, internal displays and warning lights relayed information to the astronauts.

As would be expected, the MDS had complete redundancy in sensors, electrical circuitry, and system components to increase astronaut safety.

The MDS was tested when a flight came close to an abort/evacuation activation during the first launch attempt of Gemini VI. A small electrical plug in the tail of the launch vehicle fell out prematurely, signaling falsely that a liftoff had occurred, and the MDS performed an engine shutdown 1.2 seconds before what would have been the actual liftoff. The astronauts knew—literally by the seat of their pants—that a launch had not occurred regardless of the instrument indication. They elected not to eject saving the flight. The wisdom of Chamberlin's use of the pilot-initiated abort system was well proven that day.

The value of a malfunction detection system can be seen through its absence in the events on Gemini VIII. Astronauts Armstrong and Scott had just successfully completed the first rendezvous and docking in space when one of the Orbital Attitude Maneuvering System (OAMS) thrusters stuck in an open, continuous firing position. With no reference in space, Armstrong and Scott had no warning that a problem was building. Once the problem was detected, Armstrong and Scott had no way to tell that it was their spacecraft that was the issue. Just prior to launch they had been warned by the ground crew that the Agena target vehicle with which they were docked had displayed instability in its orbital attitude system, thus they assumed that it was the Agena that was at fault. Only after the problem had become critical and the astronauts had undocked from the target vehicle did they learn that the problem was with their own spacecraft. An earlier warning of the problem would likely have allowed them to isolate the issue and take corrective action before their craft was tumbling at the rate of one revolution per second bringing the astronauts close to blackout and total disaster.

5. The electrical system was made redundant with two completely independent systems installed as well as redundancies for all in-flight sequencing.

As with the flight control system, the electrical system contained redundancies in all major circuits. The spacecraft had two individual batteries feeding two completely independent power busses with separate wiring to all critical components from the guidance system to the pyrotechnic system for spacecraft separation. Again, as with the hydraulic system, electrical redundant components were separated as much as possible with wiring and tubing running on opposite sides of the launch vehicle for added safety.

6. Combustion instability on the second stage was corrected. Second-stage propellant tanks were also lengthened to provide a longer burn time.

In the second stage, combustion instability had to be corrected (it was statistically stable—and stable enough for an ICBM—but not sufficiently stable enough for a man-rated vehicle) and propellant tanks were lengthened to provide a longer burn time.

On two of the Titan II's first four flights, the second stage engine failed to achieve full thrust, in one case reaching only half power. Unfortunately, for problem-solving purposes, initial analyses indicated that the causes of the two failures were unrelated. NASA then instituted the Gemini Stability Improvement Program (GEMSIP) to address the issue. The basic areas of focus were on the injector plate and on the starting cartridge. Work on both areas started in parallel, and the cartridge issue was the first solved. Starting shocks were significantly reduced by simply maintaining a higher minimum pressure in the cartridges and by keeping the temperature of the cartridges at a higher temperature. The second focus was on a redesigned injector plate. The new injector plates took 18 months to design and test.

Because solving the cartridge problem reduced most of the instability, the first six Gemini flights flew with the old injector plates. In an interesting change of mind, NASA decided that statistical reliability—which it had argued strenuously against—was good enough.

7. The vernier and retrorockets on the second stage were eliminated.

The military Titan II utilized two, 1,050-pound thrust solid propellant vernier engines on the second stage. These engines were used to fine-tune guidance before the release of the re-entry vehicle containing the nuclear weapon. These engines were not required for the Gemini Launch Vehicle as the equipment section of the adapter modules had a set of Orbital Attitude Maneuvering System thrusters. In addition, Stage Two of the Titan missile had retro rockets to affect the reentry of the spent stage. These were not needed for Gemini and so were eliminated. The overall reduction in weight allowed for a 180-pound increase in payload capability.

8. There were minor modifications to the equipment truss and the forward skirt assembly for mating and mounting purposes.

As would be expected, there were significant differences between the forward end of the second stage on the military and civilian versions of the Titan II. New adaptors were required to mate the second stage with the Gemini spacecraft and to contain the radiator for the spacecraft cooling system. The forward end of the adaptor was the retrograde portion. It contained four retrograde rockets and six OAMS thrust chamber assemblies for guidance and control during reentry. The aft end of the adaptor retrograde system was mated with the forward end of the adaptor equipment section. These two were mated using two strap assemblies that were severed by shaped charges during reentry.

Adjacent to the retrograde section was the equipment section which contained ten OAMS thrust chamber assemblies along with the OCS tanks, the environmental control system primary oxygen tanks, the fuel cells (batteries on the early flights), coolant, and electronics. Finally, for mating with the Titan II itself, a machined aluminum alloy ring was constructed. This ring was severed by a shaped charge during the start of reentry.

9. First stage launch profile was changed to burn-until-empty, adding a small amount of overall thrust and eliminating the possibility of a low tank pressure abort action.

The military Titan II included low-level fuel and oxidizer tank sensors. The sensors were designed to cut off propellant when the flow rate and/or pressure and engine thrust decreased as the fuel and oxidizer tanks emptied. These sensors were determined to be unnecessary on the manned Gemini launcher—the first stage could be programmed to safely go to propellant depletion. The concern for the manned launcher was that the Malfunction Detection System could detect what it interpreted as a problem and initiate an abort action. Burn to depletion provided a small increase in thrust as well as the removal of the low-level sensors in the tanks. The net result was a payload increase of 180 pounds.

IV. Assessing Success

The nine areas targeted for modification on the Titan II were selected *a priori*. Statistical analyses were completed, but in most cases, it was the educated judgement of the engineers and scientists that determined where modifications were needed. To ascertain the degree to which the modifications would be successful a testing and assessment program was required.

There are three possible approaches to testing and product improvement. The first may be called the, perhaps apocryphally named, "Offenhauser" method. The Offenhauser was an automobile engine that dominated its form of racing for a half-century due to its absolute reliability. In its early development, constructors built a batch of engines, then ran one at top speed until something broke. The faulty part was removed and strengthened and the new part was put into a new engine. This engine was then run at top speed until it broke. The process was repeated until the engine would run consistently without problem for 800 miles. The result was a very reliable and very successful engine that was also *very* heavy. This approach could not be used in the Gemini or any other space program where engineers attempt to shave tenths of an ounce of weight off where ever possible.

The second approach is statistical analysis. Hypotheses can be established and failure rates of parts can then be estimated. Just as this approach was deemed to be unacceptable with the issue of second-stage combustion instability, it could not be adopted for safety improvement assessments where the lives of astronauts were at stake.

The approach that was adopted for Gemini was that of a repetitive series of tests which looked at components, then systems, then major assemblies. Testing began in the manufacturer's plant. Testing rigs identical to those at Cape Kennedy were used for the initial checks, and testing procedures were identical at both locations unless duplication was impossible. All data collected during testing were recorded and followed the spacecraft from initial assembly to launch in order to permit engineers to check for degradation over time. Not only did data and testing reports follow the assemblies, but a "babysitter" was assigned who traveled with the spacecraft and remained with it from assembly at the manufacturer's plant until launch at Cape Kennedy. Whereas in Project Mercury spacecraft were constructed, assembled, tested, shipped, disassembled, retested, reassembled, and retested, systems were shipped by the manufacturer in assembled and tested condition and, unless necessary, testing was not repeated at the Cape. Test flights followed to assess the function of the system as a whole.[7]

One problem that was experienced in Project Mercury was that to test, repair, or replace a component, often complete disassembly of major assemblies was required. Components and systems located internally on the spacecraft within the pressurized cabin and were only accessible internally. These components could be worked on by only one man at a time. For Gemini, simplification was a key. Systems on the spacecraft were located outside the spacecraft cabin and were accessibly through external hatches.

Central to safety and quality assurance was personnel training and motivation. Economic theory posits that the condition of good held in common is suboptimal: unless an individual thinks that he or she has ownership rights, the individual will take less care in its use and operation. This theory was applied to Project Gemini. As a result, ground crew and engineers were the focus of motivational efforts. Workers were *selected* to work on Project Gemini. Once selected, workers were identified by badge and uniform as members of a team. Training, both initial and ongoing, was a high priority, and acts of commission or omission that endangered mission success were subject to strong discipline.

Astronauts frequently visited the factories and workplaces of contractors and subcontractors as well as work areas of Cape Kennedy, the Manned Spacecraft Center in Houston, and Goddard Space Flight Center. Attention was paid to the individual worker such that each person understood his or her importance to the success of the overall mission.

V. Conclusion

The changes worked—there were no failures of the Titan II booster during the complete program, and the Gemini Program met its program objectives.

As an interesting aside, the Titan II military launcher, then retired from active service, went through another series of modifications in the 1980s to allow it to serve as a space-launch vehicle for satellites and exploratory craft from 1988 through 2003. Perhaps the best-known payload was the Clementine spacecraft, which performed lunar exploration and discovered water at the polar regions of the Moon. To prepare the Titan II for its new missions, it was necessary to modify the forward section of the second stage to mate with various payloads, to upgrade the inertial guidance system as well as to modify the operational, command, and destruct systems, and to develop a series of new payload fairings and their adapters to protect the satellites during launch. Notable in this adaptation of the Titan II is the absence of the Malfunction Detection System.

About the Author

Dr. Benjamin Davis serves as President of Dulles University, a postgraduate university offering degrees in management. Previously he served as Chancellor of the University of North America, as a professor of aerospace studies at the American Military University, as an Economist for the Executive Office of the President, as a design engineer for General Motors, and as the Executive Director of The Religious Coalition.

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Endnotes

[1] While the Titan II was under serious consideration for a lunar mission with a circumlunar profile or even a solo landing mission using a modified Gemini spacecraft, it could not accelerate the significantly heavier three-man Apollo capsule to escape velocity, so the Saturn V was built as the launcher for that program.

[2] See Carey, Francis X., "Testing the Man-Rated Launch Vehicle," (March 7, 1966), *The Space Congress Proceedings*, Paper 2. p. 332.

[3] The modifications required for man-rating the Titan II were:

1) "Addition of a Malfunction Detection System (MDS), designed to sense problems in any of the vital booster systems and transmit this information to the astronauts.
2) Addition of a propulsion system Prelaunch Malfunction Detection System (PMDS) to assure satisfactory operation of the Stage I autogenous propellant tank pressurization system prior to vehicle release.
3) Addition of a redundant flight control system which could take over the functions of the primary system, should the primary system fail in flight.
4) Addition of redundancy in the electrical system and sequencing functions with necessary changes to provide power for such added launch vehicle equipment as the MDS.
5) Substitution of a radio guidance system, similar to that used on Mercury, for the inertial guidance system used on the Titan II ICBM, to provide weight reduction and a more responsive system during critical orbital injection and variable launch azimuth capability.
6) Elimination of retro-rockets and vernier rockets since their functions were not required for the Gemini launch vehicle mission.

7) Modification of the equipment truss in the vehicle second stage to hold much of the new flight control, MDS, and guidance equipment.
8) Addition of a new Stage II oxidizer tank forward skirt assembly to mate the launch vehicle to the spacecraft.
9) Addition of redundancy in the hydraulic system, where required for pilot safety.
10) Addition of equipment in the Stage I propellant feed lines to suppress the vehicle longitudinal oscillation (POGO) during first stage flight.
11) Replacement of the AVCO tube type range safety receivers by solid state Advance Communications, Inc., units, to allow weight savings and incorporate airborne time delays for astronaut escape in the event destruct command was transmitted.
12) Substitution of a high level telemetry encoder (0 to 5 v) for the Titan II system (0 to 40 mv) to increase signal-to-noise ratio, expecially [*sic*] from transducers distant from the signal conditioner.
13) Addition of the necessary logic and equipment to utilize the spacecraft inertial guidance system as the launch vehicle secondary guidance source.

Section II-B of this report described the Pilot Safety Program in terms of both philosophy and practical implementation, pointing out that the program was comprised essentially of three primary efforts:
1) Design improvements
2) Product integrity
3) Malfunction Detection and Abort capability

From a very generalized standpoint, it was meant to accomplish three basic features:
1) Through systems trade-off studies, arrive at the best practical compromise that would provide a vehicle with an acceptable "inherent" design reliability.
2) Assure that the vehicle, once designed, was manufactured and tested such that the inherent design reliability could be realized.
3) Recognizing that no system is ever 100 percent reliable, provide monitoring capability in real time that would permit malfunctions to be recognized and subsequent actions to be taken to 1) provide additional capability for mission success or 2) provide safe pilot abort."

See Gemini Launch Systems Directorate, (1967), *Gemini Program Launch Systems Final Report*, TOR-1001(2126-80)-3, El Segundo, California. Aerospace Corporation. Pages II.C-1, 7.

[4] The true acceleration of the launcher, of course, was anything but "constant" but varied from 0.48 g at 5 seconds into the launch to 5.75 g. just prior to second stage cutoff. See Missile. (2001). Accessed from http://msl1.mit.edu/ESD10/block4/4.5_NMD_01a.pdf. Slide 6.

[5] The issue of "pogo" was not limited to the Titan II. The same problem plagued the Saturn V rocket. On Apollo XII, vibration at the center engine reached 8 g's. It was believed that this was well within the 15 g. structural limit of the launch vehicle so no corrective action was taken. On the next flight, the ill-fated Apollo XIII, vibration levels reached 34 g's, causing a shutdown of the center engine but not causing a break-up of the structure.

[6] Chamberlin, James and Meyer, Andre, (1963), "Project Gemini Design Philosophy," *Astronautics and Aerospace Engineering*. February 1963.

[7] Test flights were, of course, a part of man-rating the Mercury launch vehicles. To assure the safety of the first US astronaut Alan Shepard, Wernher von Braun ordered an extra, unplanned test of the Redstone launcher, rescheduling Shepard's flight. In the interim, the Soviet Union launched Yuri Gagarin into space ahead of the United States.

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