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Hervé Moulin and Donald C. Elder
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Donald C. Elder, Series Editor

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Chapter 17

The Apollo Fire and Investigation: Facts Not Considered*

Dr. Shirley Thomas†

Introduction

The facts surrounding Apollo 1 were as incongruous as they were catastrophic. The magnificently designed spacecraft that was created with enormous effort for a journey to the moon instead was consumed by fire while undergoing a supposedly routine ground test. Three astronauts—Virgil I. Grissom, Edward H. White, and Roger B. Chaffee—eminently qualified for the ultimate lunar adventure, were trapped inside the spacecraft. Apollo had emerged as the product of an unprecedented gigantic research, development and production effort. Unmanned flight tests had been positive. Prior to the first manned flight, there was a final ground test on Pad 34 on January 27, 1967. Then, in moments, a raging conflagration reduced all of these aims to smoldering ashes. In all, about 1,200 people churned out 3,000 pages of reports. The final report, to paraphrase the Bard, was "full of sound and fury..." To complete the phrase, the report did not "signify nothing," but it omitted the major factor in the fire. Apollo 1 was undergoing a test with an internal pressure of 16.7 pounds per square inch. The significant point is that this internal pressure was being generated by pure oxygen whereas, for the ground operation, it could and should have been ordinary air. In space, oxygen filling the spacecraft poses no danger but on the ground, an oxygen filled craft was a potential inferno awaiting any spark. Lessons can

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† University of Southern California, Los Angeles, California, USA.

be gleaned from the tragedy only if all the facts are presented. That is the aim of this paper.

Good drama has a beginning, a middle, and an end. Project Apollo was perhaps the greatest drama the world had ever witnessed—and witness it we all did, from launch to landing, on television screens worldwide. In the past century, the major stimulus to thoughts of taking a man to the moon came from science fiction writers who truly drew the road maps into space, particularly Jules Verne and H. G. Wells. Scientists often cited their works as being pivotal in their younger years.

Early Believers

Cosmonaut Yuri Gagarin, the first man to orbit the earth, recounts that he very much liked the *Andromeda Space Tale*, but he added, "From the point of view of a man who has seen outer space, not everything there is realistic."[1]

Dr. Robert Goddard, the American father of rocketry, was too frail a boy to play ball so he sat reading Verne's *From the Earth to the Moon*. When Goddard had become a scientist and experimenter, the July 12, 1920 edition of the *New York Times* carried the front page headline "Believes Rocket Can Reach Moon." The following day, an editorial accused him of deliberately making the same "mistake" as Jules Verne—that of assuming a rocket could operate in a vacuum without the atmosphere to "push against."

Prof. Hermann Oberth, Germany's great rocket pioneer, who was an avid reader of Verne, said, "I realized it was not possible, technically, to make the trip the way that Verne proposed. Therefore, I began to think 'How can it become possible?' I came to the answer, 'By rocket propulsion.'"[2] Even our contemporary scientist, Dr. Carl Sagan, started his dream of "billions and billions" of stars by reading Verne and Wells.

As the experimenters gained legitimacy and acceptance as serious scientists, the difficult research changed complexion. World War II brought about in the United States some minor applications of rockets—such as jet-assist-take-off (JATO).

But an oversight at the end of World War I changed history. The statesmen who drafted the Treaty of Versailles did not even consider the seemingly ridiculous writings of science fiction when they prepared the document that spelled out restrictions to prevent Germany from rearming. The failure to restrict rocket development allowed Dr. Wernher von Braun to pursue his passion, rocketry; ultimately, he developed the V-2.

After World War II, an uneasy peace came to the world, but there were rumblings from our erstwhile ally, the Soviet Union. Under the leadership of Gen. Bernard A. Schriever, the United States Air Force began a crash program to build an intercontinental ballistic missile. Then came the USSR's launch of

Sputnik. It did not surprise the scientific community, but it stunned the rest of the world. After failed efforts, the U.S. launched a satellite; the booster was provided by von Braun, who had been brought to the U.S. at the end of the war.

All of this was like a scene-setting prelude to the stirring words uttered by President John F. Kennedy on May 25, 1961, before the combined houses of congress: "I believe that this nation should commit itself to achieving the goal before this decade is out, of landing a man on the moon and returning him safely to earth." The boldness of the President's commitment should be judged by the fact that at the time, we had 15 minutes of space flight time.

The White House asked NASA for a briefing to better inform them on planning. When the senior people in the newly formed space agency were reluctant to take on the task, it fell to Dr. Homer Joe Stewart to do the calculations; he was on leave from the California Institute of Technology to head NASA's Office for Planning Purposes.

He extrapolated from the biggest aerospace project the United States had ever undertaken, the B-52 bomber. From that he calculated that the mission to the moon would take 10 years and cost between $20 and $40 billion. Ultimately, the mission was completed in eight-and-one half years and cost $25 billion. Says Stewart, "I think that's probably as good a brief program estimate as anybody's ever made for the government."[3]

Mission Planning

In the frenzy of planning that followed, all agreed on the booster rocket; it would be Saturn, so that development could proceed. Von Braun was the Director of the Marshall Space Flight Center and Saturn was his project.

The engines to power it were already developed because in 1958, when T. Keith Glennan became NASA's first Administrator, he followed a White House approved plan to develop a big booster engine. He gave the contract for this work to Sam Hoffman, President, Rocketdyne Division, North American Aviation. Inc. Hoffman produced the mighty F-1 engine with one million pounds of thrust: it was later upgraded to one-and-one-half million pounds.

The Rocketdyne F-1 incorporated a feature that von Braun had originally designed for his V-2 engine: the regenerative cooling system. In this, the sides of the combustion chamber are double-walled; liquid oxygen at minus 300 degrees Fahrenheit, passes through the walls, reducing the heat of the chamber and, in turn, raising the temperature of the liquid oxygen before it reaches the injector plate. Five of these would generate the 7,750,000 pounds of thrust von Braun needed for the Saturn first stage.

The planners were primarily concerned with how to get to the moon. A year before Kennedy's announcement, Project Apollo was announced, but that was planned as a manned circumlunar mission without a manned landing. It was getting men on the moon that increased the problem many fold.

The debate involved all of the key people of NASA and innumerable valued consultants, and it finally narrowed down to three modes: direct flight to the moon, an earth orbit (which would require a second costly launch of a tanker by a Saturn on a refueling mission), or a lunar orbit rendezvous (with the command module remaining in orbit and the lunar lander separating to go to the moon's surface).

There were off-the-wall proposals, such as sending an astronaut on a one-way flight to the lunar surface, periodically launch rockets to resupply him, and let him remain there doing research until NASA could design and build a vehicle to bring him back to earth. That wasn't what the President had in mind.

After three million man hours of debate, the latter mode was selected. Von Braun was the last holdout, but John Houbolt of NASA produced irrefutable figures on weight-saving, so the lunar orbit was it.

The group who most feared the mode were the controllers. At that time, linking up vehicles in earth orbit was difficult enough. The plan to link up two vehicles at the distance of the moon—when the signal would be entirely lost while the spacecraft orbited behind the moon—was viewed with overtones of fear.

Innovative Design Concepts

The booster rocket third stage, S-IVB, was given to Douglas Aircraft Co. and it was in a fixed design stage of development when the second stage, S-II, was won by North American Aviation, Inc. By that time, it was apparent weight was going to be important—the less the better for that long journey.

With that in mind, Harrison "Stormy" Storms, President of North American's Space Division, decided it would be a common bulkhead design. That was what S-IVB was, but it was a bulkhead of 22 feet in diameter and the S-II was 33 feet. The added 10 feet made the bulkhead an immense engineering challenge. Later, it was described as a "self-inflicted" company punishment; they proposed a weight empty factor, including engines, of 7 percent, and that was locked into the trajectory plan.

Storms was accustomed to attempting the impossible—and succeeding. He had designed the X-15 rocket plane, the B-70 bomber that cruised at Mach 3, and had contributed to many other designs. He hadn't gotten the nickname "Stormy" by being a passive man, so he charged ahead with full awareness of what he was undertaking.

To improve efficiency and save weight, the bulkhead design was changed from the spherical contour used on the S-IVB stage to a modified ellipsoid where the internal lines of strength followed the pressure loads more closely.

The primary consideration had to be strength, for the upper tanks of both the S-II and the S-IVB stages contained liquid hydrogen at a temperature of minus 423 degrees Fahrenheit and the lower tanks contained liquid oxygen. Both stages used 2014T6 aluminum.

Storms gave the S-II a major design advantage by putting the insulation on the outside of the tank, thereby keeping the metal colder. Over 2,000 tests proved colder metal gained 10 percent in compressive strength (resistance to buckling). The S-IVB had the insulation on the inside of the tank, and thus it did not benefit from the low temperature.

These were not incidental distinctions between the two stages. The structural engineering allowed the S-II to carry four times the propellant (fuel) for three times the weight of the metal, the design shortened the stack, and the savings were great: The production cost on the S-IVB was $800 per pound and on the S-II was $418 per pound.

The process of transferring the design of the 33-foot diameter bulkhead from paper to hardware required the invention of a special computer-controlled tool of engineering "elegance" created to contour it to an accuracy of one-fifteen-thousandths of an inch.

As delays continued and costs mounted on the extremely difficult engineering problems, Eberhard Rees, Deputy Director, Marshall Space Flight Center, was so alarmed that he wrote a seven-page memo to von Braun and to Gen. Samuel Phillips, USAF (Ret.), NASA Apollo Program Director, saying he feared that on testing, the S-II would explode and damage the test stand.

An old safety rule carried forward from airplanes was that the object should be able to test to 150 percent of its required performance. The Saturn first stage was designed to perform only to 140 percent, but 150 percent was expected of the upper stages. The Douglas S-IVB had exploded on its first test, damaging Douglas' test stand. Now, it was time for the S-II to be tested on a stand at North American facilities in Seal Beach, California.

The S-II was put into a room-temperature environment (without the freezing cold of liquid nitrogen to add that 10 percent of strength to the metal) and it was filled with water (14 times heavier than liquid hydrogen), and the testing began. The pressures increased to 144 percent, then it ruptured. The test was deemed a failure. However, the design was reluctantly accepted.

So Rees' words of warning were prophetic. He did not factor in that Storms had achieved the practical limit of the state of the art; the S-II had a weight empty fraction of 7.6 percent, whereas the S-IVB had a fraction of 9.6 percent. Rees' attitude lacked any appreciation of the difficulty of the design. He said: "For me, it is just unbearable to deal further with a nonperforming contractor who has the Government tightly over a barrel when it comes to a multibillion dollar program of such national importance as the Apollo program."[4] His memo had stated that the bulk of the S-II manufacturing facilities were owned by the government, so NASA should consider turning them over to another contractor.

This was but one of the continuing incidents that caused a senior executive at North American to say that "NASA was terrorizing the contractor."

The Lifeblood of Aerospace

The spacecraft—command module and service module—were among the last elements of the Apollo project to be defined because the selection of the route determined the configurations. Once the lunar orbit was chosen, NASA gave 12-month study contracts for the spacecraft to three companies: Convair Division of General Dynamics, Martin Co., and General Electric Co. As an example of the importance the companies attached to this privilege, Martin assigned 300 people to work on the design and they generated 9,000 pages of detailed analyses.

From the study by these three companies, NASA was able to draw up their Request for Proposal (RFP) that specified just what they wanted in these two major elements of Apollo. North American had several pieces of the project already—the S-II stage, and Rocketdyne's F-1 and J-2 engines; the latter powered both the S-II and the S-IVB stages.

But this wasn't enough for Storms. He wanted to bid the big one, the heart and soul of the lunar craft. He organized his team, planned his approach, and with boundless enthusiasm made his first pitch—not to NASA but to his own top executives. Companies had to make bids on the big contracts in order to stay in business, obviously, but such a massive proposal was a very costly exercise that might or might not pay off. J. H. "Dutch" Kindleberger, Chairman of the Board, was the object of Storms' first pitch. The two men had some characteristics in common—they were both hard driving rough-and-tumble, and supremely determined. After a dramatic and persuasive presentation, Storms and his team received reluctant consent from Kindleberger. He allowed Storms $1 million to make the bid. Storms knew that was not enough, but he didn't protest.

NASA distributed the RFP to 14 companies, and it was assumed by many that Martin—with their enormous effort over a year to study it—would triumph. But North American had too much credibility to ignore. J. Leland Atwood, President and CEO, was esteemed for his engineering ability and his intellect; the aircraft produced included the B-25, the P-51, and the F-100, as well as the first "spaceplane," the X-15. This record of achievement, plus the capability of Storms and his presentation team, won for the company the prized contract. Now they were faced with the design and delivery of the most complex and advanced machine ever conceived and there were no precedents.

The contract for the lunar excursion module (LEM) was given to Grumman Aircraft Engineering Corp. and they faced the same design dilemma. Between the original plan and weight calculation to the construction phase, it suffered a 30 percent increase, 7,500 pounds. The Saturn stack could not possibly put Apollo into a lunar trajectory with this added weight.

Salvation came when Rocketdyne was able to provide its J-2 engines with a thrust increase of 15 percent, together with a fuel saving of 1 percent (which, considering the quantity consumed, was significant). At the very time this achievement was announced, October 5, 1967, the Congressman from New York, William Ryan, released a letter from von Braun to Rocketdyne's President, Sam Hoffman, criticizing "hardware failure traceable to human error..." The incongruity of this criticism with the actual performance was, at the least, difficult to comprehend.

As the Apollo program progressed, 400,000 people working for contractors nationwide were involved. It dwarfed the Manhattan Project and became the longest research and development program the United States had ever undertaken.

After several test flights were conducted over a period of about four years for launch vehicle development, it progressed to test Saturn with Apollo boilerplate. The first with a complete spacecraft, unmanned, occurred on February 26, 1966.

Astronauts selected for the first manned flight of Apollo 1 (designated by North American as Apollo 204) were Virgil I. "Gus" Grissom, Edward H. White, and Roger B. Chaffee. They had been in intense training for the flight and were eager to end the testing.

The command module slated for the first manned flight had arrived at Cape Kennedy, and both the primary crew—Grissom, White, and Chaffee—and the backup crew—James McDivitt, Rusty Schweikert, and David Scott—had "flown" it several times inside a high altitude pressure chamber. They were pleased with its performance.

January 27, 1967, was one of the last routine run-throughs for the primary crew. Joe Shea, Manager Apollo Spacecraft Programs Office at the Manned Spacecraft Center in Houston, was at the Cape and Astronaut Wally Schirra suggested Shea get in with the crew to better understand what it was like to run through these tests. Shea agreed and tried to get a communications line installed, but it could be done only if the hatch were left open, and the test called for a closed hatch so emergency egress could be simulated at the end of the run-through.

Astronaut Deke Slayton, Chief Flight Crew Operations, Manned Spacecraft Center, rode the elevator to the top of Pad 34 with the crew. Grissom suggested his buddy, Deke, come into the spacecraft to see their problems, but Deke felt he could be of more benefit in the control room. The three men were strapped in, the hatch was secured, and the test began. Hours passed as they ran the man routine and tedious routines.

During this time, a far different atmosphere existed at the White House in Washington, D.C. President Johnson was exuberant about the signing of a space law treaty by representatives of 62 nations in ceremonies held not only at the White House but also in London and Moscow. The President felt it would keep space free from the implements of war, and it would assure that American astronauts and Soviet cosmonauts "will meet someday on the moon as brothers and not as warriors."

Attending the ceremonies were many dignitaries, Dr. George Mueller, Associate Administrator for Manned Space Flight, and members of the Apollo Executives Group, which Mueller had organized. It consisted of key NASA people plus the chief executive of each major contractor.

After the White House ceremony, the group went to the International Club for dinner. Then an attendant told Atwood he had a phone call. Storms was on the line: "Lee, we've had a terrible tragedy. There was a fire in the spacecraft, and the three astronauts have been killed."[5]

Atwood heard the words but was disbelieving. He knew that spacecraft. There was nothing in there to burn.

Word flashed around the room. Mac McDonnell invited Atwood to Washington National Airport to fly with him in his Grumman Gulfstream to the Cape. Webb dispatched Phillips to impound information, seal off the area, and give the press only general statements. Others hurriedly left to find other jets.

Joe Shea heard it on his squawk box in Houston where he'd flown after the test began. He remembered a speech he had given at a U.P.I. dinner where he predicted that sooner or later, there would be an accident and an astronaut would die and people would live knowing they might have done things differently.

Storms had received a call while the flames were still spewing from the spacecraft, then he called Atwood, then he made an uncharacteristic decision: For once, he would put his family before his work: he would not race to the Cape that evening (it was too late. anyway), but would remain home for his son's wedding the next morning.

Webb went to NASA Headquarters for he had decisions to make. In a meeting that lasted until dawn with his deputy, Dr. Robert Seamans, Public Affairs Director Julian Sheer, and Mueller, they planned that NASA would conduct the investigation. They also selected the chairman and designated who would be members of the board.

Early the next afternoon, Webb called at the White House and was ushered upstairs to the President's bedroom. The nation's chief executive was in his pajamas for his afternoon nap, but he had time to talk with Webb about the crisis. Webb enumerated the options for the investigation and the drawbacks to each. After some consideration, the President asked Webb what he felt should be done. Webb replied that NASA was the best organization to conduct the investigation, find the cause, and fix it. Johnson agreed and they shook hands on it. Webb had succeeded in guiding the President to make the "right" choice—the choice he had made the night before.

The Probe Begins

The NASA Review Board was immediately formed and the names were released to a press corps eager for some news.

Chairman: Dr. Floyd L. Thompson, Director, Langley Research Center. Members: Frank Borman, Astronaut; Maxime A. Faget, Director of Engineering and Development, Marshall Space Flight Center; E. Barton Greer, Associate Chief of Flight Vehicles and Systems Division, Langley Research Center; George Jeffs, Chief Engineer, Apollo, North American Aviation; Frank A. Long, President's Science Advisory Committee Member; Col. Charles F. Strang, USAF, Chief of Missiles and Space Safety Division, Air Force Inspector General, Norton Air Force Base.

Jeffs was the only member of the board representing the contractor; he served just one week before Seamans announced his status was changed from member to consultant. Ad hoc committees and 21 task panels were added; 1,500 people became involved.

It was a stark image on Pad 34 on "the day after." NASA authorized one representative of the news media to visit and report on the site; it was George Alexander of *Aviation Week*. He said the spacecraft "looked like the inside of a furnace ... the interior ... is a darkened, dingy compartment. Its walls are covered with a slate-gray deposit of smoke and soot; its floor and couch frame are covered with ashes and debris—most of it indeterminate."[6]

The first tone sounded by the press was totally sympathetic. On January 28, 1967, the Washington *Evening Star* reported: "There is bitter irony in the fact that the first disaster in our space program came during a simulated launch..." The *New York Times* lead line was this: "By chance, Grissom, White, and Chaffee died on the day the space treaty was formally signed..." Even Radio Moscow expressed appropriate words: "We in the Soviet Union are deeply grieved at the news of the tragedy at Cape Kennedy."

The congress, at first, followed the same pattern of reaction. Condolences, respect for the courage of the three astronauts—all the right words. But that wasn't the end of congress' involvement. Soon the questions were expressed: Was it "haste"—was the program being pushed too hard? Was it "waste"—should those dollars be "wasted" on space or should they be spent to help the poor and the hungry? The litany did not originate then and it likely will never cease; there are those who simply don't grasp that space efforts have brought and are still bringing gigantic advancements to mankind.

On Pad 34 at the Cape, activity was carefully supervised. When the fire occurred, the spacecraft was in a launch configuration attached to a Saturn booster; thankfully, it was not fueled. But the launch escape system right above the charred mass was "live"; it had a rocket the size of the Redstone that carried Shepard and Grissom into their suborbital flights. It was very carefully removed.

The Board laid a plan of procedure: They wanted a matching spacecraft to disassemble as they worked to take apart the burned module. A nearly matching vehicle was immediately shipped from Downey to the Cape for that purpose. Then it began.

The process of taking apart the grand machine was both tedious and disheartening. The technicians placed each component in an individual plastic bag and assigned it a number, and it was then taken to what would serve as a morgue for Apollo, the Pyrotechnic Installation Building. These components—with which imaginative design engineers had assembled a chariot to fly to the moon—were arrayed on tables to be examined. To augment the personal inspection by Board members, 3,400 pictures were taken of the 1,261 items.

In addition to the spacecraft sent from Downey for the purpose of disassembly, there was another Apollo spacecraft that was at the Cape at that time. It had undergone inspection by both NASA and North American personnel before it left Downey, and inspection by NASA on arrival at the Cape. But had something been overlooked? NASA ordered another inspection. Every component was scrutinized. The 12 main display panels were removed for another look. The vehicle's mission control programmer was returned to North American for another inspection. In all, the NASA scrutiny had noted 1,407 deficiencies.

The biggest "find" was the tiny tip of a socket wrench that had been left inside. Pictures of this tip were blown up to make it look huge and the newspapers built a sensational story around it. The tip should not have been left in the vehicle, but it did not cause the fire in another vehicle. This was how irrational the clamor became.

Thomas McDermott had taken over as Head of Quality Control for North American at Downey. He says this: "Most of the receiving inspection defects were related to such factors as the wire harness being too tight or too loose and factors of this type. Whether movement of the spacecraft resulted in some of these errors or they were just difference of opinion is hard to explain. The net effect is that they were minor squawks.

"The comments from NASA are what you would expect on a major program of the Apollo nature. The customer always feels that he could have done a better job, or some other contractor is better qualified, until a problem arises with him, etc."[7]

The Deliberations

Three days after the Apollo Review Board convened, its member, Col. Strang, announced that an accident in an altitude chamber at Brooks Air Force Base had killed two airmen; a flash fire had swept the oxygen-filled pressure chamber.

Dr. Charles A. Berry, Chief of Center Medical Programs, Manned Spacecraft Center, testified that three previous fires had occurred in the pure oxygen environment, but these had been in simulators and caused by test equipment and procedures that would not be used in the spacecraft. He said the pure oxygen was used primarily to prevent astronauts from getting the bends.

The ominous facts were emerging. The condition under which the Apollo test was being conducted was 100 percent oxygen atmosphere at 16.7 p.s.i.a. (pounds per square inch absolute), which was in excess of ground pressure of 14.7 p.s.i.a.

Four days after the accident, Webb made a statement to the press defending NASA's oxygen policy. Later, Faget said that in the short time (hours) on the pad, the danger was small. Such a statement was obviously fallacious; it took only 18 to 20 seconds for the astronauts to become unconsciousness and die by asphyxiation. There was a schism between the policy being overtly defended and the action being taken internally within the space agency. On May 9, a directive was quietly circulated instructing all contractors and government agencies to stop all Manned Spacecraft Center related manned testing in environments with high oxygen content.

As the deliberations of the Board continued, a ground swell of criticism was mounting. Marvin Miles, aerospace editor for the *Los Angeles Times*, wrote that the accident was caused in large part by NASA's shortsightedness and that NASA was trying to hide its negligence; NASA had failed to provide an explosive hatch and a fire suppression system, and he concluded by stating "The nation should be told the whole truth." Miles, in turn, was blasted in an editorial in *Technology Week*: "It is our impression that the agency is trying valiantly to come up with just such information and we don't understand the implication of a cover-up."

Up on Capitol Hill, the feeling was this: Congressional leaders did not entirely share the views and misgivings of the press. In a bipartisan move, Senator Clinton P. Anderson, Chairman of the Senate Committee on Aeronautical and Space Sciences, and Senator Margaret Chase Smith arranged for publication of executive hearings. This openness of Congressional deliberations helped to defuse media criticism about the objectivity of the ongoing investigations.

The NASA Review Board Report, nearly 3,000 pages, was finally completed on Sunday, April 5, 1967. Webb had it widely distributed. "Although the Board was not able to determine conclusively the initiator of the Apollo 204 [later officially designated Apollo 1] fire, it has identified the conditions which led to the disaster: (1) A sealed cabin, pressurized with an oxygen atmosphere; (2) An extensive distribution of combustible materials in the cabin; (3) Vulnerable wiring carrying spacecraft power; (4) Vulnerable plumbing carrying a combustible and corrosive coolant; (5) Inadequate provisions for the crew to escape; and (6) Inadequate provisions for rescue or medical assistance."[8]

Caldwell Johnson wrote an incisive article in which he makes these points: "The final list of 11 'findings, determinations, and recommendations' came down hard on North American Aviation, manufacturer of the capsule charging that 'deficiencies existed in Command Module design, workmanship and quality control.' These faults created an unnecessarily hazardous condition and their continuation would imperil any future Apollo operations.

"But the Apollo investigative board had skirted the most obvious problem on Pad 34 that awful January evening. Following a NASA procedure that dated back to Project Mercury, technicians had pressurized the capsule with pure oxygen at 16.7 pounds per square inch [absolute]. In this exceedingly flammable environment, there was no way to make the capsule fireproof. The tiniest spark would instantly set off an inferno. The final report did not even recommend halting this procedure."

He goes on to say, "Both Webb and Seamans vehemently deny that NASA management manipulated the findings, though Seamans believes that NASA bore responsibility for 'missing the point' about the danger of an all-oxygen cabin."[9]

The Senate hearings that convened were bruising to all involved in the space program. After the preliminaries of prepared statements, a junior senator, Walter Mondale, was tipped off by television commentator, Jules Bergman, to inquire about the Phillips Report. It was a highly critical appraisal of North American's performance prepared for Muller after Phillips' Tiger Team had investigated the company for schedule slippage and cost overrun. The report was scathing in its appraisal of Storms and recommended removing him. It spoke of "degradation of hardware performance" and suggested moving elsewhere the work not being done well.

This is not the kind of document any agency head wants in the hands of congressional investigators. Worst of all, Webb had not even heard of the Phillips Report, so his response was fumbling and vague. Webb was so upset at the tone of the hearing that on the way back to NASA Headquarters, he severely reprimanded his deputy, Seamans, for volunteering some information.

Problems at Other Centers

The events on Capitol Hill were not Webb's only concern. He had severe problems with morale at the Manned Spacecraft Center in Houston. "Astronaut Tom Stafford, an Oklahoman, concerned that Webb was not being informed of the situation through channels, called Webb's former associate and friend in Oklahoma, Jamie McWilliams. 'I want you to get a message to Webb. Tell him that if something is not done to straighten out the problems down here, several of us will pull out of the program. I want you to get Webb to do something,' Stafford said."[10]

Joe Shea was the person in Houston Webb was most concerned about. Shea had been deeply affected by the fire. For a period, like many others, he slept too little and drank too much. He agreed to take a vacation. He agreed to be examined by two doctors for a professional opinion as to his capability to function; he passed. Still, there was concern about him. So Mueller promoted him to NASA Headquarters as his Deputy. Then, Shea was given virtually nothing to do. He soon left the space agency.

Shea never lost faith in Apollo. He felt it would be "a mistake to go back into the Apollo spacecraft and make sweeping changes. The appropriate fixes were straightforward and limited; do more than that and the program risked coming out of the process with a less mature spacecraft in which new problems might be hiding."[11]

To finally quell the continuing barrage of questions from the press and from congressmen alike, statements from the astronauts were particularly meaningful. After all, they were the ones most concerned with the safety of future Apollo flights. When a congressman expressed doubts Walter Schirra, Deke Slayton, Alan Shepard, and James McDivitt all expressed confidence. This was the response from Frank Borman: "We are trying to tell you that we are confident in our management, and in our engineering, and in ourselves. I think the question is really: Are you confident in us?"[6] Borman's plea to stop the witch hunt was effective.

Senator Anderson essentially ended the tumult with these words: "The accident has taken a toll in morale and in the momentum within the program ... [but] that momentum will be regained and NASA will emerge stronger. I intend to support NASA in its requests for manpower and funds to get on with the important job."[6]

So is this the end of the tragic drama of Apollo 1? To those who glean information superficially, it may appear so. To those who peer behind the scenes, it is less than half the story. There were two major players: One had all the dialogue—made all the statements, voiced all the accusations, and essentially controlled the story line; that player was the customer. The second player—excluded from any representative on the Apollo Review Board, with only fragmentary information—was mute, he could not respond, he could not protest, he could not sue for untrue statements: the second player was the contractor. The story just told was that of the customer, NASA. The story yet to be told is that of the contractor, North American Aviation.

This is fact finding time.

Engineering Orders Carried Out

Atwood was aboard the first small private jet to land at the Cape just before midnight on that terrible night when Apollo 1 burned; Gilruth, Mueller, Debus, and Phillips were also on board. Technicians on Pad 34 were removing the bodies, so the group gathered in the control room and listened to the controllers.

For Atwood, there was a sudden unbelievable discovery: Pure oxygen had been used in that deadly test on the *ground.* The entire system had been designed for oxygen in *space.* There is no comparison in the conditions. On the ground, with the oxygen pressure of 16.7 p.s.i.a., was, as Borman phrased it, "like sitting on a time bomb" because of the danger of fire. But in space, even a candle will not burn (unless it is gently fanned) because there is no convection. (An internal spacecraft pressure of 16.7 p.s.i.a., which is 2 p.s.i.a. above ground level, must be maintained at all times to insure its fragile shell is not crushed. The pressure may be air or oxygen.)

Atwood, trying to grasp the stunning revelation about pure oxygen being used in the test first assumed that he had erred; every detail of what was happening must not have filtered to his executive office. But then he learned Storms did not know. Dale Myers, North American's Program Manager, Apollo Command Module, did not know. George Jeffs, Chief Engineer on Apollo, did not know. It was not that only he, Atwood, was in the dark. The entire cadre of people who designed and built Apollo did not know that NASA was conducting ground tests under such an atmospheric condition. The space agency had not specified it and had not informed the contractor it was being done.

Perhaps the most astounding consideration when the entire story unraveled to Atwood is this statement regarding the test: "Strapped down as though waiting for launch, they began purging their space suits and the cabin of all gases except oxygen, a standard operating procedure." Standard operating procedure! This meant it had been done since the beginning of NASA's flights.

Slayton, one close to the entire picture since the first manned flights, exploded at the realization of the danger of the situation by saying, "Man, we've just been lucky. We've used that same test procedure on everything we've done with the Mercury and the Gemini up to this point, and we've just been lucky as hell."

Von Braun said simply, "We had a blind spot." Walt Williams, Assistant to the Administrator, remained objective and non-accusatory toward North American; he felt it was NASA's complacency. They had conducted the Mercury and Gemini tests without mishap and did not really analyze the situation when Apollo started.

The original design North American had submitted was a two-gas system, nitrogen and oxygen, like that air we breathe. Storms wanted it. Chief Engineer

Charlie Feltz wanted it. But the customer directed a change to pure oxygen not only inside the spacesuits, but also inside the command module.

NASA issued to North American a Contract Change Authorization on August 28, 1962, signed by C. D. Sword, the Contracting Officer, with these provisions:

"1. Reference Command Module Environmental Control System to provide a cabin atmosphere of 5 PSIA pure oxygen.

2. Delete nitrogen system provisions from Command Module and Service Module.

3. All provisions of the present statement of work inconsistent with this change are hereby superseded. It appears that this should be significant cost and schedule reduction."

If NASA engineers had not fully understood the danger of the situation, they certainly had received enough cautions from outside the space agency by knowledgeable people who were aware of the practice. One of those was Hilliard Paige of General Electric. He wrote Shea a letter expressing his misgivings.

For four days after the accident, Webb considered the input he was getting, then determined the official stance: He defended the use of oxygen. He said in a public address reported in the *Washington Post* "NASA's decision to use 100% oxygen in spacecraft had been made after a long series of tests and evaluations. Any change would be made only after a most careful examination of the alternatives."[12] Air Force and other experts who commented were uniformly critical, as reported by the *Washington Post* and *Space Business Daily*.

Despite Webb's protestations, two months later, NASA quietly changed over to part nitrogen for ground tests. NASA has never publicly admitted the gross error of using oxygen on the ground. Instead, they have taken other avenues to defend their policy. On April 12, 1967, Mueller told the House Committee on NASA Oversight that the space agency felt it "had control of the sources of ignition ... [but] underestimated badly ... the course such a fire would take. If more thorough testing of flammable materials used in the cockpit had been conducted, the accident might not have happened."[8] There was a more obvious way the accident could have been prevented—change the policy of using pure oxygen.

How Could It Happen

It still seems inexplicable. The contractor's people were all over the Cape. Atwood was asked to explain further how this could have happened: "At the Cape, there were North American technicians who were maintaining the spacecraft. We had inspectors there, electrical people, structural people, but they were not there to question NASA's operating procedure since they were the operating authority. None of the engineers at the Space Division knew they were going to inflate it with oxygen to 16.7 p.s.i.a. and operate it."

The next logical question is how this situation could have existed—wasn't it a responsibility of systems engineering? Atwood explained in these words: "it certainly is, but North American was not the systems engineer. On the Mercury, Gemini, and Apollo programs, NASA bought the major components separately and assumed the systems responsibility itself and merged that function with its operating procedures. The contractors' control ended at the interface with the adjoining components. Incidentally, this has now been changed, and Boeing has the system responsibility on the space station."

Atwood continued: "Why had a fire not occurred on Mercury or Gemini? Probably good luck and random chance. The electrical systems on these craft were much simpler and more of the wiring was outside the pressure cabin. Even so, the Gemini 8 (with Neil Armstrong and David Scott) experienced a short circuit in space flight that caused a thruster to fire and the spacecraft to roll out of control until emergency recovery measures were employed. If this short circuit had occurred on the pad with full convection of gravity, with a 16.7 p.s.i.a.. pressure of oxygen, a fire would surely have happened. On Apollo 1, electrical records showed no short circuit, and the cause of that fire was never accurately determined."

After all the examination, deliberation, and output of reports, the cause could never be pinpointed; the soot-covered semi-melted remains could not yield many clues. The area of the fire seemed to be at Grissom's feet; when a North American engineer, John McCarthy, suggested Grissom may have kicked the wires, an instantaneous and vociferous protest occurred. McCarthy was slandering a fallen hero, it seemed to some people.

The feature that finally sealed the fate of the three astronauts was the escape hatch. As NASA instructed it be built, it was behind the astronauts' heads, weighed 90 pounds, and required 90 seconds to open. Storms and his design team had originally planned an outward opening hatch for the command module, but NASA put through an engineering change order for a two-hatch system, inward opening.

Doubtless influencing NASA's decision on this was the history of the second suborbital flight on July 21, 1961, with Grissom in a Mercury capsule that he named Liberty Bell 7. The capsule design had been modified since Alan Shepard made his first suborbital two months earlier because the astronauts were concerned about emergency egress. The Shepard capsule required wriggling around the instrument panel to escape at the top. So the capsule for Grissom had been modified with an explosive charge of the side hatch (through which the astronauts entered the vehicle). It was ironic, in retrospect, that this "safety" feature nearly cost Grissom his life.

Grissom made a perfect 16-minute flight and landed near the precise target in the Atlantic Ocean. Then the hatch blew. The capsule immediately began to flood. Grissom had removed his helmet and rolled up the neck band of his spacesuit, but it did not seal. Later tests proved the neckband material "sets" in two days, so it did not have immediate integrity to seal his suit, and it began to fill with water.

The two hovering helicopters became absorbed with trying to save the sinking Mercury capsule and the pilots did not see that Grissom was battling to stay afloat. Only when the water-filled capsule became too heavy to rescue did a pilot finally see his plight and rescue him.

In the investigation about the mishap, there was speculation that Grissom might have triggered the hatch, which he steadfastly denied. He was later exonerated; his hand did not have the tell-tale bruise of everyone who ever intentionally triggered the explosive device.

John A. "Shorty" Powers, the former NASA Public Affairs Officer who became famous as the "A-O.K." voice of Project Mercury, believed Grissom bore this analogy: "There was once a character created by Al Capp called 'Joe Bftsplk' who always walked around with a cloud over his head. When the sun was shining on everyone else in the world, it was raining on Joe. And so it seems to have been with Gus Grissom."[13]

Dr. Nicholas Hoff, a Professor of Structural Engineering at Stanford. was a consultant to the Space Division of North American. He recalls it this way: "NASA accused the manufacturer of poor performance. In reality all the details of the atmospheric test were prescribed by NASA, often contrary to the manufacturer's wishes. In particular, they were very hard on Harrison Storms, who had done outstanding work.

"The only person at NASA who did not lose his judgment was von Braun. He said instead of looking for the guilty person all inside and outside, NASA should join in an effort to remedy the situation."[14]

Retired Astronaut Alan Shepard made candid remarks that were quoted in Pensacola, Florida's *Blade Citizen*, May 6, 1995. He blames both the Apollo 1 and the Challenger disasters on "hi-tech hubris." He elaborated by saying it is insidious when people who are extremely successful begin to believe they can do anything they want.

Atwood has another slant on a weakness he perceived, and it related to the youth of the NASA organization. "Through long experience in procurement of aircraft and related equipment through the competitive selection process, the Air Force and Navy had learned that, after entering into a contract with a company for an advanced technical product, it was to everyone's advantage to make the contractor's problems his own. The 'not invented here' reflex seems to be the attitude of a new and self-conscious organization. More recent NASA actions are much more mature."

Atwood's statements are highly respected, for he was the only CEO of a major contractor to hold an engineering degree. At that time, he had about forty years of engineering and contracting work, including the concept of the Mustang fighter and a long line of aircraft, rocket engines, and electronic equipment. He was totally dedicated to the Apollo program. Even when the unjust accusations were being uttered, he said, "I would have felt it was close to treasonable to try to block NASA action or injunction—no matter what the incongruity might be."[15]

Atwood recalls, "My reputation for veracity was smeared by certain Congressmen and some reporters for the *Washington Post* and *New York Times* who were apparently anticipating and hoping for my indictment."[16]

Internal Machinations

Webb was deeply concerned. He felt everyone had let him down. Writes Seamans, the one closest to him in NASA: "Now his house of cards was down. How? Why? Who had destroyed his dream? It was necessary, of course, to carry out a complete and careful investigation, so that the engineering failures that had led to the fire could be corrected. But Jim was not interested in investigating the engineering. He wanted to know what individuals had failed him? He felt personally betrayed."[17] This is the situation that existed in the aftermath of the disaster.

Webb, according to Seamans, talked about his staff behind their backs—even Mueller. Then he started bypassing Seamans, his deputy. (Seamans did not long remain at NASA.) Webb was even more obsessive about North American personnel—particularly Storms. Atwood did not comply with Webb's suggestion that Storms be removed from the project.

Next, Webb seized control of the Apollo program "with a vengeance," as his biographer wrote. Atwood well remembered that period and related part of it in a lecture he gave in 1990: "At that point, Mr. Webb went directly to Robert A. Lovett, a member of the Board of Directors of North American Aviation and distinguished former Secretary of the Departments of State, Defense, and Treasury, to complain about my management of the Apollo program, when, actually, the fire resulted from a failure of the NASA systems function. I had known Mr. Lovett since wartime mobilization days, and he declined to join in the orchestrated criticism of the company for this tragedy."[18]

When Webb tried in that way to challenge Atwood's position as head of North American, it became a personalized attack Atwood had not expected. But he could not allow even this incident to consume his full attention.

From the time of the tragedy, Atwood placed the aim of restoring Apollo first and financial arrangements second. Fiscally, the accident had a sizable impact. Atwood had dealt with the post-World War II downsizing, of reducing employment from a peak of 100,000 to 5,000 after the end of the war. He had experience with such problems should the Apollo Project be partially or totally moved to another contractor. There was another sensitive consideration: The company was discussing a possible merger with Rockwell.

In January 1967, the situation with NASA was tenuous. The cost-plus-incentive-fee contract negotiated between NASA and North American in October 1965 had expired on December 3, 1966; in January 1967, there was doubt about the legal status between the two.

NASA had issued the incentive contract with the aim of getting faster delivery of spacecraft and cutting cost overruns. The contractor did not need incentives; it needed solutions to problems never before faced. Apollo was unique so to state "how long and how much" was still a best guess exercise. The company was devoted to meeting schedules, but had to deal with the reality of transforming plans into hardware. They were diligently applying best brains and best efforts.

The schedule consisted of Block I for unmanned flights. The tests had been 80 percent successful, which, objectively, was considered a tremendous achievement. Block II for manned test flights had gained momentum in production and costs were being contained. Then came the test on Pad 34 of the first of the Block II spacecraft, and it brought the disaster.

After the fire, Seamans had the good judgment to remove the enormous pressure under which both the contractor and NASA centers had functioned. Official schedules were scrapped; only an internal schedule would be drafted to keep the project on course. Heaviest emphasis was placed on quality and flight performance.

In April 1967, the chief of the NASA Apollo Office Program Control Division, John J. McClintock, advocated that the follow-on should be an incentive contract. That did not factor in the state of relations between Atwood and Webb and the continuing attack on the administrator by members of Congress; several were focusing their hostility not on the space agency broadly but specifically on Webb.

The Showdown

Meetings between Atwood and Webb were prolonged and tense. Past was the day when the contract had expired and they continued on a handshake. One of the conditions Webb set forth was that Atwood replace Storms, and Atwood as firmly refused.

"Atwood also was holding firm against other changes Webb wanted. Webb was adamant about penalizing North American financially for the fire. As Dembling [Paul G. Dembling, Chief of Legislative Liaison] recalled, Webb told Atwood, 'I'm not going to pay you any bonuses [as the company was due under its arrangement with NASA], I can't face the American people and tell them we're going to pay the contractor bonuses after three people got burned up. You can sue me. You can do whatever the hell you want. I am not going to pay you. We're going to enter into a new contract.'

"He did not believe North American had dealt with the government in good faith in the earlier contract negotiations. 'They had a lot of people out there that didn't want to do it our way,' recalled Webb, 'but our way had to prevail if we were really going forward with Apollo... I told them they had to do certain things... 'They said we are not going to do them and I stood up at the table and I said, 'All right, Lee [Atwood], these are not negotiable, if you are not going to do them I am going to take away every goddam contract work you have with us if I can give it to somebody else.'"[10]

Seamans frankly told Webb he probably could not move the work to another contractor and meet NASA's stated goal for a moon landing. But Webb had made a threat and he carried through. He summoned North American's Washington representative, Larry Green and gave him a letter to deliver to Atwood, who by then had returned to his offices in California.

Webb wrote, "I am asking senior officials of those companies with well recognized capabilities, including particularly Boeing, Lockheed, Martin, McDonnell, and General Electric to give me their frank judgment as to whether there are resources in the country that can help us get the Apollo program moving forward in a better way than I now feel we can with the present pattern with its heavy reliance on North American."[15]

Mike Gray, author of *Angle of Attack*, terms NASA's treatment of North American "unvarnished industrial terrorism."

Atwood had major considerations after Webb's ultimatum. First, his company. What devastating effects would it have to lose the gem of all contracts? How many employees would be involved? There were thoughts of his country. The USSR launched the first satellite, *Sputnik 1*, not because the U.S. couldn't do it, but because of other reasons that seemed ridiculous in hindsight, they didn't do it.

This confrontation with Webb was ridiculous. But if the school bully holds all the marbles, you play his game. The achievement of President Kennedy's goal, the prestige of the country, was being jeopardized.

Ultimate Injustice

After an excruciating period of deliberation, Atwood called Storms on a Sunday morning and asked him to come to the corporate office. Atwood had to do an unjust and unkind act: He had to "promote" Storms and remove him from the Apollo project. Storms became the fourth "casualty" in the accident.

Webb's comment in his biography about Storms is: " ...He had failed technically."[10]

The day following Atwood and Storm's meeting was truly black Monday at North American's Space Division. "As the news flashed out through the far-flung division to the 35,000 in a hundred locations to whom he was known simply as Stormy, anger welled up like a sea. It was outrageous. If Harrison Storms hadn't held everybody's feet to the fire on the S-2 common bulkhead, there would be no moon landing in this decade; there was no way Saturn 5 could have lifted the weight of the other design. And the spacecraft was unquestionably a masterwork—a labyrinth of systems more complicated than an aircraft carrier packed into a stainless-steel phone booth—and anybody with hands-on experience knew that it was the finest piece of machinery ever assembled. The bastards should have been carrying Stormy around on their shoulders instead of tarring him with this terrible brush."[5]

There was one added blow to Storms. Atwood had to select his replacement. It was logical, reasonable, and practical to replace Storms with the man who had been president of Martin when that company had the Apollo study contract and had researched it for a year, where they had generated 9,000 pages of analyses. That man was Storms' arch rival, Bill Bergen, who was at that time already with North American. NASA's Source Evaluation Board had originally recommended Martin be given the contract, but Storms' powerful and imaginative bid had won it. This final time around, Bergen won.

The NASA-North American contract was renegotiated, minus the previously planned incentive fees. "Webb insisted on severely cutting the possible earned profit of some $15 million and later refused to honor a contingent bonus," Atwood said. NASA assumed the cost of some of the spacecraft redesign; North American agreed there would be no charge for certain other changes. Boeing was brought in to perform an Apollo technical integration and evaluating program, which North American endorsed. By a small step at a time, the space program was getting back on track.

Redesigned as First Planned

The command module redesign included an outward-opening hatch, which Storms had in the original design until NASA directed an inward opening hatch. For this change, a unified hatch was approved by NASA. "The new component was heavier than the old, but it would open outward in five seconds, had a manual release for either internal or external operation, and would force the boost cover cap out of the way on opening."[8] Atwood had this engineering comment: "The quick opening hatch modification was a psychologically necessary change—important to have while the spacecraft is on the pad, but it would have no value if a fire starts after liftoff where the flammability danger is the greatest."

The old battle about the atmosphere was addressed. There had been a virtual crusade against 100 percent oxygen, even in space, waged by Storms and A. Scott Crossfield (the famed test pilot of the X-15 rocket plane), Apollo Director of Test and Quality. The NASA engineering change order, dated August 28, 1962, specified "delete nitrogen" was voided. Finally, Apollo was being tested on the pad with a nitrogen-oxygen mix of 16.7 p.s.i.a. But still, NASA clung to its design of 100 percent oxygen in space. Only with the advent of the Space Shuttle did they finally concede that "air" was the proper atmosphere for people in space, just as it is on earth.

On this sticky point, on which disagreement continued between NASA and North American, Atwood says this about a comment from Webb quoted in his biography: " ...going to the two-gas system would mean a larger spacecraft and spacecraft walls capable of standing greater internal pressure in the vacuum of space."[10] Atwood, the engineer, says, "This is patently absurd and seems to be an excuse of obfuscation. All subsequent Apollo spacecraft used two-gas inflation where really necessary—on the pad and in launch—with no increase in size or cabin wall thickness."

The issue arose again on the final mission of the spacecraft. On July 15, 1975, Apollo 18, was the one that achieved a link-up in space with a Soviet vehicle and the mission was called Apollo-Soyuz. In the planning, the politics were resolved, but another sticking point remained: the United States used pure oxygen in their orbiting spacecraft and the Soviets used a mixture equivalent to plain air. The Soviets considered our system too dangerous. Said Caldwell Johnson in his article, "They had the correct system. They were concerned about us, and they had a right to be."[19]

The article explains how it was resolved: "The solution to the atmosphere problem was a docking module, which was carried into space on the nose of the Apollo spacecraft and acted as a regulator between the two environments. Before transferring between the two spacecraft, the Apollo crew would enter the docking module and add nitrogen until its atmospheric pressure was 10 p.s.i.a. The Soviets agreed to reduce their atmospheric pressure while docked."[19]

What about the astronauts who flew the Mercury and Gemini missions before Apollo? Why had they allowed themselves to be placed inside spacecraft containing such threat? How could they add pouches of Raschel netting attached by velcro to the interior for convenience in attaching their needed items that would otherwise float in space? (The contractor authorized using 500 square inches of velcro, but astronauts were using 5,000 square inches of the flammable tape.) These were the "red flag" items placed inside the module on the pad, ones not tested for flammability by the contractor—and even those tests did not apply to the launch pad pressure that NASA was using. It was the noncerebral process of assumption. "We have always done it that way" summed up the attitude.

The fallout from this part of the investigation brought about more than 3,000 laboratory tests of 500 kinds of materials for flammability. The nylon cloth parts previously used were replaced by Beta fiber, Teflon, or fiber glass.

Once the initial shock and sorrow of the fire began to subside, when the anger and accusations gave way to rational thought, it was like a second wind to the program. Borman—who served in the Apollo Investigation Board and whose testimony that he was still willing to fly in Apollo turned around the mood of Congress—was asked by Robert Gilruth, Director, Manned Space Flight Center, to head the spacecraft team at the North American plant in Downey and immediately accepted: "After four months of investigation, I think I know as well as anyone else what has to be done."

Moving Ahead

Prof. Holt Ashly, Stanford University, says, "Lessons learned from Pad 34 led to Apollo improvements. There were numerous important changes. The whole interior was reorganized so as to reduce or eliminate flammable materials, place utilities like wiring in protected locations, etc. The manufacturing team worked like Trojans to implement this redesign and deserve special credit. In order to stay on schedule, there were times when seven or eight people were working within the confined interior."[21]

NASA redoubled its effort. Whatever else may be said of Webb, he was the knowledgeable bureaucrat who kept the investigation contained; Apollo was progressing at full tempo in four months, as opposed to the later Challenger disaster where a Presidential Commission performed the fact-finding and made the recommendations, and the Shuttle program was thereby delayed for about three years. The board may have seemed to some to be stacked toward NASA and against the contractor, but it brought in reasonable recommendations—aside from sidestepping the oxygen problem.

Borman made varying statements: "We didn't sweep a single thing under the rug." Two pages later, he says of his testimony before Congress: "... we in the space program had overlooked the obvious hazard of putting a 100% oxygen environment into a spacecraft pressurized to more than 20 p.s.i. [sic]."[20]

Ashley made this comment: "... the engineers who carried out the investigation were under no pressure to conceal facts or try to make NASA 'look good.' Their most important goal was to learn from the experience and find ways to improve the safety of Apollo design and operation."[21]

Atwood said of the investigation "it is unfortunate that anyone ever applied the term 'cover-up.' That was not true. I do not believe that any individual in NASA or North American withheld any facts or information intentionally."

But Atwood still cannot understand why the board failed to recognize the oxygen at ground pressure as a key to the disaster.

Wrote Atwood as recently as February 25, 1996: "To this day, NASA has never, in word or publication, stated that the oxygen over-pressure on the pad was not specified to the company as an operating condition, nor that the wire insulation and other flexible materials in the spacecraft were never tested for flammability at the 16.7 p.s.i.a. straight oxygen pressure."[22]

Whatever was previously lacking in interchange of information was considerably overcome at NASA Headquarters after the fire when Mueller set up a Master Control Center. Its purpose was to coordinate all investigations, redesigns, funds, allocations, personnel assignments, reports, etc. It continued to function when Apollo moved on.

Freitag says this about the center: "I was personally involved in running much of the activity. It worked beautifully; it kept data under control; it got needed data to users promptly; it stopped rumors; it effectively managed funds and resources; and it was one of the soundest management techniques that kept the program (and investigation) on track."[23]

Optimizing Downtime

As time lent perspective to the event, it became apparent that a break in the furious if not frantic pace of the original schedule was beneficial. Freitag says, "The fire, in one view, was a blessing in disguise. The spacecraft benefitted from the second look. The time used by the investigation and problem solving allowed NASA and North American to complete an overall spacecraft redesign that really assured success.

"There had been many deficiencies (not defects!) that were reworked for a safer and more reliable spacecraft. The crews were able to complete better training, as were the flight control people. The Saturn vehicle needed no such redesign, but it did benefit greatly by the extra development time. The fire assured success of the Lunar Landing more than any other single event."[24]

The down-time allowed many elements to catch up. The LEM, which at one point was reported to be a year behind schedule, was still a pacing item in August 1966; the guidance and navigation system; the computers; and, most of all, the simulators. They could never stay up with NASA's constant engineering change orders and so exasperated Grissom that on the day he returned to the Cape for that test run from his home in Texas, he picked a big lemon from his tree and hung it on the simulator.

This became a prevailing reconsideration: "The Apollo command module was the most complex flying machine ever devised, an intricate package crammed full of state-of-the-art equipment. It would have been naive not to expect all kinds of things to go wrong the first time they put one together. And no one, at NASA or North American, had knowingly compromised the astronauts' safety.

"And in the next weeks the astronauts came to admit what Stafford, Young, and Cernan said over a few drinks one night, that there was a hidden blessing in the disaster: the wreckage of Apollo 1 was there for the accident board to examine, not in a silent tomb circling the earth or drifting in the trans-lunar void. Although three men had died, three or perhaps six more lives had probably been saved."[24]

Ashley says, "Another big improvement that resulted from Pad 34 lessons was the redesign of the command module hatch so as to permit much more rapid escape. It is a terrible thing that three astronauts had to die in order to motivate this and many other changes, but the experience contributed to subsequent safety and success of the Apollo missions. They were a miraculous engineering achievement. One must recall that, despite Apollo 13, no astronauts were even injured during the manned space portions of the program."[21]

Many hold the view that the fire assured the success of Apollo 11, the flight that finally landed two men on the moon—and despite delays, did it earlier than President Kennedy's goal had specified. Atwood points out that the mission needed all the help it received, for the Eagle landed Armstrong and Aldrin on the lunar surface with only 20 seconds of fuel remaining.

Test pilots, with courage and dedication, have given their lives since men first left the ground. There have been so many. Among the famous are these: Capt. Glenn Edwards (for whom Edwards AFB is named) in the Flying Wing in June 1948; Maj. George Welsh in the F-100, 1955; Capt. Mel Apt (the first man to achieve Mach 3, exceeding 3,000 mph) in the X-2, September 1956; and Mike Adams, who after 199 missions in the X-15, flew his last one in 1965. They wear the distinctive pin an their lapels, "X" for "Experimental Test Pilot." People die testing new craft.

Grissom himself had said in an interview several weeks before the fire, "We are in a risky business. We hope if anything happens to us, it will not delay the program. The conquest of space is worth the risk of life."[8]

The three astronaut victims were given memorial services. Other victims lived on with their thoughts. The three widows asked that the aborted mission be called Apollo 1 instead of Apollo 204; history obliged their wish. North American made a six-figure settlement on the widows, but money did not fill that empty spot in their lives—it never does. Pat White committed suicide a few years after the event; Betty Grissom and Martha Chaffee learned to cope and forge different lives. Other victims were certainly Storms and Shea. The path to the moon was strewn with many broken lives.

The Ultimate Vindication

After the publication of the book, *Powering Apollo: James E. Webb of NASA* by Prof. W. Henry Lambright, Atwood wrote this to the author: "in the interests of the thousands of my very talented and hard-working associates, I regret the fact that recognition of their exceptional accomplishments was obscured by the 'massive mistake' of the NASA operating group and official unwillingness to accept any blame. However, it is apparent that these North American efforts were recognized at the responsible engineering level in NASA. The award of the space shuttle and its main engines to these same people may be recognition enough."[25]

The space shuttle, the gem, the follow-on to the Apollo project—North American had won the big one again. So NASA obviously did not really believe they were such a poor contractor.

Even in the fervor of the investigation period, there were indications that the hypercritical view of North American was not the truly held appraisal. Almost as though the private opinion had slipped out, Webb said on April 17, 1967, in his first appearance before the Senate Space Committee investigators, in defense of the contractor that had been showered with blame, "I don't think you can call it negligence if somebody is unable to operate at 100%. They did not do all the things they should have done, but I can say the same things for all of us at NASA."[10] Webb's biographer concedes, "He may not have been fair in his treatment then of certain officials in NASA and North American."[1]

Atwood recalls that during one of the congressional hearings, he said to Mueller, "George, if it were not for the oxygen pressure [on the pad], that spacecraft would have made a good flight." Mueller's answer was unforgettable to Atwood, "Of course it would." Atwood adds, "Such an answer simply would not do for Webb and the congressional opposition and the media, and I believe Mueller knew that."

On April 13, 1997, "Dep. Administrator , Dr. Robert C. Seamans, Jr., and Associate Administrator for Manned Space Flight, Dr. George E. Mueller, testifying before the Senate Committee on Aeronautical and Space Sciences, absolved North American Aviation, Inc. of direct blame for the Jan. 27 Apollo fire..."[6]

"After the dust had settled and emotions subsided, there was this significant comment to William Dean, who was the Manager of the S-II in its latter stage of production: Phillips told me he wished he had never written the Phillips Report."

Atwood had heard about the document since the day after it was written, December 18, 1965, in a letter from Mueller. A television commentator had a copy, some members of congress had copies, but Atwood (the one most concerned), did not have a copy. He never saw a copy until 1989 when one was handed to him by Martin J. Collins, who was getting Atwood's oral history for the Smithsonian Institution.

Even these 24 years later, Atwood was appalled by the severity of the criticism. It was focused on the S-II, which won highest acclaim from the engineering community. He said, "This is egregiously and categorically in error on any comparison. It seemed Storms and Wickam [Chief Engineer on the S-II] were too dedicated to engineering design; they could have turned out a heavier booster stage much earlier, but with it, Saturn would not have been able to put the spacecraft into a lunar trajectory."

Of even graver importance was Atwood's shocked realization of how vulnerable he had been to being indicted and tried for perjury for denying knowledge of the document in sworn testimony before a congressional committee.

Just as the process of erosion can round the sharp edges of granite, time softens the bitterness of human feelings. One by one, those who were the most critical came to regret their attacks on the contractor. Even an aging Webb sent a handwritten letter to Atwood 16 years after the Apollo fire. This is what it said:

> November 30, 1983:
>
> Dear Lee,
>
> Congratulations on your selection for the Wright Memorial Trophy. You have made tremendous contributions to aviation, too [sic.] space, to your country and your company. Along with your other friends, I am most happy to see these recognized.
>
> Unfortunately, I am house bound and cannot attend the dinner on the 8th and 9th—unless in a wheelchair, which is too hard on everybody. But I will be there in spirit and wishing you the best.
>
> Most sincerely,
>
> Jim Webb.[26]

Perhaps that letter ameliorated some of Atwood's memories, such as the fact that Webb had used his contract authority and the intimidation of a team of FBI agents to force Atwood to remove Storms from the Apollo project.

At this period in his life, was Webb trying to gain closure on his actions, to ease his conscience? What part did this experienced bureaucrat play in saving the entire young space agency? Did his approach save the Apollo program? Was he keenly aware of the fickle nature of Congress—aware that they might have pulled the plug on the entire costly space program if they had any more doubts about NASA? We will never know how Webb would have answered these searching questions. He died in 1992.

After All

From 1989 to the present, some of the key people of the Apollo 1 project have been members of the Aerospace Historical Committee of the California Museum of Science and Industry: Atwood, Mueller, Storms (dec.), Freitag, Phillips (dec.), and 25 others (see Appendix A). Over the years, in turn, each of these leading figures of Apollo has been presented with the committee's prestigious International von Kármán Wings award. What memories must flood back as they graciously greet one another? Their innermost thoughts are concealed by the sheath of propriety.

Another member of the committee is Donald E. Paglia, M.D.—scientist and artist—who was in NASA's Apollo Applications Program to become a scientist-astronaut. That, too, changed when the fire disrupted plans and schedules.

Paglia sees the event with the eye of a visionary and the soul of a poet. With special permission, he was allowed to visit the still sealed-off charred remains of the site:

> The Apollo 1 tragedy that occurred at Pad 34 transformed it in the minds of some to an unacceptable symbol of failure. As such, it was dismantled. This act removed it from public consciousness. The accelerated senescence and demise of Pad 34 has left relics that we may view now in an archeological context.
>
> Similarities in structure and form are readily apparent between Stonehenge and Pad 34: They both incorporate basic posts and lintels that are centrally placed in concentric ovals of stone and aligned by prominent radials. If compared to Neolithic burial chambers, Pad 34 might be seen as a modern funerary because of common elements of trabeate architecture. The framing effect of the central test stand on Pad 34 transforms, metaphorically to a window or doorway to Space, the modern unknown.[27]

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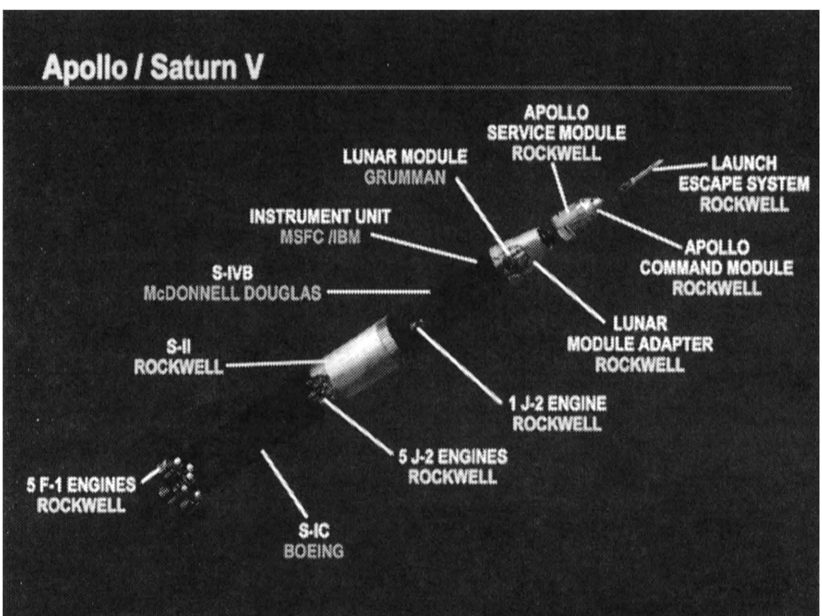
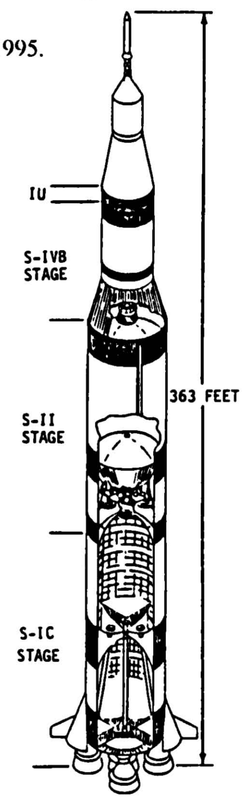
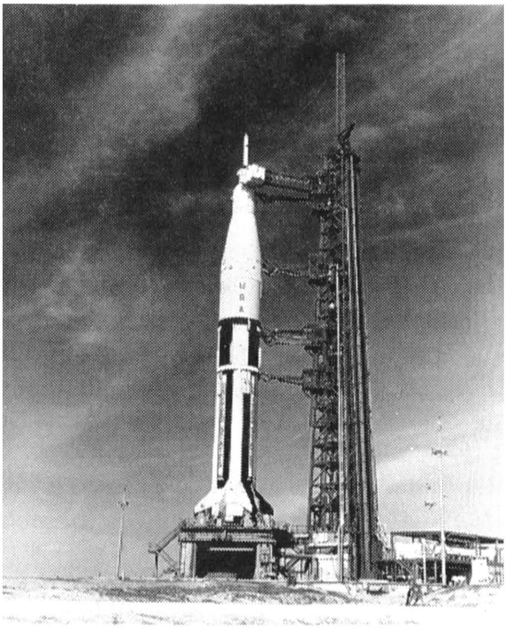


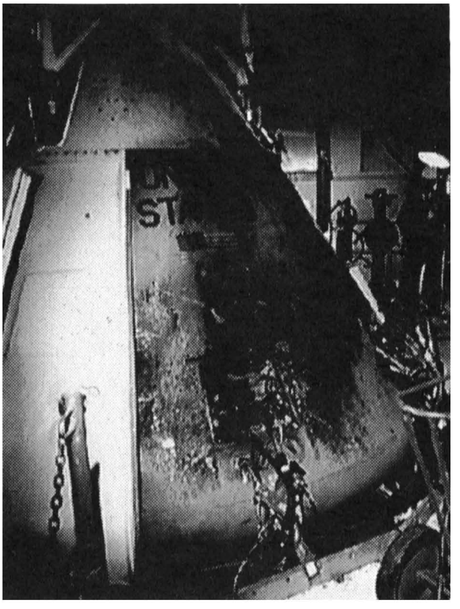


PRE-LAUNCH LAUNCH VEHICLE GROSS WEIGHT ≈ 6,348,659 POUNDS

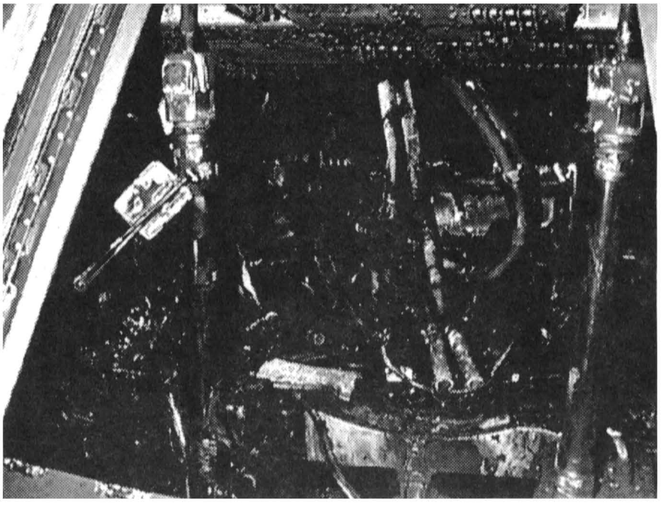


Apollo 9 atop the Saturn 1B Launch Vehicle.

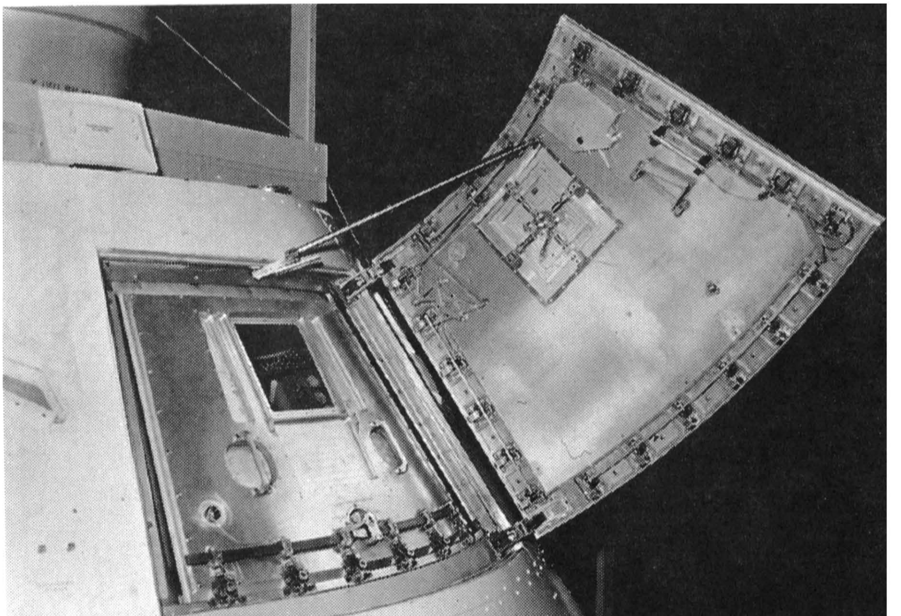
The Crew of Apollo 1: Left to Right: Edward C. White, Virgil I. Grissom and Roger Chaffee.

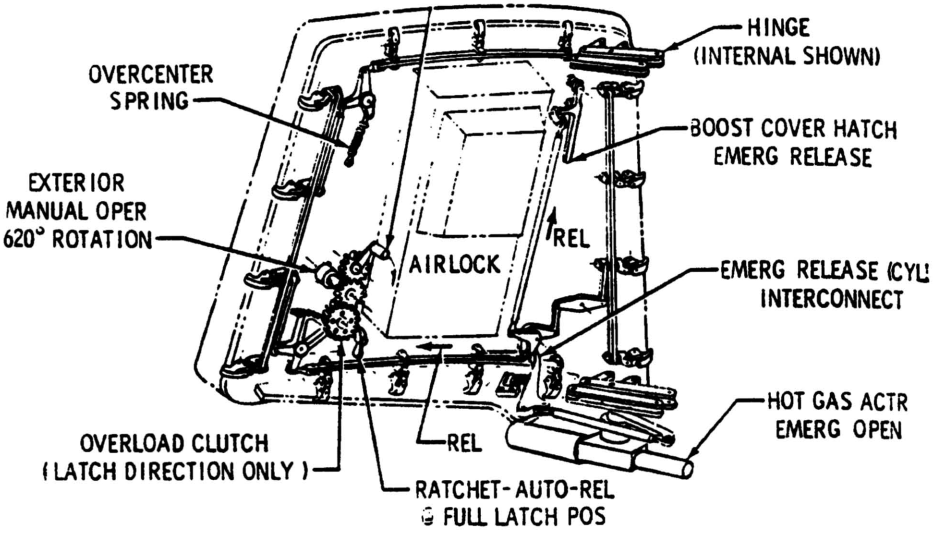


Apollo 1 Command Module After the Fire.



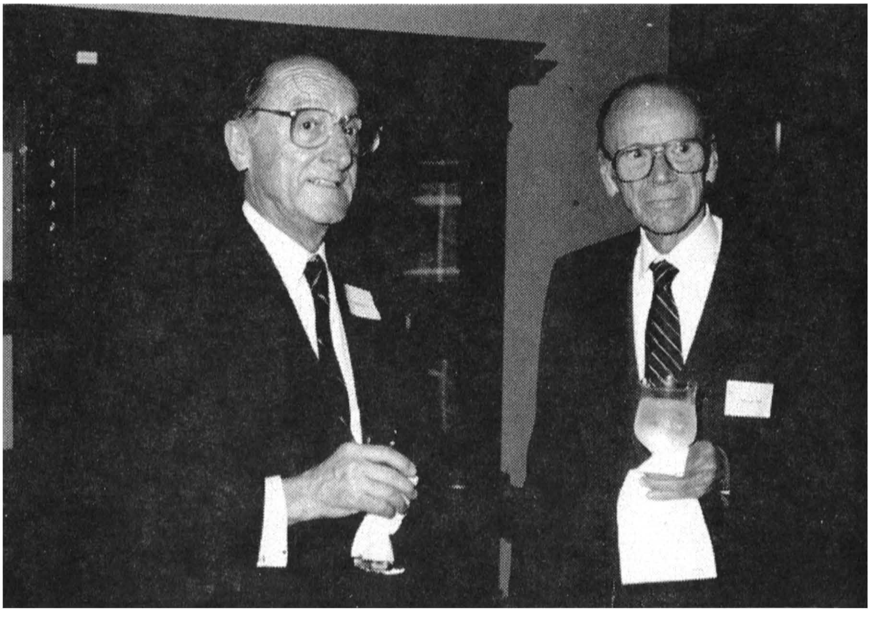
The Apollo 1 Escape Hatch Required 90 Seconds to Open.





The Redesigned Escape Hatch for the Apollo Command Module Required 5 Seconds to Open.

August 5, 1985, J. Leland Atwood, Gen. Samuel Phillips and Dale Myers at a Meeting of the Aerospace Historical Committee.



June 29, 1989; Dr. George Mueller attended when Harrison Storms (right) received the International von Kármán Wings Award of the Aerospace Historical Committee.

Pad 34.

Appendix A
AEROSPACE HISTORICAL COMMITTEE

Chairman: Dr. Shirley Thomas
Members: Dr. Buzz Aldrin; Mr. J. Leland Atwood; Mr. Steve Bayrd; Mr. Earl Blount; Mr. Fred Bowen; James C. Brooks, Esq.; Mr. A. Scott Crossfield; Capt. Robert F. Freitag, USN (Ret.); Lt. Col. James C. Ghormley, USA; Mr. Roy Gibson; Mr. James J. Harford; Mr. Willis Hawkins; Lt. Gen. Richard C. Henry, USAF (Ret.); Dr. Albert Hibbs; Dr. Alfred Ingersoll; Gen. David C. Jones, USAF (Ret.); Mr. Gregory P. Kennedy; Dr. Edwards Metcalf; Dr. George E. Mueller; Hon. Dale D. Myers; Dr. William A. Nierenberg; Donald Paglia, M.D.; Dr. Dawn Marie Patterson; Mr. William C. Perkins; Dr. William H. Pickering; Dr. Robert W. Rector; Dr. Harold Rosen; David S. Sauber, M.D.; Mr. William A. Schoneberger; Gen. Bernard A. Schriever, USAF (Ret.); Dr. H. Guyford Stever; Dr. Homer J. Stewart; Dr. Edward C. Stone; Dr. Michael I. Yarymovych.

Appendix B
The Apollo Fire - An Analysis
by J. Leland Atwood, October 1988

On January 27, 1967, the fast developing Apollo moon landing program, initiated by President John Kennedy in 1961, was hit by the first operational tragedy in the U.S. Space Program. Veteran space pioneers Gus Grissom, Ed White, and first-time astronaut Roger Chaffee were killed by a fire in their Apollo spacecraft in a ground test that was not considered or classified as a hazardous procedure. Saddened and shocked, many were struck and even baffled by the incongruity of the circumstances which involved no rocket engine blasts or high velocities, or even altitudes above the ground. The nature of the tests and the routine operational aspects of the procedures seemed to give no hint of danger, and the entire management cadre of the program, as well as the public in general, were confounded and stunned.

Although the smaller and less complex Mercury and Gemini craft had gone through similar procedures repeatedly, and the Apollo vehicle had been under test for some time before the initiation of the fire, it became apparent afterward that the crew had been at great risk because the ground test was basically dangerous and that the probability of disaster occurring during the tests was high.

Though much was written and the accident report consisted of some 3,000 pages in several parts, I am unaware of any concise assessment of this tragic sequence. This analysis is offered for the record with a minimum of technical terminology.

A key factor in this circumstance is the elemental gas, oxygen. The earth's life is water-based and oxygen-activated, and our atmosphere is 21% oxygen by volume, with the remaining 79% consisting primarily of nitrogen which is relatively inert and inactive chemically at moderate temperatures. Atmospheric pressures range from nearly fifteen pounds per square inch at sea level to five pounds at just under 30,000 feet and one pound at 60,000 feet. Before pressure cabins were developed, airmen had flown to approximately 56,000 feet with supercharged engines, breathing oxygen from tank supplies. This appears to be about the limit for free flight since bodily fluids—principally water—approach boiling or the vapor point at body temperature and about one pound per square inch pressure which occurs as noted above at about 60,000 feet.

Nitrogen also has its effect on the human body—not in a chemical but in a physical manifestation. Under pressure, as normal atmospheric, some nitrogen is absorbed in the blood. This nitrogen, under constant pressure, is not in a gaseous (bubble) condition. If pressure is increased, as in ocean diving or undersea tunneling, the absorption of nitrogen is increased, and if the pressure is relieved too rapidly, the nitrogen forms bubbles which interfere with blood flow, creating the dangerous and painful condition called "bends," usually felt first in the joints. This condition is ordinarily relieved by reducing external pressure gradually, allowing the excess nitrogen entrained in the blood to escape through the lungs rather than causing gas embolisms or other damage.

Unpressurized airplane flights to very high altitudes have involved a considerable period of time, most of an hour, and gaseous oxygen was ingested by the airmen during the climb. Under such conditions, the formation of nitrogen bubbles and the onset of "bends" was not likely to happen.

These considerations confronted the aeromedical personnel involved with the planning of the first human space flights. The rocket launch would loft the spacecraft above the sensible atmosphere with a rapid decrease in cabin pressure in only a fraction of the time it would take an airplane to reach its ceiling, and a number of factors had to be taken into account. Basic considerations were adequate oxygen, sufficient minimum pressure, and time for the dissipation of nitrogen entrained in the blood. These factors are quite inexact, and substantial allowances are usually made.

These aspects were considered at length, and it was decided that the baseline cabin pressure in space would be established at five pounds per square inch of pure oxygen. This, in a practical way, seemed to eliminate most of the concern about nitrogen bends and established a space environment which would give the astronauts the equivalent of flying unpressurized at just under 30,000 feet while breathing pure oxygen. This atmosphere of pure oxygen became an accepted standard and was used on the Mercury, Gemini, and the Apollo.

This five pounds of oxygen pressure could not, however, be directly used for ground tests and liftoff conditions. All the spacecraft were fragile structures where minimum weight was essential. Submarine-like structures can resist large external pressures, but while all spacecraft are capable of some internal pressure, they are prone to buckle and collapse under external pressure. This characteristic and the attempt to limit the exposure of the astronauts to nitrogen absorption before launch led to the practice of bringing the internal pressure of pure oxygen in the spacecraft on the ground to more than atmospheric. In fact, NASA records show that the Apollo spacecraft that burned had an internal pressure of 16.7 pounds per square inch of pure oxygen at the time of the fire. That created a concentration of oxygen about five and one-half times the concentration in the normal atmosphere at sea level. *This, however, was never specified as an operating condition.*

The use of oxygen under such pressure and normal gravitational force had to presume that no source of ignition would develop, and apparently, such an assumption was made either directly or implicitly.

There was, however, a forewarning that such immunity was not to be counted on. In the official NASA record of the Gemini program, entitled "On the Shoulders of Titans," the flight of Gemini VIII—carrying Neil Armstrong and Dave Scott—was disrupted by an attitude thruster which fired and continued to fire, and started the craft into an uncontrolled gyration. The record shows that a short circuit in the spacecraft wiring caused the thruster to fire, and only the cutoff of all power to all the thrusters by the resourceful crew stopped the wild spin and allowed an emergency recovery.

In space, when the spacecraft is not under acceleration, as in orbit, there is no comparative effect of gravity, and as a consequence, combustion is difficult. It is generally known that, even in oxygen at normal cabin pressures, a candle will not burn in the absence of gravity because there is no convection—i.e., cool air (heavier) will not sink and hot air (lighter) will not rise to bring fresh oxygen to the candle wick. On the other hand, if this short circuit had occurred at sea level, as on the pad, with over sixteen pounds of oxygen pressure, the resulting heat source, sparks. etc., would likely have caused a fire in the Gemini spacecraft before launch. With this in mind, it is clear that the possibility of fire in a vehicle in space with five pounds per square inch of oxygen and no effective gravity is almost negligible compared to that in the same vehicle on the ground under full gravity convection and the corresponding high pressure of oxygen.

Continuing to the Apollo spacecraft and fire, it is apparent that the ground testing followed the Mercury and Gemini pattern, and internal oxygen pressure was raised to 16.7 pounds per square inch in order to well exceed the ambient atmospheric pressure of nearly fifteen pounds per square inch so that there was no chance of imploding or crushing inward of the light pressure shell.

The circumstances were generally similar to the tests of the Mercury and Gemini capsules, although there were some differences in scale. The Apollo craft, because of a higher heat flux resulting from a much higher reentry velocity, had more of its electrical machinery inside the heat-shielded cabin area—and being larger, had a much greater volume of oxygen although the pressure was the same.

The source of the ignition was never determined, but the combustion of a wide variety of components, though made of fire-retardant materials, including wire insulation, cabin linings, hoses, pressure suits, and even thin metals continued until the oxygen was exhausted.

The fate of the crew was really determined, however, by an entirely different circumstance. The original Mercury spacecraft was designed with an exit hatch that could be blown away explosively by the pilot if he wanted to make an emergency exit. Ironically enough, Gus Grissom's Mercury sank to the bottom of the Atlantic after an ocean recovery when the hatch was accidentally blown for some reason that was never conclusively determined, allowing sea water to enter and the craft to be lost. This incident, along with other considerations, led to the design decision to eliminate the quick-escape factor in the Apollo hatch. As a result, even a desperate and expert outside crew required more time to open the hatch than the unfortunate occupants had available. If the hatch could have been immediately opened, it is most likely the crew could have escaped without harm.

It might be pointed out here that, while the fire danger on the pad was high as events turned out, the probability of fire shortly after launch would have been materially greater. The first-stage Saturn thrust of 7.5 million pounds immediately begins to accelerate the six million-pound stack. On launch, the initial acceleration increases the gravity vector by about one-fourth, and as fuel is consumed, this acceleration is increased. Cabin pressure is also bled down with increasing altitude, so it is probable that the greatest convective augmentation through acceleration, combined with internal oxygen pressure, occurs within the first few minutes after launch. If the temperature at any point in the cabin rises to the level which causes the start of oxidation of any material, the resulting heat rise and increased convection of upwardly flowing oxygen quickly bootstraps combustion out of control. If the fire had thus occurred during launch, the mystery and difficulty of investigation would have had a very large and undeterminable effect on the total program.

In the aftermath, there was no Rogers type commission—such as that which investigated the 1986 Space Shuttle disaster—but a team of NASA personnel, with other technical assistance, made the investigation and filed the report mentioned before. With no lack of appreciation for the Rogers investigation, the decision by President Johnson to have the inquiry done internally by NASA was probably a major factor in allowing the program to continue promptly in relatively good order. Since the assassination of President Kennedy, the schedule for completing a lunar mission within the decade had become, symbolically, nearly as important as the program itself. There was not time for extended testimony, redesign, and retracing decisions. It was soon apparent that a diluted oxygen atmosphere and redoubled attention to quality and detail could see the program through, and such was the case. A quick-escape hatch was also incorporated, but was only used for routine access.

No ignition source was identified, and as a matter of record, the source was never discovered. The report was critical of workmanship and identified a socket wrench tip left in a wire gallery and certain other discrepancies which could not very rationally be connected to the fire. Naturally, the question of workmanship was of much concern, and while no such connection with the fire has been made, it is quite possible such a defect created the heat source.

The question of a short circuit in the wiring was, of course, critical. All power circuits in the spacecraft were recorded on a broad inked tape driven by a multiplex circuit that sampled all power channels ten times per second. This writer personally examined the tape records early the next morning after the evening fire, and with the support of a test engineer, was unable to detect any unexplained voltage drop which would have indicated a short circuit.

Nonetheless, after all other factors are taken into account, it is apparent that the actual ignition was caused by a heat source that was sufficient to create the cascade of oxidation, increased heat, greater convection, and disaster. This could have been in an instrument, relay, motor, circuit board, resistor, junction box, wire terminal, test equipment, or other component of the complex electrical system.

Whether from a workmanship defect or detail design oversight, such as a code error in selecting an electrical resistance component, something certainly did heat beyond the low threshold of combustion of some material in the dense oxygen atmosphere. I believe the most probable source was a slightly loosened wire connection where the cycle of electrical resistance, heat and oxygen corrosion progressively increased until the wire insulation caught fire.

After the fire, tests were run on flammability and fireproofing with various proportions of oxygen and nitrogen in dummy capsules. It was determined that the spacecraft pressured with 16.7 pounds per square inch of oxygen could not be fireproofed with any acceptable materials—so the sea level atmosphere was changed to a mixture of 60% oxygen with 40% nitrogen as a quenching agent. Fire would not propagate in any of the spacecraft materials with this mixture of gases. Before launch, the crew breathed pure oxygen through masks or helmets, and the cabin atmosphere was bled down to five pounds per square inch after launch and replenished with oxygen at the same pressure. Most of the concern about the absorption of nitrogen was resolved, as it is now in the space shuttle, by breathing oxygen for an adequate period before launching and before going into pressure changes such as in an air lock or a space suit. Some nitrogen is retained in the blood for a time even under a pure oxygen atmosphere, so adjustment time is allowed in all major pressure changes. At the lower pressures as in space suits, of course, pure oxygen is used.

It can be seen how the high pressure of oxygen in spacecraft at sea level developed into a standard operating practice. It is probably true that relatively few people involved with the Apollo program were aware of the magnitude of the sea level oxygen pressure and that those who did know of it relied on past experience and precedent.

The aeromedical profession has been a strong participant in the manned space program from the start. In the astronaut selection process, medical considerations are of the highest importance, and much of the training and indoctrination process is supervised by medical doctors. Their criteria are given priority on every mission, and the physical condition of all crews is continually monitored on all flights and recoveries. The space program probably involves more cooperation between the medical and the engineering sciences than in any other endeavor, although atomic power requires much such interaction in a somewhat different way. The two sciences are not competitive and have little overlap—although interdependence is heavy. Medical science is primarily empirical rather than analytical—while in engineering science, this relationship is largely reversed. It seems that analysis stopped just short of the intended intersection of the two disciplines.

As Wernher von Braun said, "We had a blind spot."

J. Leland Atwood, Aeronautical Engineer and President of North American Aviation/North American Rockwell from 1948 to 1970

Postscript

It is, of course, not possible to know, but if the question had been put properly to any top Apollo executive (including the writer)—e.g., "Did you know that the astronauts are being locked in with all that electrical machinery and the spacecraft is being inflated to 16.7 pounds per square inch with pure oxygen?"—I believe a whistle would have been blown.

Although some North American Aviation employees at the Cape participated in the tests, neither Harrison Storms (Space Division President), Dale Myers (Program Manager), Charles Feltz (Project Engineer), nor the writer, had any idea that the spacecraft was to be inflated with straight oxygen on the pad. Furthermore, it is most probable that the executive management level of the NASA also was unaware of this procedure.

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