FEATURE

Saturn's Fury

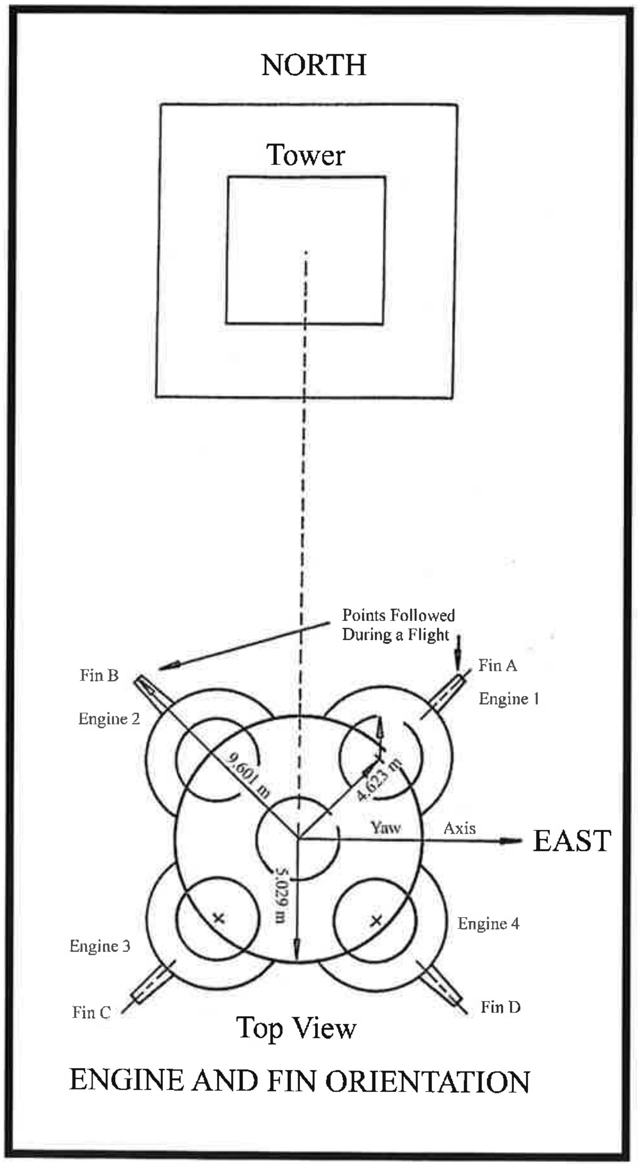
Effects of a Saturn V Launch Pad Explosion

By DWAYNE A. DAY

The Saturn V was the largest rocket ever built by the United States. A true monster of a launch vehicle, it generated 7.5 million pounds of thrust at liftoff and carried 5.5 million pounds of fuel and oxidizer. If the Saturn V exploded, it could do so with the force of a small atomic bomb, the equivalent of half a kiloton, or about 1/26 the size of the bomb that destroyed Hiroshima. Naturally, this was a significant concern for Apollo program officials.

During the course of the Apollo program, NASA officials conducted several studies to evaluate the effects of the ultimate worst-case scenario: a launch pad explosion of a Saturn V rocket. This was the worst possible accident for several reasons. The Saturn was most loaded with fuel at that point and posed the greatest danger to people on the ground. It also presented the fewest abort options, requiring the firing of the Launch Escape System (LES) rockets that would blast the Command Module away at high acceleration.

Early in the Saturn development phase, NASA officials had carefully selected a launch site that was sparsely populated and where the actual launch pad could be isolated from other necessary facilities such as the Launch Control Center. They selected sites on the Atlantic Coast of Merritt Island, surrounded by swampland and beaches. In 1961 and 1962 NASA planners decided the locations of physical structures for the two Saturn V launch pads,



The orientation and displacement of the Saturn V with respect to the launch tower was critical in assessing the risk of a catastrophic launch failure due to a Saturn V collision with the tower.

and designated the pads Launch Complexes 39A and 39B. Because of the pads' isolation, after 1962, the Saturn designers were less concerned about the damage that a launch pad explosion could do to the surrounding area than they were about the damage that an explosion could do to the astronauts who were trying to escape it.[1]

In September 1963, NASA conducted a short study of Saturn V booster explosion hazards and how they affected the survivability of the Apollo spacecraft.[2] Entitled "Saturn V Booster Explosion Hazards and Apollo Survivability Analyses," the study focused on an on-pad explosion and its authors calculated the propellant weights in each of the three stages and determined their equivalent weight in terms of TNT, a common means of establishing a benchmark for explosive yields. The study's authors concluded that there was the equivalent of 490,000 pounds of TNT in the S-IC first stage, 558,000 pounds of TNT in the S-II second stage, and 150,000 pounds of TNT in the

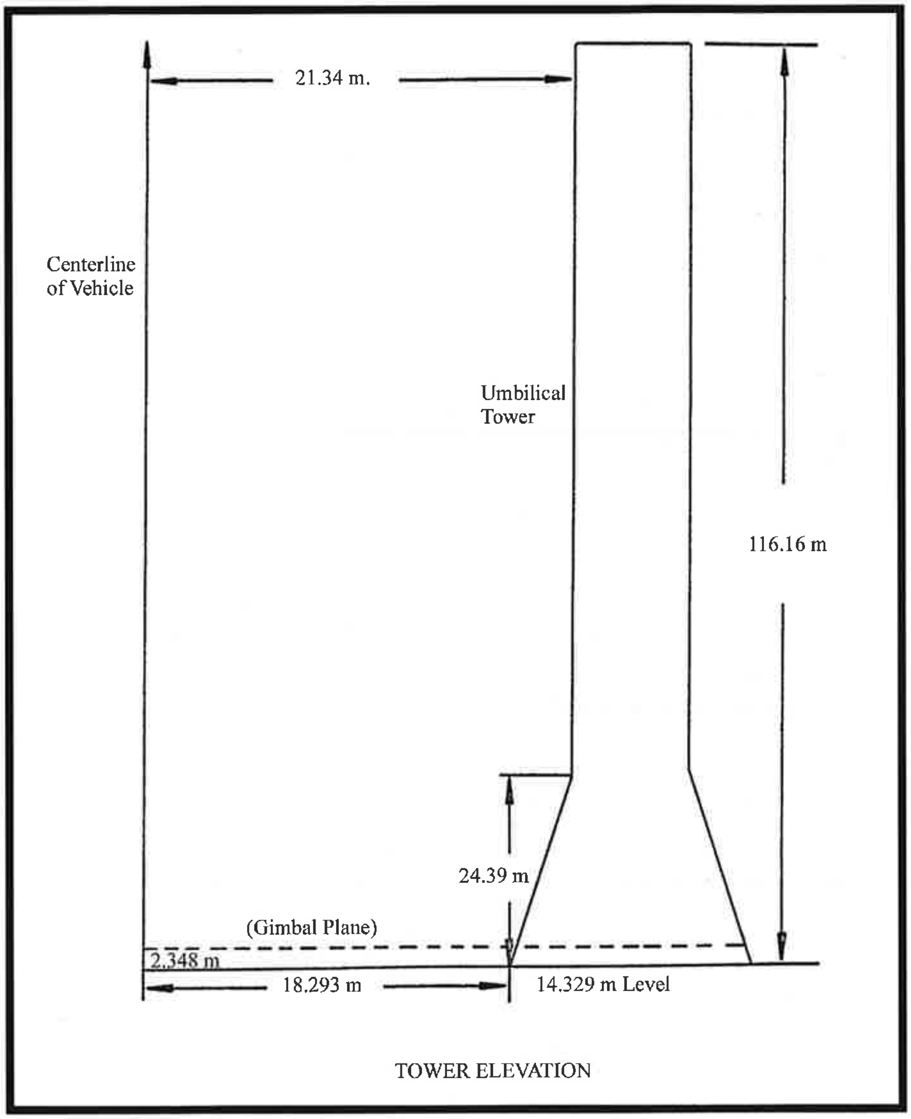
S-IVB third stage. Although the propellant weight of the first stage was considerably higher than the second stage, the second stage's explosive yield was greater because it utilized more explosive liquid hydrogen and liquid oxygen. The S-IC first stage was fueled with liquid oxygen and kerosene. The third stage, although also powered by liquid hydrogen, had far less fuel than the S-II stage.

Together, the three stages had a theoretical maximum explosive yield of 1,198,000 pounds, or 599 tons of TNT, or a little over half a kiloton, to use the terminology common to nuclear weapons.

Based on existing data, the study's authors felt that it was unlikely that all of the fuel in the Saturn V would be consumed in an explosion. In previous on-pad explosions of other liquid-fueled rockets such as the Atlas and Titan, significant amounts of fuel fell to the ground and burned long after the initial explosion. In the case of the Saturn V, this was most likely to occur for the heavy kerosene in the S-IC first stage.[3] The figure of 599 tons of TNT is therefore an absolute limit and the study's authors suggested that the likely yield was probably only 60% of this, or around 400 tons.[4] Rocco Petrone, who was the Saturn launch director, estimated that the real figure was more likely to be 300-400 tons.[5]

Even this lower yield explosion would have completely destroyed the launch tower, the Mobile Transporter, and significant parts of the launch pad itself. The detonation of the hydrogen and oxygen in the S-II second stage would have created a tremendous blast wave close to the launch tower, knocking it down. The fuels would have caused fires in the surrounding vegetation and killed animal life for miles around.

Some sense of the possible devastation can be surmised based on the results of the July 3, 1969 launch pad explosion of the Soviet N-1 rocket, which detonated with an estimated force of 250 tons of TNT. The explosion completely destroyed one of the launch pads and shattered windows nearly 30 miles away.[6]

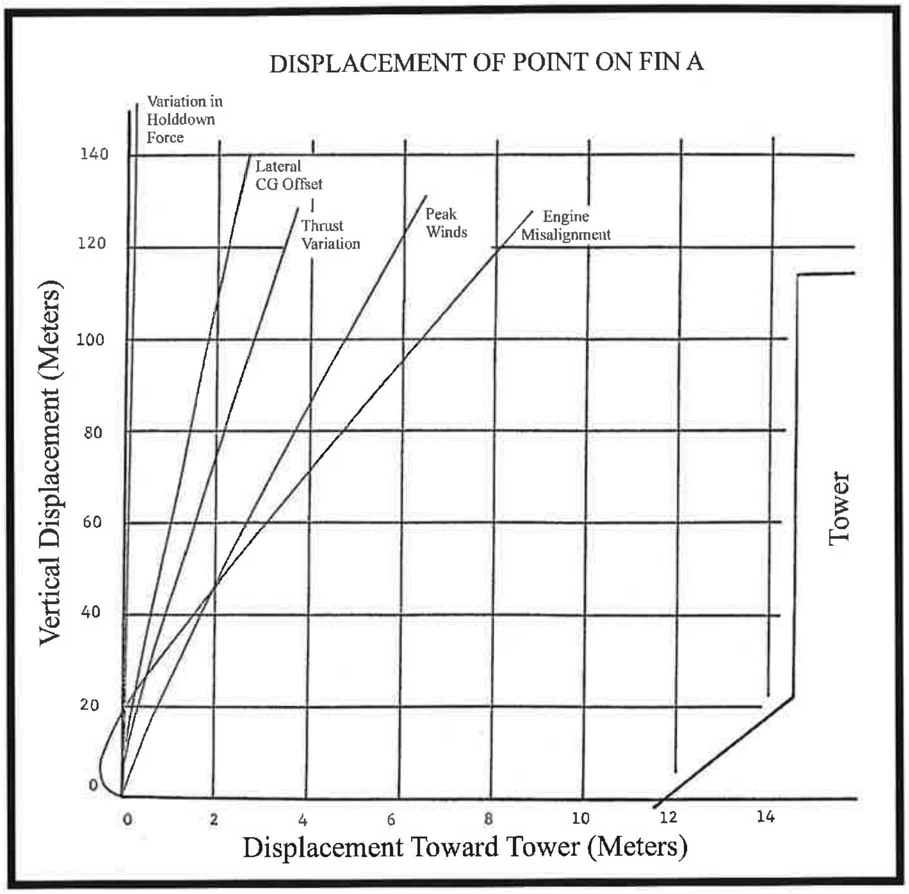


The major cause of a launch pad explosion was if the Saturn V's trajectory made it collide with the launch tower.

The September 1963 explosion hazards study divided the hazards from a Saturn V explosion into six categories: overpressure; dynamic pressure; fire; acoustic intensity; shrapnel; and impulse. Overpressure is the blast wave that is formed when the atmosphere surrounding the explosion is forcibly pushed back.[7] The study's authors considered overpressure to be the primary and most immediate threat to the Command Module in a sea-level (i.e. on-pad) explosion, although dynamic pressure from an explosion--the actual dynamic load imposed on the vehicle--became a greater threat than overpressure at high altitude (approximately 95 seconds into flight).[8]

The study assumed that an overpressure greater than five pounds per square inch (PSI) would destroy the spacecraft. Because the S-II stage had the greatest explosive yield, that stage dictated how far the Command Module had to travel in a launch pad explosion to avoid the shock wave, which diminished over distance. The distance requirement for the S-II was 1,040 feet. But because the Command Module was already 142 feet from the assumed center of the explosion in the S-II, the Command Module only had to travel 898 feet to escape the lethal overpressure wave and therefore survive the explosion.[9]

The study's authors determined



The risks of a launch explosion of the Saturn V due to various design, manufacturing and wind variations were individually quite small.

that the fireball, shrapnel, and noise were irrelevant factors for an on-pad explosion. Because any shrapnel from the exploding stages had to travel through the stages above them as well as through the Lunar Module, Service Module, and Command Module heat shield, shrapnel was not considered a threat to the spacecraft except in a case where the vehicle toppled over on the pad. Noise would not be important either. With respect to the fireball, although it would be the biggest ever produced by a non-nuclear detonation, at most the capsule would spend only 2-3 seconds inside of the fireball and the temperature would never be greater than what the spacecraft was already designed to withstand during reentry.[10]

In late 1964 or early 1965, the engineers at the Manned Spacecraft Center in Houston, Texas initiated the "Fireball Study" to evaluate the effects of the fireball produced during an on-pad explosion of either a Saturn IB or a Saturn V. In August 1965, Richard W. High and Robert F. Fletcher of the Flight Engineering Section and Mission Feasibility Branch, respectively, issued their report on the effects of a fireball produced by a Saturn IB or Saturn V explosion.[11]

Although the earlier explosion hazards study had indicated that the fireball posed no major threat to the Command Module itself, NASA engineers became concerned about the effect of radiated heat from a fireball on the parachute shroud lines of a descending Command Module. It would do the astronauts no good to escape the initial explosion and the fireball only to have their shroud lines burn up because of the heat of the fireball. Plummeting to the ground from a few thousand feet was no better than being crushed in the initial blast wave.

High and Fletcher used both mathematical models and data gathered from previous on-pad explosions, such as a recent March 2, 1965 Atlas-Centaur failure, to calculate the size, duration and thermal emissions from a fireball. But they admitted that some of their conclusions were little more than educated guesses.[12]

The two men assumed that virtually all of the propellants in the rockets would be consumed in a fireball, feeding it even after the initial explosion. They based this assumption on the belief that the initial blast wave would completely rupture all of the fuel tanks and that any fuel not consumed in the initial explosion would burn underneath it, and feed it.[13]

Based upon these assumptions and their calculations, High and Fletcher determined that the fireball from a Saturn V exploding on the launch pad would last for 33.9 seconds.[14] This fireball would rise, but they assumed that it would only begin to rise in the last quarter of its expansion phase, based upon empirical data. They were unable to make an accurate calculation of the maximum surface temperature of the fireball and ultimately settled for the maximum value they obtained from several other studies--2,500 degrees Fahrenheit.[15] They then calculated the radiated heat at a distance of 2,000 feet from the surface of the fireball. This information was then used in the design of the Launch Escape System.

These studies provided useful data for the requirements for the Launch Escape System and emergency planning -- but they started with the assumption that the vehicle was exploding. NASA engineers also looked at the question of what set of circumstances could lead to such a situation in the first place. In a conclusion that surprised few rocket veterans, they determined that the most likely cause of an on-pad explosion of a Saturn V was a collision with the tower during liftoff.

Colliding with the tower would immediately rupture the fuel tanks causing fuel to flow out and contact the hot engine exhaust, leading to an explosion in fractions of a second. Tower collisions had been a major concern for earlier rocket programs, including the Saturn I. Saturn program officials even placed cameras on the top of the Saturn

I launch tower looking down to assist in manually determining if the rocket was sliding toward the tower.

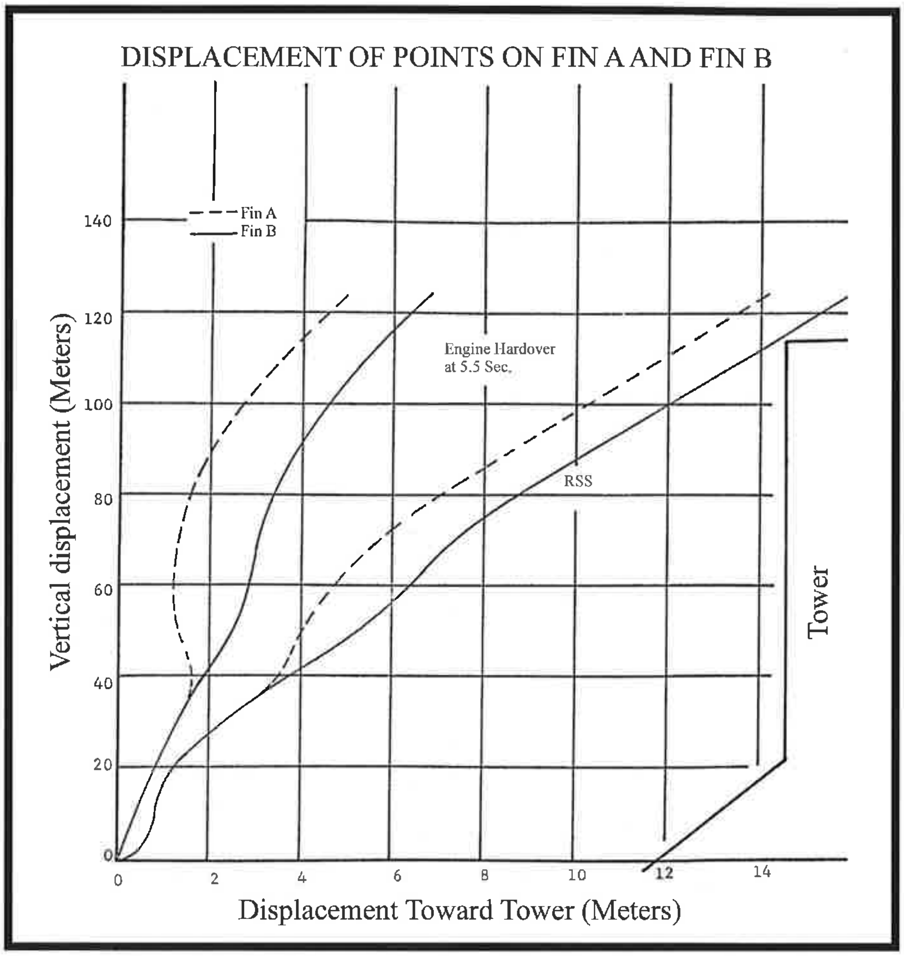
In 1964, David Mowery of the Control Applications Section at Marshall Space Flight Center in Huntsville, Alabama conducted an evaluation of the Saturn V liftoff. The primary purpose of Mowery's study was not to estimate the chances that a tower collision could take place, but to determine what factors could actually cause it. By knowing this, the designers of the Launch Escape System could develop sensors and electronic equipment for determining when this was about to happen in order to fire the escape rockets.

The Saturn V did not simply rest on its launch pad through force of gravity. It was actually held down to the pad by four pairs of holddown arms which kept the rocket secure until the five F-1 engines achieved their proper thrust, at which time the arms retracted and the rocket lifted off the pad. Mowery noted that due to structural considerations, the Saturn V could not be released instantaneously, so Saturn designers were developing a system to release the rocket gradually. The holddown force would decrease linearly to zero in 0.6 seconds. But this system had to work perfectly or it could create a dangerous situation during liftoff.[16]

Mowery considered seven factors that could disturb the liftoff path of the vehicle. These were: a variation in the holddown force of plus or minus 15%; a variation in thrust of 4%; engine misalignment; an offset in the vehicle's center of gravity; wind; engine failure; and an "engine hardover."

Engine failure and engine hardover, unlike the other factors, were considered vehicle malfunctions and if they occurred for either of the engines closest to the tower, engines 1 and 2, they posed a danger during the initial liftoff phase.

In order to steer the giant rocket in flight, the Saturn V's huge F-1 engines could gimbal or move in several directions, pushed by actuators. In an engine hardover, a failed actuator would push



The most significant single risk of a launch pad explosion of the Saturn V was an engine "hardover" case. When combined with plausible variations in manufacturing and wind speeds, this could cause the Saturn V to collide with the tower.

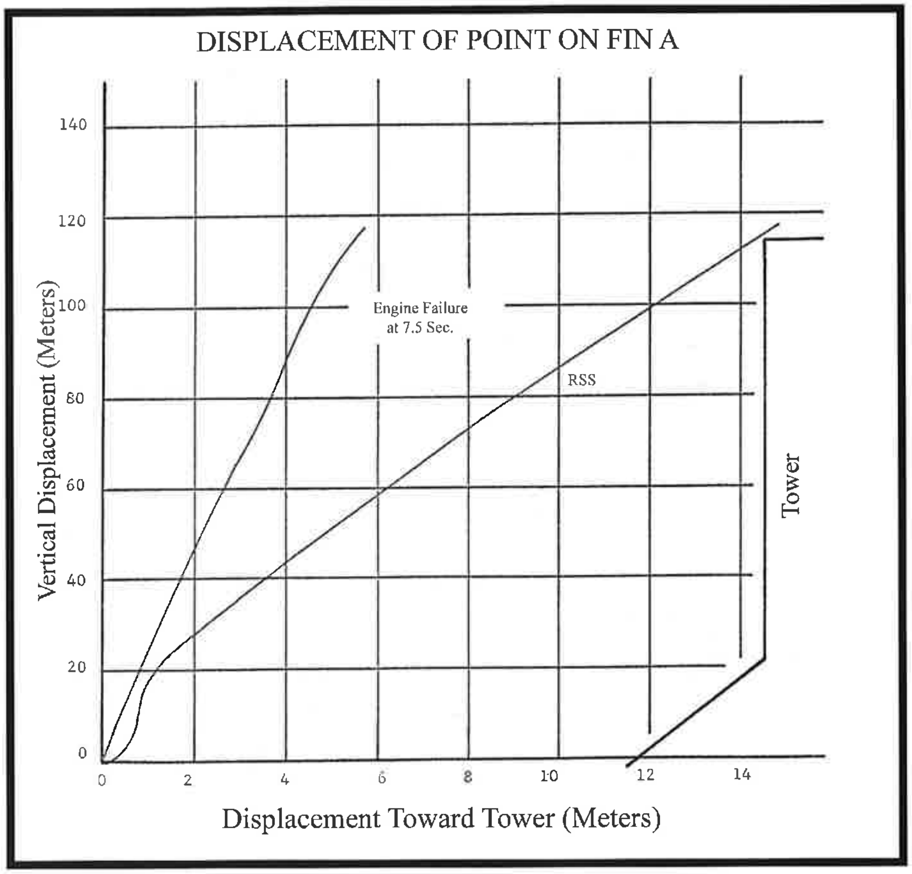
the engine all the way to its maximum gimbal limit, rolling the rocket in the opposite direction and causing it to slide toward the tower. If this happened for one of the inboard engines before the Saturn had risen above the height of the tower, it could push the Saturn V toward the tower. It took 7.5 seconds for the Saturn to clear the tower.[17]

Mowery concluded that: "no problem as to tower collision exists for combined disturbances if a malfunction does not occur." In other words, simply wind or a misaligned vehicle, even in combination, could not cause a tower collision. In addition, neither an engine failure or an engine hardover for either of the inboard engines alone could cause a tower collision.

But if any of the other factors occurred combined with an engine malfunction, the vehicle would roll and slide toward the tower and one of its large fins would collide with the tower structure, causing a catastrophe. Probably the most likely non-malfunction factor would be wind pushing the vehicle toward the tower. The Saturn was designed to be capable of launching in windy conditions with no risk of tower collision provided nothing else went wrong during liftoff. Of the two kinds of malfunction, engine failure posed the greatest overall risk because the vehicle was most susceptible to this failure for the longest period of time. An actuator failure between T minus zero and T plus 5.5 seconds could cause a tower collision. But engine failure at any time between T minus zero and T plus 7.5 seconds could cause a collision.[18]

CONCLUSION

NASA launched thirteen Saturn V's without a single catastrophic failure, a perfect record that has not been



In a single engine failure case, the Saturn V trajectory would clear the tower, and was thus a minimal risk.

achieved with any other launch vehicle. Although the vehicles did experience occasional engine problems in flight, an engine hardover never occurred, and these problems did not greatly affect mission performance.

But during the launch of the first vehicle, *A.S. 501*, Rocco Petrone watched the rocket lift off from his seat in launch control and kept his hand near the button that would close protective covers over the windows if the Saturn V exploded. But he always suspected that if something did go catastrophically wrong and the Saturn V detonated with the force of a small atomic bomb, he would simply keep watching instead.[19]

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[1] For a discussion of the siting of various structures at a safe distance form the launch pads, see: Charles D. Benson and William Barnaby Faherty, *Moonport: A History of Apollo Launch Facilities and Operations,* (Washington, DC: NASA SP-4204, 1978).

[2] "Saturn V Booster Explosion Hazards and Apollo Survivability Analyses," September 13, 1963, Box 63-63/63-64, Folder: "Sept. 13-15, 1963," Apollo Historical Documents Collection, University of Houston, Clear Lake, p. 3.

[3] Richard W. High, AST, Flight Engineering Section, and Robert F. Fletcher, AST, Mission Feasibility Branch, "Estimation of Fireball From Saturn Vehicles Following Failure on Launch Pad," NASA Program Apollo Working Paper No. 1181, Manned Spacecraft Center, Houston, Texas, August 3, 1965, Box 83-31, Apollo Historical Documents Collection, University of Houston, Clear Lake, p. 11.

[4] "Saturn V Booster Explosion Hazards and Apollo Survivability Analyses," p. 31.

[5] Charles Murray and Catherine Bly Cox, *Apollo: The Race to the Moon,* (New York: Simon and Schuster, 1989), p. 437, fn. page 88.

[6] Asif Siddiqi, *Challenge to Apollo,* (Washington, DC: NASA SP-2000-4408, 2000), pp. 692-692.

[7] "Saturn V Booster Explosion Hazards and Apollo Survivability Analyses," pp. 3-4.

[8] "Ibid., p. 29.

[9] Ibid., p. 27.

[10] Ibid., pp. 30-31. Shrapnel became a major explosion concern later in flight, when the spacecraft was in vacuum.

[11] Richard W. High, AST, Flight Engineering Section, and Robert F. Fletcher, AST, Mission Feasibility Branch, "Estimation of Fireball From Saturn Vehicles Following Failure on Launch Pad," NASA Program Apollo Working Paper No. 1181, Manned Spacecraft Center, Houston, Texas, August 3, 1965, Box 83-31, Apollo Historical Documents Collection, University of Houston, Clear Lake.

[12] Ibid., pp. 1-3.

[13] Ibid., p. 2.

[14] Ibid., p. 6. The fireball duration figure for the Saturn IB was 20.1 seconds.

[15] Ibid.

[16] D.K. Mowery, to Distribution, "Saturn V Liftoff Study," George C. Marshall Space Flight Center, Huntsville, Alabama, 13 May 1964, Box 64-33,64-34, Folder: "May 11-14, 1964," Apollo Historical Documents Collection, University of Houston, Clear Lake.

[17] Ibid., p. 2.

[18] Ibid., p. 4.

[19] Charles Murray and Catherine Bly Cox, *Apollo: The Race to the Moon,* p. 245.