Human Factors Investigative Approach to Apollo 1 Disaster: A Case Study

Zachary Bloom

Embry-Riddle Aeronautical University

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Dr. Tossell

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Apollo 1 Disaster

On January 27, 1967, a preflight test was to be conducted on the launch pad at Cape Kennedy. This test was to explore if any system errors presented during the pressurization process of the capsule, and for the crew to implement flight checks. The pressurization was set to 16.7 pounds per square inch (PSI) with an atmospheric environment consisting of 100% oxygen (Uri, 2021). NASA divorced the idea of utilizing a mix-gassed system due to costs, complexity and added weight (Evans, 2024). The command module capsule started production shortly after the creation of the Apollo program in 1961. It was delivered to NASA from production in 1966; the capsule only took 2.5 years to manufacture (Uri, 2021). This rapid production is largely attributed to the political pressures by John F. Kennedy and the competing USSR. John F. Kennedy famously stated in an address to the nation that he plans to have humans on the moon and return home safely by 1970 (*The Decision to Go to the Moon*, 1998). The rapid manufacturing of the capsule led to many safety and design concerns, with Gus Grissom even hanging a lemon outside of the capsule—a symbolic sign of poor quality (Lilley, 2013). Grissom is notably remembered for his sub-orbital flight within the Mercury program. During reentry, static electricity prematurely deployed his capsule's hatch (Neuman, 2021). Once entering the ocean, the capsule swelled with water, sinking rapidly, almost killing Grissom (Neuman, 2021). Due to this incident, and with hatch design concerns raised by Gus Grissom, the Apollo 1 capsule lacked an explosive bolt system, removing the option for rapid emergent escape in the event of an emergency. In addition to concerns regarding the capsules hatch, astronauts warned of defective electrical systems, such as frayed wiring. There were also reports of the Environmental Control System (ECS) leaking a flammable glycol coolant, which was small but consistent (Gillen, 1972). The interior of the capsule also consisted of highly flammable

materials, such as Velcro, nylon, and Styrofoam. Exacerbating concerns, NASA had a poor reporting culture at the time. Meaning, certain reports for repairs, errors, and critical concerns were non-traceable. They could only see if an issue was resolved, or in progress, limiting the scope of concerns and failing to isolate potential failures (Lilley, 2013).

During the preflight test on January 27th, 1967, at 6:31 p.m. a flash fire engulfed the interior of the capsule killing Gus Grissom, Ed White, and Roger Chaffee. Due to the change in the hatch design, escape was almost entirely impeded. Communications between the crew, engineers, and mission control were limited due to interference (Evans, 2024). NASA viewed this test as non-hazardous; thus, emergency preparations were limited with no fire response teams readily available. Unfortunately, a failure to perceive fire risk accurately led to a passive design which failed to implement a fire-retardant system. After the fatal event, NASA imposed a news “black out,” waiting 2 hours before publicly sharing the crisis. At the time, NASA attempted to offset blame of the disaster on the manufacturing company, North American Aviation (NAA). Then Gordon Harris, a public affairs official from NASA, stated that they failed to consider this kind of catastrophe (Kauffman, 1999). Rather than incompetence on the lethality of a pure oxygen environment, it could be argued that NASA was aware of the risks due to other fatal events occurring before Apollo 1. In the Apollo 204 Review Board Report, acknowledgments were made of the hazards that oxygen-enriched environments pose (Long, 1967). Examples included a Navy lab fire which was caused due to a frayed wire arching and discharging electrical currents in a 100% oxygen environment, several personnel were burned during this event (Long, 1967). Another occurrence happened in 1962 when Colonel B. Dean Smith was testing the Gemini Space suit prototype in a 100% Oxygen rich environment. During testing, a flash fire occurred, similar to the Apollo 1 disaster. Thankfully, Colonel Dean Smith

survived the incident, as the Gemini space suit was designed to include “fireball protection” (Johnston, 1966). Though these events have limited public reports, it shows a historic acceptance that oxygenated environments pose a real and severe fire risk.

The purpose of this case study is reviewing the events which occurred on January 27th, 1967, utilizing modern day risk assignments, human factors investigation tools, performance shaping factors (PSFs), cognitive science, and biomechanics; to explore if the Apollo 1 system required the astronauts to perform beyond their physical and cognitive limits. The study will conduct a human reliability analysis, utilizing an analytical framework from SPAR-H, HFIT, and SHF.

Methodology

Case studies are generally qualitative in nature but can also utilize a mixed-methods approach when appropriate. Qualitative research focuses on the causational, contextual approach to assist in gathering rich data. For this case study, the implementation of observation and document analysis would be utilized. In addition to these methodologies, I will also use the framework of SPAR-H, HFIT, and SHF. Through qualitative methods, I will attempt to discover the Action Error, Error Recovery, Situation Awareness, and finally the Threat which led to the accident occurring (Gordon et al., 2005). Action error is a method to help explore any observable errors before the accident occurred. This will help discover any quality errors, omissions, or violations present within the system. Error recovery is a socio-technical framework that adds psychological considerations involving safety. This can be seen exploring an individual’s ability to detect an error, notify others of said errors, and if possibly their ability to correct the error. Situation awareness shows the cognitive awareness of individuals involved within the accident. This section explores cognitive functions such as attention, memory, decision making, and

assumption. Finally, Threats, are situations within the environment, or company, that could influence or exacerbate the potential of errors occurring. These situations could be work preparations, training methods, policies, standards, work environment, and teamwork.

The standardized plant analysis risk-human reliability analysis (SPAR-H) was developed in 1994 by the U.S. Nuclear Regulatory Commission (NRC) (Gertman, 2004). This method was developed as part of the accident sequence precursors program to standardize the analysis of human error in accidents. Human performance is a key component to many high-profile accidents within the nuclear industry (Gertman, 2004). SPAR-H will not be used to analyze the entire Apollo 1 system, rather, SPAR-H specializes in human task performance regarding a specific environment, condition, and event. This section of the paper will expand on the astronauts' ability to diagnose a threat, and what action they took during the threat. Additionally, this section will introduce performance shaping factors (PSFs), which explores how the systems complexity, environment stressors, and cognitive limitations influenced human performance. Together a conclusion will be reached on the expected rate of successful human performance within this system.

Since SPAR-H focuses on individual tasks and environments, it lacks the expansive oversight to discover the origin of a potential risk or event. To compensate for this, the paper will include a section utilizing the Human Factors Investigation Tool (HFIT). Here is where we will explore the action errors, error recovery mechanisms, conceptual processes which lead to action error and any underlying causalities (Gordon, 2005). This complete overview will explore communications, local working conditions, situational factors, organizational factors, and external factors which could have contributed to the event.

Space Human Factors (SHF) will be used to explore any constraints specifically unique within the space environment. This will be utilized to discover any limitations, errors, perceptions, or investigative methods possibly overlooked by the other methodologies. It will be used primarily to analyze space specific environments, like the space capsule, suits, communications, biomechanics, and their limitations.

Limitations

Many documentations are still redacted and due to the political pressure at the time certain information may be inaccessible or not digitalized. I do not have access to athletic performance records, cognitive performance records, or other health metrics in relation to the astronauts. So, the metrics used when comparing or recognizing reasonable accommodation will be in relation to a standard American adult. This turns the case study into a direction where the exploration stops searching for if an astronaut could have survived the incident, and rather, if the system would have continuously failed when compared to an average human's limitations.

The main source of material is pulled from a singular source, the Apollo 204 Review Board Report. Similarly, additional sources are either published by NASA, the company where the incident occurred, or the United States Government. The situation relies on accurate self-reporting, and successful internal investigations. The risk of certain factual evidence not being reported, due to the lack of a third-party investigation, is a limitation worth noting.

SPAR-H

Before the fire was identified astronauts, engineers, and mission control had been conducting tests for over 6 hours. Audio recordings within the hour before the fire showed heightened frustrations between mission control and the astronauts. This was most likely due to prolonged communication disruptions, long work hours, and uncomfortable environmental

conditions for the astronauts. Even in comfortable, supportive environments after prolonged focus and heightened cognitive workloads it can take just 1 hour before adults become mentally fatigued and irritated. This can negatively affect time-on-task (TOT) effects, continuously decreasing performance efficiency (Lim et al., 2010). Another study found that slight interruptions can increase sequence errors and harm performance efficiency even further (Altmann et al., 2014). This shows evidence that after 6 hours of consistent high cognitive loads, and static interruptions from mission control, both parties were most likely suffering from fatigue and irritability.

At 6:31pm an astronaut reported “Flames,” 17 seconds later the hull of Apollo 1 ruptured due to intense heat (Evans, B. 2024). It is speculative to wonder if the astronaut’s reaction of the fire was hindered due to high cognitive fatigue. A more factual understanding is that during high stress, threatening, situations the human body prioritizes survivability (Levy & Schiller, 2021). High levels of anxiety can reduce communication, and stall physical responses (Levy & Schiller, 2021). We know communications were hindered by the stressful event, but evidence does show that the astronauts attempt every physical opportunity to exit the capsule before being overcome by toxic gases; pathologists concluded that the crew died of asphyxia from carbon monoxide and other toxic gases (Uri, 2022). Table 1 will look at the performance shaping factors (PSFs) and its effect on Human Error Probability.

Performance Shaping Factors (PSFs) For Apollo 1

PSFs	Apollo 1 Situation	SPAR-H Rating	HEP Effect
Time	Limited, 10-15 seconds	Severe	Major
Stressors	Heat, Smoke, Fear, Sensory Distress, Fatigue, Confusion, Fire.	Severe	Major
Task Complexity (Escape).	Multitudinous System Failures.	High	High
Training	Trained, but not for this scenario.	Adequate	Neutral
Procedures (Fire)	None	Lacking	Major
Ergonomics	Restrictive, Space Suits, Tight Quarters, Manual Bolts	Poorly Designed	Major
Work Environment	Delayed Communications	Lacking	Moderate
Work Readiness	Highly Trained Crew, Space Suits and necessary gear	Moderate	Neutral
Environment	100% oxygen environment, high pressure.	Extreme	Major

SPAR-H separates diagnosis tasks from action tasks. Diagnosis was not the weak point: the crew recognized and reported the fire within seconds (see Table 3), so this analysis focuses on the action task of opening the hatch and escaping the cabin. SPAR-H calculates the human error probability (HEP) as HEP = NHEP × Π(PSF), starting from a nominal HEP of 0.001 for action tasks, where each performance shaping factor acts as a multiplier (Gertman, 2004). Two SPAR-H rules decide this case. First, when the time available is inadequate, the probability of failure is set to 1.0 regardless of the other factors. Second, when three or more performance shaping factors are negative, the composite multiplier must be adjusted so the result cannot

exceed 1.0: HEP = (NHEP × PSFcomposite) / [NHEP × (PSFcomposite − 1) + 1]. Applying the multipliers used in this analysis (20 × 10 × 50 × 10 = 100,000) gives HEP = (0.001 × 100,000) / (0.001 × 99,999 + 1) ≈ 0.99 even before the time rule is applied; with inadequate time, the HEP is 1.0. Under SPAR-H, the crew's probability of escaping through the hatch in the time available was effectively zero.

Human Factors Investigation Tool (HFIT)

Restating, HFIT will be utilized to look at the organization, behavioral contribution, and environmental influences manipulated decisions which lead to the event. Similar to the Swiss-Cheese model, HFIT attempts to find every stage a system failed to lead to the event. The HFIT model utilizes 4 categories which contain 28 elements. All of which will be present within this case study. The 4 main categories are Action Error, Error Recovery, Situation Awareness, and Threat.

Action Errors

Action Errors are primarily task-based and focus on clear, observable, errors which generally occur prior to the incident. Action Errors contains the following elements: omissions, timing errors, sequence errors, quality errors, selection errors, communication errors, and violations. Table 2 will show how these errors influenced the fire and failure to open the hatch.

HFIT Action Error

Action Error	Description
Omission	No omission by the crew: they attempted to open the hatch and fight the fire. The omissions lay in the system, which had no fire suppression equipment and no emergency egress procedure.
Timing	The crew had only seconds to open the hatch or extinguish the fire, far less than the at least 90 seconds the hatch required (Benson & Faherty, 1978).

Sequences	Flammable materials were consistently brought within the environment.
Quality	The correct action, attempting to open the door hatch, was enacted.
Selection	The correct equipment was present, and used, to try and open the hatch. There was no equipment present for fire suppression.
Communication	Faulty connections limited communication between astronauts and mission control.
Violations	None.

Error Recovery

Error recovery helps explore, study, and learn from near misses when they arise. Uniquely, this system incorporates behavioral responses to see how the event was identified and responded to. It focuses on Detection, Indication, and Correction. With detection cues ranging from internal feedback, system feedback, external communication, and planning behaviors. This method attempts to take a preventative approach when errors are discovered, some actions might include holding interviews with staff involved and implementing recovery mechanisms. Unfortunately, the operators within the capsule did not survive, so individual interviews were not an option. However, NASA and Congress implemented investigations to explore the Apollo 1 systems to prevent this catastrophe in the future.

Situation Awareness

This system focuses on the cognitive awareness that an individual might possess during the error. It utilizes Information processing to develop a cognitive error module for the industrial sector; however, many other sectors such as aviation also use this module. An individual's unique perceptual knowledge is explored in relation to the presented error and expanded across seven elements. These cognitive elements are attention, detection/perception, memory, interpretation, decision making, assumption, and response execution. Table 3 explores these

elements in relation to the Apollo 1 disaster in how the astronauts most likely responded, cognitively, to their environment.

Situation Awareness Apollo 1

Attention	The astronauts were experiencing immense cognitive fatigue due to a long working shift. However, humans can cognitively identify fire within milliseconds of visual stimuli. This Novel stimuli would have uncontrollably demanded the attention of the astronauts. This is known as the Orienting Response. The astronauts most likely paid full attention to the fire, and on their attempts for escape.
Detection/ Perception	The astronauts made a verbal communication "fire," immediately after visual confirmation of an open flame. Quickly a bottom-up process occurs cognitively alerting the astronauts of the danger fire presents.
Memory	No memory lapse occurred during the event. The decision to remove the quick-release hatch was made during design; it is a latent condition, examined under Threats, rather than a failure of the crew's memory.
Interpretation	There was no interpretation errors discovered. A fire was detected, a distress call of "fire" and "we have a really bad fire" were sent to Mission Control.
Decision Making	Records suggest one astronaut attempted to put out the fire, and another attempted to remove the bolts from the capsule latch. Even though this disaster was not trained for, the astronauts made accurate decision making under extreme stress and fear.
Assumption	There was an assumption of safety and that a fire was unlikely. This cognitive belief was shared with all staff at NASA. This assumption led to no safety implementation of any kind for a fire.
Response Execution	Since Gus Grissom was a respected veteran of space exploration within NASA. Engineers may have overlooked the dangers of a non-explosive release hatch after Mr. Grissom suggestion to remove that feature.

Threats

Earlier in this paper the Swiss Cheese Model was mentioned, this model is commonly used in the healthcare sector to guide root cause analyses (RCAs) for patient safety. It works by discovering the "holes" within a system, and how multiple layers of a system fail to cause the patient harm. *Threats* within the HFIT works by discovering how those "holes" developed in the first place. It looks broadly at 12 different elements such as Policies/Standards/Procedures, Work preparation, Job factors, Person factors, Competence/Training, Communication, Teamwork, Supervision, Organization safety culture, Work Environment, System-equipment interface, and Tool/Equipment. After analyzing each element, the potential *threats* for errors occurring become more visible and proactive measure can be implemented before any harm is done. It can also be analyzed in a reactive way to fully understand the depth of a problem within an organization. In the case of Apollo 1 we will be looking at these factors in a reactive way to discover exactly which *threats* caused the error leading to the death of the astronauts.

Policies, standards and procedures. The astronauts not only assisted with certain design applications of the capsule, but they trained extensively with the implemented systems. If one thing was done correctly, it was the training of the professionals involved. Unfortunately, the failure derives from poor safety cultures and lack of follow-up on maintenance tickets. Additionally, due to political pressure and strict time constraints, certain critical safety concerns were overlooked or deemed acceptable; an example of this would be the leak from the Environmental Control System (Lilley, 2013). There were no planned systems for fire suppression, and no emergency procedures developed in the event of a fire. Additionally, material engineers failed to realize that the interior was filled with flammable material.

Work preparation. There was no system or preparation for a rapid evacuation of personnel within the capsule. Additionally, NASA labeled this test as "non-hazards" and did not have

medical, fire, or rescue resources available on location. The astronauts were placed in their space suits, which did provide protection from the fire. But they were not connected to a separate life support system, and they died of asphyxia from carbon monoxide and other toxic gases (Uri, 2022).

Job factors. During the fire, the task of opening the door was impossible for any human in such a short time limit. Extra emotional stressors impeded the situation further. The inner hatch opened inward and had to be unlatched by hand; even under routine conditions, opening the hatches took a minimum of 90 seconds (Benson & Faherty, 1978). Worse, rising cabin pressure during the fire held the inner hatch shut: the Review Board found that, due to internal pressure, it could not be opened before the command module ruptured (Long, 1967). The fire overwhelmed the cabin within seconds.

Person factors. Each astronaut was motivated by self-preservation during the event. Extreme attention, passion, and urgency were experienced while attempting to open the capsule. Personal perceptions on the dangers of oxygenated environments is where all staff at NASA fell short.

Competence and training. Training played no faulty part in this accident. All astronauts were fully competent and aware of the systems within the capsule. They trained daily, and countless hours were invested in opening the capsule hatch. The main reason for failure was the extreme time constraint.

Communication. Communication had been a problem throughout the entire 6-hour flight test, with radio communication frequently becoming disrupted by static. Even the emergency reports barely broke through the constant static. Mission control had to communicate with other personnel to fully understand the weight of the emergency.

Teamwork. The teamwork that mainly failed was among design engineers and astronauts. It is obvious that anxieties from past missions influenced the astronauts to want a non-explosive bolt hatch. The engineers should have fully explained the risks, limitations, and concerns regarding a difficult to open hatch. Teamwork was divided among departments, and poor management lead to mistakes occurring and spreading across departments. This led to increased tension among departments, leading to a reduction in error reporting.

Supervision. Supervision was lacking among mid-and high-level managers. Many encourage rushing the project due to political and public pressures.

Organizational and safety culture. Attempted to ignore critically urgent errors in attempts to complete the project within time.

Work environment. The work environment fostered curiosity and the need for exploration. However, political factors plagued the working force creating a toxic, untrustworthy, and anxiety-driven environment for many.

System-equipment interface. The user friendliness of the capsule was low and needed dozens of hours of specialized training to understand its systems. The door itself needed several minutes of intense labor to open. Visibility was limited, and communication interfaces were malfunctioning.

Tools and equipment. The astronauts had to use a specially designed tool to unscrew several bolts holding the hatch frame in place. This equipment was not electric, or automated, and had to be performed manually, while inside a space suit limiting mobility.

Space Human Factors

Space Human Factors (SHF) explores the unique risks present to humans in certain space bound environments. By exploring human performance and limitations it becomes possible in analyzing the likelihood of success when performing a task. In this case study, SHF will be

utilized to judge if the unique space environment aided in the disaster. This will cover 4 elements, environmental control, mission control's situational awareness, survivability, and human systems integration.

Environmental Control.

The Apollo Command Module had an active thermal control system which assisted in temperature regulation. This helped support the crew and the electronics during testing. The system also was able to create and maintain 16.7 PSI, in addition to a 100% pure oxygen atmosphere. They planned to use cryogenic oxygen stored in pressured tanks to maintain this oxygen environment while in space. However, control was limited, with the environment control system plagued with leaks and constant repairs. The astronauts, nor mission control, could change the environment's chemical mixture at will, and there was no purge option to remove the oxygen from the capsule. They also had no methods of suppressing severe heat, or fire within the environment.

Mission Control's Situational Awareness

Mission control has the perceptual understanding that there were no hazards present during the test. Additionally, due to communication delays, Mission Control lost the ability to provide real-time assistance, guidance, and direction to the astronauts. Removing the collective *brain* of hundreds of scientists. Mission Control also had very limited visual representation and only primarily used radio to communicate. So, when the fire started, Mission Control was left scrambling for answers, rather than aiding in survival efforts.

Survivability

Since the crew died of asphyxia from toxic gases rather than from burns (Uri, 2022), if the astronauts were fully dressed, they may have survived the fire. Since this was ground test,

astronauts did not need to don their gloves or helmets. Additionally, these astronauts were not connected to the back up life support system which would have provided them with clean oxygen. The space suits, Gemini, were designed to help protect astronauts from “fire balls” and extreme temperatures. However, since safety procedures were more relaxed, no beneficial protection was provided.

There was also no system to help the astronauts escape their environment or put out the fire. A handheld fire extinguisher may have provided enough assistance when the fire was first discovered. A fully fire-retardant system, and atmospheric purge may have guaranteed survivability.

Human Systems Integration

The Apollo 1 systems failed to incorporate a human-centric design, harming the operator’s integration with its complex systems. Astronauts reported several concerns regarding flammable material used to hold certain equipment, exposed wiring, communication concerns, and the potential for safety issues. Even though the astronauts had a large hand with the initial design of the capsule, so many changes occurred over the year that the astronauts struggled to maintain competency on the simulator. Displeasure rose so high that Gus Grissom hung a lemon on the capsule.

Conclusion

Applying SPAR-H, HFIT and a space human factors lens points to the same answer: the Apollo 1 system demanded more than any crew could deliver. Once the fire started, the crew recognized it immediately and acted sensibly. But an inward-opening hatch that took at least 90 seconds to open, and that cabin pressure held shut during the fire, together with a pure-oxygen

atmosphere, flammable materials and no fire suppression or rescue plan, left no path to survival. Those conditions were set long before the test, through design decisions, the assumption that a ground test was non-hazardous, schedule pressure, and a reporting culture that let known problems persist.

The Apollo 204 Review Board recommended a redesigned hatch that could be opened in two to three seconds instead of a minute and a half (Benson & Faherty, 1978). That fix removed the system's dependence on human speed under extreme stress. Safety-critical systems in any industry, including healthcare, should be judged the same way: by whether ordinary people, under real stress and time pressure, can succeed when something goes wrong.

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