5-1-2020

Cognitive Bias, Normalization of Deviance, Communication and their Impact on the Apollo 1, Challenger, and Columbia Accidents

Robin Holt Flachbart

Cognitive Bias, Normalization of Deviance, Communication and their Impact on the Apollo I, Challenger, and Columbia Accidents

by

Robin Holt Flachbart

An Honors Capstone

submitted in partial fulfillment of the requirements

for the Honors Certificate

to

The Honors College

of

The University of Alabama in Huntsville

5/1/2020

Honors Capstone Director: Dr. Stephen Waring

History Department Chair

Robin H. Flachbart 5/1/2020

Student Date

Director (signature) Date

Department Chair (signature) Date

Honors College Dean (signature) Date

Introduction

There was a point in the data file when the numbers just ended. That was the point when the Space Shuttle Orbiter *Columbia* had broken up during its fiery re-entry, severing its telemetry with ground controllers. A sense of sadness and resolve overwhelmed me at that moment in a conference room of the National Aeronautics and Space Administration's (NASA) Michoud Assembly Facility, where I had traveled to serve as a team member for the *Columbia* accident investigation. The Apollo I fire was a sad event in history that I could not remember. The *Challenger* accident shocked me as a young mechanical engineering student, who dreamed of working for NASA and couldn't believe that the Shuttle had exploded. The *Columbia* accident, I took personally, having supported the Space Shuttle Program at NASA for over ten years. Each year, at the end of January, NASA pauses on one day to remember the seventeen lives lost in the Apollo I, *Challenger*, and *Columbia* accidents. Observing a day of remembrance is not enough to honor their legacy. It is vital that NASA and its contractors, including me, assume the responsibility to understand the root causes of these accidents and lessons learned, in order avoid repeating the mistakes of the past.

It is easy to look at U.S. space program accidents merely from the hardware failure perspective. Conventional lessons learned wisdom says that if one understands the root causes a hardware failure, one can take steps to prevent that type of failure again. The three missions to be investigated in this work are the Apollo Saturn 204 (AS-204), Plugs Out Test fire in 1967, the *Challenger* explosion during ascent in 1986, and the *Columbia* destruction during re-entry in 2003. All three accidents were a result of hardware failures, but the hardware failed for different reasons and during different mission phases. Charles Perrow states that due to its complexity, the space business retains a “residual propensity for system accidents”.[1] To accomplish a complex mission in harsh, unforgiving environments, space vehicles will always be complex. Because of this complexity, it is beneficial to track hardware failure lessons learned and NASA has put a significant amount of effort into capturing and documenting these lessons. However, there are also human factors leading to the accidents in addition to the hardware failures themselves.

This paper will investigate some non-hardware factors that contributed to these accidents. While investigating these factors, some fundamental questions will be explored. Were there any warning signs before the accidents? What was the impact of poor decision making? Did something as simple as poor communication contribute to these accidents? The history of space accidents can be examined in order to identify human behaviors/errors that lead to these accidents and to formulate actionable strategies that could prevent future accidents. Despite three different examples of significant hardware failures, all three U.S. space accidents can be traced back to poor decision making, which can be the result of multiple factors. Thus, there were multiple technical and non-technical factors that led to the three U.S. space accidents. This work will show that there were three key factors, cognitive bias, normalization of deviance, and most of all, communication breakdown, that led to poor decision making which was a significant contribution to the three U.S. space accidents. This paper will explore and evaluate each accident for the presence of the above factors.

The primary sources for this work focus on the documentation, interviews, and Congressional testimonies surrounding the investigation of the three accidents. One source is the

---

[1] Charles Perrow, *Normal Accidents: Living with High Risk Technologies* (Princeton: Princeton University Press, 1999), 258.

Report of the Apollo 204 Review Board to the Administrator, National Aeronautics and Space Administration, which documented the investigation following the AS-204 fire. For the most part, it focused on the technical causes of the fire, mainly highly combustible materials in a capsule pressurized with pure oxygen.[2] Even though it does not cover non-technical factors in detail compared to sources on *Challenger* and *Columbia*, some may be inferred. Another source is the *Report on the Presidential Commission of the Space Shuttle Challenger Accident*, also known informally as the *Rogers Commission Report*. In addition to a thorough discussion of the Solid Rocket Motor O-ring failure that led to the accident, it also discusses the acceptance of chronic O-ring erosion over the life of the Shuttle beginning with the second mission, STS-2.[3] It also discusses the multiple communication issues present on the day before and the day of launch.[4] The source documenting the *Columbia* accident is the *Columbia Accident Investigation Board Report*, also known as the *CAIB Report*. In addition to the documentation of both the External Tank foam strikes on the *Columbia* Orbiter during ascent, it explains in forensic detail the disintegration of the vehicle during re-entry. It also goes into much greater detail than the investigation reports of the other two accidents with respect to the non-technical causes of the accident. Again, NASA was shown as accepting anomalous behavior, foam liberating from the External Tank and striking the Orbiter, as normal.[5] It also provides detail on numerous instances of communication breakdown including multiple missed opportunities to discover the damage to

---

[2] *Report of the Apollo 204 Review Board to the Administrator, National Aeronautics and Space Administration*, (Washington: Government Printing Office, 1967), 5.9 – 5.11.

[3] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* (Washington: Government Printing Office, 1986), 65.

[4] *Report on the Presidential Commission of the Space Shuttle Challenger Accident*, 83.

[5] *Columbia Accident Investigation Report* (Washington: Government Printing Office, 2003), 130.

Columbia and attempt a repair.[6] Additional primary sources were consulted, but the investigation reports for each of the three accidents show a pattern of issues with decision making and communication.

Many secondary sources have attempted to explain why the accidents happened, both from a technical and a non-technical perspective. One source, Charles Perrow's *Normal Accidents: Living with High-Risk Technologies*, explores failures in various industries and attempts to explain why they occur. Perrow points out that systems that are very complex, with multiple interactions between the sub-systems, will inevitably lead to failure.[7] His conclusion is sobering, given that most space vehicles, particularly human-rated vehicles, are extremely complex. Diane Vaughan, in her book *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA*, emphasizes what she terms "Normalization of Deviance", which is a tendency to accept hardware anomalies over time such that they become a new "normal" condition.[8] Although her book focuses on the *Challenger* accident, this phenomenon was observed on both the *Challenger* and *Columbia* accidents. She contended that there was no evidence of NASA breaking rules or willful misconduct, but that there were issues with the NASA organization and culture which led to the acceptance too much risk.[9] One significant contribution that Vaughan's work made was that it impacted how NASA conducted the *Columbia* investigation, shifting the main emphasis on the technical causes to equal emphasis on

---

[6] *Columbia Accident Investigation Report*, 140-166.

[7] Perrow, *Normal Accidents*, 93-94.

[8] Diane Vaughan, *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA* (Chicago: University of Chicago Press, 2016), 136-143.

[9] Vaughan, *The Challenger Launch Decision*, 56-58.

the technical and non-technical causes.[10] In fact, the chairman of the CAIB had read her book, and was already making note of parallels between the *Challenger* and *Columbia* accidents before the Board began its investigation.[11] Vaughan would eventually join the CAIB, writing a chapter of the report, "History as Cause: *Columbia* and *Challenger*."[12] Charles Perrow did not completely agree with Vaughan's interpretation of the Challenger accident causes. He asserted that management made poor decisions based on schedule/production pressure and used their power/influence to suppress the opinions of engineers in their organizations.[13] This certainly challenges Vaughan's assertion that there was no willful misconduct. However, Perrow did state that he saw no "criminal activity" when comparing the space industry to others.[14] Stephen Waring, in his chapter "Losing the Shuttle (or nearly): Accidents and Anomalies," from the book *Space Shuttle Legacy: How We Did It and What We Learned*, presents a balanced account that discusses both the technical and non-technical causes of the Shuttle accidents. He asserted that too much emphasis has been put on a "flawed NASA technical culture" and instead focused on flawed decision making and communication breakdown that led to both Shuttle accidents.[15] All three accounts agree that issues with the complex hardware led to the accidents, but that equally important, issues such as flawed decision making, acceptance of poorly performing

---

[10] Vaughan, *The Challenger Launch Decision*, xix.

[11] Vaughan, *The Challenger Launch Decision*, xx.

[12] Vaughan, *The Challenger Launch Decision*, xxi.

[13] Perrow, *Normal Accidents*, 379-380.

[14] Perrow, *Normal Accidents*, 258.

[15] Stephen Waring, "Losing the Shuttle (or Nearly): Accidents and Anomalies," *Space Shuttle Legacy: How We Did It and What We Learned*, eds. Roger Launius, John Krige, and James Craig (Washington: American Institute of Aeronautics and Astrodynamics, 2013), 215.

hardware, and the breakdown of communication were significant factors that drove these accidents.

Definition of Terms

Decision makers in organizations such as NASA must have the best possible information in order to make an informed decision. Even when they have high quality data available to them, decision makers can be subject to cognitive biases which affect how they view the information placed before them. Daniel Kahneman, Paul Slovic, and Amos Tversky conceptualized cognitive bias in the 1970s.[16] According to them, cognitive bias is a method for a person to use "judgmental heuristics" to understand a situation in which there is considerable uncertainty.[17] In other words, the human brain uses methods to simplify a complicated or uncertain situation and make it much easier to process. Although these attempts to simplify a situation can lead to errors in judgement, the authors maintain that they are not necessarily motivated by "wishful thinking or the distortion of judgements by payoffs or penalties."[18] Although there are many defined types of cognitive bias, the main sources of cognitive bias I observed in the three U.S. space accidents were confirmation bias, anchoring bias, and near-miss bias. For each accident, this work will discuss how one or more cognitive biases impacted decision makers.

Confirmation bias is the tendency for a decision maker to accept only information or data that is consistent with his/her current belief about a situation. Data that does not support that position is either ignored or dismissed. Kahneman describes this thought process as "a deliberate

---

[16] Daniel Kahneman, Paul Slovic and Amos Tversky, "Judgement Under Uncertainty: Heuristics and Biases," *Science* 185, Number 4157, (Sep. 27, 1974), 1124.

[17] Kahneman, et al, "Judgement Under Uncertainty," 1124.

[18] Kahneman, et al, "Judgement Under Uncertainty," 1130.

search for confirming evidence" instead of testing a belief by trying to find contradictory evidence.[19] Anchoring bias is the tendency for a decision maker to start at some initial estimate and then update it, but often these "updates" are insufficient.[20] In other words, a decision maker with anchoring bias puts significant value on the first information received, which is perceived as the most important. This creates a challenge when additional data is introduced. It seems to me that anchoring bias can set up a position by the decision maker that can make him/her susceptible to confirmation bias when additional information is introduced.

The most common cognitive bias observed in the three U.S. space accidents was near-miss bias. A near-miss is a successful event that avoided a negative outcome, often due to "good luck."[21] According to Robin Dillon, Edward Rogers, and Catherine Tinsley, decision makers who survived a near-miss "made significantly more risky decisions in the future."[22] Thus, near-miss bias is often a negative by-product of previous success. It appears in engineering when hardware with a known design flaw operates successfully, and this success breeds the belief that the design flaw is acceptable and will not fail in the future. Near-miss bias is strengthened with each successful test or flight. This bias seems to lead to the phenomenon "normalization of deviance" described by Vaughan. Unfortunately, based on my experience, NASA budgets and schedules have never been robust enough to afford the number of tests/flights that would enable engineers to make a sound conclusion that the hardware is completely safe to fly. If the hardware is a complicated space vehicle, it is unlikely that the engineering team will fully

---

[19] Daniel Kahneman, *Thinking Fast and Slow* (New York: Farrar, Straus, and Giroux, 2011), 81.

[20] Kahneman, et al, "Judgement Under Uncertainty," 1128.

[21] Robin Dillon, Edward Rogers and Catherine Tinsley, "The Near-Miss Bias in Decision Making," IEEEAC, Paper Number 1201 (October 25, 2005), 2.

[22] Dillon, et al, "The Near-Miss Bias in Decision Making," 2.

understand it.[23] If the team does not understand all of the potential sources of risk, then it may conclude after a few successful tests or flights that the hardware, even though it does not meet requirements, is still good to fly. One point of significant concern expressed by Dillon, et al, was that decision makers who have what is perceived as success, even if due to a near-miss, are more likely to be promoted.[24] Thus near-miss bias can become "institutionalized […] within an organization."[25]

Another source of poor decision making, and closely related to the near-miss bias, is normalization of deviance. Normalization of deviance goes beyond near-miss bias and causes decision makers to accept design and performance issues as "normal".[26] There is a gradual shift from labeling hardware anomalies to accepting poor hardware performance as expected and acceptable. Hardware performance is monitored, and each occurrence of a potential issue is compared to an "experience base" and labeled as "in family" or "not in family".[27] Often, with normalization of deviance, the "experience base" can shift to accommodate observations "not in family".[28] Thus what is "normal" gradually shifts with time, often to a new normal that has increased risk.

For each of the three accidents, this work will discuss issues with communication. A decision maker cannot choose the right path to take if he/she does not receive all of the relevant

[23] Perrow, 257.

[24] Dillon, et al, "The Near-Miss Bias in Decision Making," 2.

[25] Dillon, et al, "The Near-Miss Bias in Decision Making," 2.

[26] Vaughan, *The Challenger Launch Decision*, xii.

[27] *Columbia Accident Investigation Report*, 122.

[28] Vaughan, *The Challenger Launch Decision*, 136-141.

facts. All three accidents can be traced back to issues with communication. These issues fell roughly into two categories: 1. Engineering concerns not reaching decision makers, and 2. Data presented in a way that is not clear. There were multiple sources of poor or missed communication. Examples were advance warnings from the hardware performance and engineers, silencing of dissenting technical opinions, engineering concerns not reaching the decision makers due to broken or complicated communication channels, mistaken assumption that communication was heard and understood, and the presentation of data to decision makers that was unclear or confusing. Unfortunately, each accident had multiple communications failures.

The AS-204 Plugs Out Test (Apollo I) Fire

In order to understand the details of the non-technical factors that caused the three accidents, it is necessary to review a brief history of each accident. The AS-204 (retroactively named Apollo I) Plugs Out Test fire occurred on January 27, 1967 on Launch Pad 34 at Cape Canaveral.[29] The astronauts reported a fire in the Command Module (CM), which lasted less than twenty-six seconds.[30] The fire produced extremely high temperatures and toxic gases as well as consumed the oxygen in the capsule.[31] It is likely that the astronauts were rendered unconscious by the toxic fumes and then died of asphyxiation.[32] Even if the astronauts had remained conscious, the hatch design was such that it could not be opened in less than ninety

[29] U.S. Congress, Senate, Committee on Aeronautical and Space Sciences, *AS204 Accident*, 90th Cong., 2nd sess, S. Rep. 956, 1968, 1.

[30] U.S. Congress, Senate, *AS204 Accident*, 1.

[31] U.S. Congress, Senate, *AS204 Accident*, 5.

[32] U.S. Congress, Senate, *AS204 Accident*, 5.

seconds and the inward opening design would have made it impossible to open given the high pressure inside the cabin.[33] The exact ignition source of the fire was never determined, but it was believed to have been an electrical arc in the wiring near the floor under the crew seats.[34]

Confirmation bias was observed in the events leading up to the Apollo I fire. An example of confirmation bias associated with the AS-204/Apollo I fire was the decision to use highly flammable pure oxygen instead of a much less flammable dual gas air system (oxygen and nitrogen in proportions like air) in the CM for life support.[35] This was a risky design choice since nearly anything, even metal, will burn rapidly in a pure oxygen environment. NASA engineers knew that a pure oxygen environment was hazardous. The agency had funded studies to understand the behavior of fire in a pure oxygen environment.[36] In fact, at least two fires had occurred during the test program, injuring personnel and damaging equipment.[37] The fires were ultimately attributed to test equipment and not to the hazard of using pure oxygen.[38] The decision makers focused on the successes of the Mercury and Gemini programs, which used pure oxygen, and completely discounted the fires seen during NASA testing.[39] Thus the decision

---

[33] U.S. Congress, Senate, *AS204 Accident*, 3.

[34] U.S. Congress, Senate, *AS204 Accident*, 5.

[35] U.S. Congress, Senate, Committee on Aeronautical and Space Sciences, *Hearing Before the Committee on Aeronautical and Space Sciences on a Review Background Information and Systems Decisions Preceding the Apollo Accident of January 27, 1967* (Washington: Government Printing Office, 1967), 23.

[36] U.S. Congress, Senate, *AS204 Accident*, 3.

[37] U.S. Congress, Senate, *Hearing Apollo Accident of January 27, 1967*, 32.

[38] U.S. Congress, Senate, *Hearing Apollo Accident of January 27, 1967*, 33.

[39] U.S. Congress, Senate, *Hearing Apollo Accident of January 27, 1967*, 32.

U.S. Congress, Senate, *AS204 Accident*, 3.

makers were accepting the data that confirmed their design decision and discounted the already known danger of using pure oxygen including the fires that occurred during testing.

Near-miss bias was also a factor in the Apollo I fire. It has been discussed the Apollo program came on the heels of the highly successful Mercury and Gemini programs.[40] The Mercury and Gemini capsules were also pressurized with pure oxygen.[41] The dual gas system was considered for the Apollo CM atmosphere but was ultimately rejected due to the risk of astronauts getting the bends as well as the added complexity and weight.[42] James Chiles also pointed out that during this time, the Apollo team was likely distracted by two near-misses.[43] The first near-miss occurred during a test of a potential dual gas Project Mercury life support system when a test pilot was almost asphyxiated as nitrogen leaked into the oxygen supply of the his spacesuit.[44] The second near-miss was the hatch that blew off prematurely after splashdown of Gus Grissom's Mercury capsule, which likely led to the complex, difficult to open, Apollo hatch.[45] Since there had been no mishaps with the pure oxygen atmosphere during the Mercury and Gemini Programs, it was assumed that using a pure oxygen was safe to fly in the Apollo CM.[46] Alan Shepard and Deke Slayton asserted that because pure oxygen had been used in the

---

[40] U.S. Congress, Senate, *AS204 Accident*, 3.

[41] U.S. Congress, Senate, *AS204 Accident*, 3.

[42] U.S. Congress, Senate, *Hearing Apollo Accident of January 27, 1967*, 16.

Alan Shepard and Deke Slayton, *Moon Shot: The Inside Story of America's Race to the Moon* (Atlanta: Turner Publishing, 1994), 197.

[43] James R. Chiles, *Inviting Disaster: Lessons from the Edge of Technology* (New York: Harper Collins, 2001), 145.

[44] Chiles, *Inviting Disaster*, 145.

[45] Chiles, *Inviting Disaster*, 146.

[46] U.S. Congress, Senate, *AS204 Accident*, 3.

capsule without any problems, “NASA engineers had become complacent about the possibility of a fire.”[47]

The Apollo I fire occurred almost thirty years before Diane Vaughan coined the term normalization of deviance. However, one can look at the events leading to the fire in order to determine if this accident was another example of normalization of deviance. As discussed earlier, normalization of deviance involves the acceptance of design/hardware issues as normal to the point that there is a shift to a new, more risky, normal.[48] One could view the risky acceptance of a pure oxygen atmosphere as normalization of deviance. However, this atmosphere had been used since the beginning of U.S. human spaceflight and thus there was no real shift in what was considered normal. However, there could be one additional aspect of the Apollo I fire that was an example of normalization of deviance. There were significant hardware issues with the CM such as various component workmanship issues and failures as well as “deficiencies in design, manufacture, installation, rework and quality control” of the electrical wiring.[49] The CM had been described as “sloppy and unsafe” by an Apollo quality control inspector and was reported to have had extensive failures during fabrication and assembly.[50] It appears that NASA was shifting to a “normal” of accepting hardware with multiple issues. Another finding even more surprising to me was that there was originally supposed to be an un-crewed pure oxygen pressurization test of the CM prior to the Plugs Out Test.[51] This test, which

---

[47] Shepard and Slayton, *Moon Shot*, 200.

[48] Vaughan, *The Challenger Launch Decision*, xii.

[49] U.S. Congress, Senate, *AS204 Accident*, 6-3.

[50] Shepard and Slayton, *Moon Shot*, 199.

[51] Shepard and Slayton, *Moon Shot*, 194.

had once been considered "essential", was skipped due to schedule pressure.[52] This shift away from un-crewed testing a piece of critical human-rated hardware could be another indication of normalization of deviance at work in the Apollo Program. This was particularly surprising to me given that Apollo's budget was significantly more generous than that of the Shuttle Transportation System. However, regardless of the available funding, schedule pressure was still present given President Kennedy's goal of reaching the Moon within the decade.

Most people in the space business believe that the likelihood of an accident is greater in flight. Perhaps that could account for the shock when the fire engulfed the Apollo I capsule during the Plugs Out test at Pad 34. The purpose of the Plugs Out Test was a "dress rehearsal" to simulate pre-launch and launch conditions.[53] The most obvious communication failure happened on the day of the test. The words of Walter Schirra to mission Commander Virgil "Gus" Grissom, before entering the CM were almost prophetic: "It'll take you a minimum of ninety seconds to get all those hatches open (so) if you have a problem, even a communications problem, get out of the cabin until the problem is cleared up."[54] The test experienced multiple issues with communications between the crew and the ground controllers.[55] The audio of the test was muffled, garbled and at times had a great deal of static/white noise.[56] In fact, Grissom quipped "How are we gonna get to the Moon if we can't talk between three buildings," and

---

[52] Shepard and Slayton, *Moon Shot*, 194.

[53] Shepard and Slayton, *Moon Shot*, 194-195.

[54] Shepard and Slayton, *Moon Shot*, 196.

[55] *Report of the Apollo 204 Review Board*, D-13.7.

[56] AS-204 Plugs Out Test Audio, YouTube, https://www.youtube.com/watch?v=274lQSbpkRg.

Senior Pilot Ed White replied “They can’t hear a thing you’re saying.”[57] The AS-204 investigation concluded that the communications system was “marginal” for normal operations and inadequate for emergencies.[58] Poor communication likely slowed down the process of identifying that a fire was taking place as well as slowed down the response to the fire. After the fire starts, White shouts frantically, “Hey! We’ve got a fire in the cockpit” and Pilot Roger Chaffe screams “We have a bad fire…we’re burning up,” yet there was no response from ground controllers until roughly twenty seconds later when they attempted to re-establish communications with the crew.[59] All that is heard after that point is the Test Conductor instructing pad personnel to get the crew out.[60] The test should have been halted when it was discovered that there were inadequate communications between the crew and the controllers, so why wasn’t it stopped?

In the Preface of the report of the U.S. Senate Committee on Aeronautical and Space Sciences concerning the AS-204 fire, there is a statement that “no single person bears all of the responsibility for the Apollo 204 accident […]” and that it occurred “[…] because many people made the mistake of failing to recognize a hazardous condition.”[61] The AS-204 accident investigation board had concluded that the personnel responsible for the test did not identify it as hazardous.[62] We discussed earlier that the successes of Mercury and Gemini and the resulting

---

[57] AS-204 Plugs Out Test Audio.

[58] *Report of the Apollo 204 Review Board,* D-13.7, D-13.12.

[59] AS-204 Plugs Out Test Audio.

[60] AS-204 Plugs Out Test Audio.

[61] U.S. Congress, Senate, *AS204 Accident*, III.

[62] *Report of the Apollo 204 Review Board,* 6-1.

near-miss bias may have had an impact on the decision to use pure oxygen in the CM.[63] This bias may have also played a role in the decision to not classify the test as hazardous. This decision had significant implications with respect to communication.

Lack of communication that this was a hazardous operation had a cascade effect, eliminating many potential crew safety/escape options. Despite the pure oxygen environment of the ground test, many highly combustible materials were placed in the capsule for the test.[64] The "time critical" procedure for the crew to egress from the CM required seven non-trivial steps to complete before they could exit.[65] The accident investigation revealed that the crew did not accomplish much, possibly any, of these steps before they lost consciousness.[66] There were no procedures to rapidly depress the cabin and remove the complex three-part hatch either from the inside or outside and personnel had not been trained to remove the hatch during an emergency.[67] There was no fire extinguishing equipment on board and no instruments to directly warn them or the ground controllers of an ignition.[68] The Firex system on the pad used for fire suppression could not be activated remotely from the control room and one of the two systems for activating it on the pad was not functioning.[69] Thick smoke in the white room adjacent to the CM impeded the rescue and there was no system for venting the smoke.[70] There were no medical or fire

[63] U.S. Congress, Senate, *AS204 Accident*, 3.

[64] U.S. Congress, Senate, *AS204 Accident*, 3.

[65] *Report of the Apollo 204 Review Board,* D-13.5.

[66] *Report of the Apollo 204 Review Board,* D-13.5.

[67] *Report of the Apollo 204 Review Board,* D-13.5, D-13.8 - D-13.9.

[68] *Report of the Apollo 204 Review Board,* D-13.7.

[69] *Report of the Apollo 204 Review Board,* D-13.7.

[70] *Report of the Apollo 204 Review Board,* D-13.8.

personnel stationed on site during the test.[71] The crew egress path from the pad was complicated and filled with hazards.[72] Crew egress training was not adequate and the first realistic egress exercise was planned to take place after the Plugs Out test.[73] Ultimately, the decision not to classify the test as hazardous, communicated to the test team that the test was safe and that precautions mentioned above did not need to be taken.

Why did no one deem this to be a hazardous operation? Using pure oxygen was enough of a concern that NASA attempted to eliminate all ignition sources in the CM and testing was conducted on the flammability of materials in pure oxygen.[74] My initial thought was that schedule pressure must have been a factor, given everything that would have needed to be corrected if the test had been labeled hazardous. However, in the hearings before the Senate, James J. Gehrig the Committee Staff Director asked Dr. Charles Berry, NASA Chief of the Manned Spacecraft Center Medical Programs, if the Apollo schedule had an impact on the decision to use pure oxygen instead of a dual gas system in the CM.[75] Dr. Berry said that the decision was made based on "our experience from other programs and it was not related to any expediency whatever."[76] It is difficult to determine if this statement can be taken at face value, or was the result of a witness sticking with "the party line." The AS-204 accident investigation board offers another potential explanation for why the test was not deemed a hazardous

---

[71] *Report of the Apollo 204 Review Board,* D-13.8.

[72] *Report of the Apollo 204 Review Board,* D-13.9.

[73] *Report of the Apollo 204 Review Board,* D-13.9.

[74] U.S. Congress, Senate, *Hearing Apollo Accident of January 27, 1967*, 21.

[75] U.S. Congress, Senate, *Hearing Apollo Accident of January 27, 1967*, 23.

[76] U.S. Congress, Senate, *Hearing Apollo Accident of January 27, 1967*, 23.

operation. One of their findings was that the "criteria for defining hazardous test operations" were not complete."[77] They also concluded that the requirements that were needed to review and approve spacecraft test procedures were "not well defined."[78] Here we find a source of poor written communication in vital requirements that are supposed to help engineers determine if an operation or test is hazardous.

It is clear that there were multiple communications issues associated with the AS-204/Apollo I fire. The communications during the test, vital to its success and the safety of the crew were poor and likely impacted the response to the fire. Although using pure oxygen is inherently dangerous, the decision by NASA to not classify the test as hazardous resulted in the use of combustible materials in the CM, inadequate training, no emergency personnel stationed at the pad, a hazardous egress path from the pad, and a test crew that did not discontinue the test due to poor communication quality. The written requirements for defining a hazardous test and for approving test procedures were not well defined and incomplete. Thus, poor written communication ultimately prevented test personnel from implementing the proper safety procedures appropriate for a hazardous operation. It is possible that better communication might have prevented the Apollo I fire, but better communication would not have changed two technical factors, a complex hatch design and a high-pressure pure oxygen environment. We are left to wonder if the un-crewed test that was skipped would have resulted in a fire, which would have damaged the CM, but spared the lives of the Apollo I crew.

---

[77] *Report of the Apollo 204 Review Board*, D-13.13.

[78] *Report of the Apollo 204 Review Board*, D-13.13.

The *Challenger* STS-51-L Accident

The Space Shuttle Challenger, STS 51-L, exploded seventy-three seconds after liftoff on January 28, 1986.[79] During ascent, the right-hand Solid Rocket Booster (SRB) aft field joint began to leak hot combustion gas from inside the booster.[80] The flame from the leak was directed onto both the External Tank (ET) and the aft strut connecting the booster to the ET.[81] The jet of hot combustion products from the booster burned through the wall of the liquid hydrogen tank, releasing highly explosive hydrogen fuel.[82] Around the same time, the aft strut connecting the booster to the ET failed, allowing the booster to rotate at the forward attach point.[83] The aft end of the ET hydrogen tank failed and the rotating Booster struck the Intertank and the aft end of the liquid oxygen tank.[84] The release and ignition of the ET fuel and oxidizer resulted in a catastrophic explosion, breaking the ET and the Orbiter *Challenger* apart.[85] The Roger's Commission concluded that the failure of the right booster aft joint was due to a poor design that was "sensitive to a number of factors."[86]

The main source of cognitive bias associated with the Challenger accident was near-miss bias. The SRB field joint design was considered flawed from the beginning, yet there was no

---

[79] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 19.

[80] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 19.

[81] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 20.

[82] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 21.

[83] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 21.

[84] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 21.

[85] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 21.

[86] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 73.

effort to redesign it.[87] The SRB contractor, Thiokol maintained that the design was acceptable as it was similar to their reliable Titan III rocket motor designed for the Air Force, although there were enough design differences to make that comparison invalid.[88] Damage to the O-rings used to seal the joint had been observed in post-flight inspections since the second Shuttle mission.[89] Instead of launching an effort to redesign the field joint, NASA and the SRB contractor Thiokol deemed the damage acceptable since it had not caused a failure of the SRB.[90] It is also possible that problems with the SRB nozzle to case joint, which was considered a greater concern, distracted Thiokol from the dangers of the field joint.[91] Thus NASA continued to fly the Shuttle with a known hardware problem, thinking that since it hadn't caused a major mishap, it would likely not pose an issue for future flights.

The *Challenger* accident essentially gave birth to the concept of normalization of deviance, when Diane Vaughan used it to describe NASA's decision to continue flying an SRB field joint that was susceptible to O-ring damage. As early as in the design and development phase, NASA MSFC engineers expressed concerns with the SRB field joint design, yet they were not addressed.[92] Then damage to the field joint O-rings was observed almost from the

---

[87] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 124.

[88] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 122.

[89] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 126.

[90] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 120.

Vaughan, *The Challenger Launch Decision*, 124.

[91] Allan J. McDonald, *Truth, Lies, and O-Rings: Inside the Space Shuttle Challenger Disaster* (Tallahassee: University Press of Florida, 2009), 29.

[92] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 121.

beginning yet they didn't stop to redesign the joint.[93] Thiokol offered rationale that there were two O-rings providing redundancy such that if the first O-ring failed, the second would hold.[94] The criticality rating of the SRB field joint had been Criticality 1R, which meant it could fail, but remain safe due to redundancy provided by the second O-Ring.[95] The criticality rating would eventually be changed to Criticality 1, indicating that some at NASA did not think that there was true redundancy in the field joint.[96] However, the launch constraint and thus the increased hardware scrutiny that the Criticality 1 rating required, was regularly waived by the SRB Project Manager.[97] Vaughan asserts that NASA was following the rules when processing these waivers.[98] I would agree, from a legalistic standpoint, NASA was following the rules, but the waivers seem to me to have been processed out of expedience. Over time, NASA and Thiokol increased the amount of O-ring damage that they would deem "acceptable."[99] One of the surprising examples was the mission STS 51-C about a year before the Challenger accident, which launched after three days with a record low temperature.[100] Alan McDonald recalled that it was clear to them that the cold temperatures had made the O-rings less compliant.[101] When inspection of the O-rings after recovery revealed erosion on both, which was the first occurrence

---

[93] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 126.

[94] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 123, 127.

[95] Vaughan, *The Challenger Launch Decision*, 129.

[96] Vaughan, *The Challenger Launch Decision*, 129.

[97] Vaughan, *The Challenger Launch Decision*, 132-133.

[98] Vaughan, *The Challenger Launch Decision*, 132-133.

[99] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,*120.

[100] Vaughan, *The Challenger Launch Decision*, 153-155.

[101] McDonald, *Truth, Lies, and O-Rings*, 47.

of erosion on both seals, the explanation at the FRR for the following launch was that the cold weather affected the O-rings.[102] In addition, the condition was deemed "not desirable but acceptable."[103] NASA crossed over from near-miss bias to normalization of deviance when they chose to accept an inadequate design and shifted with respect to what performance from that design was acceptable. Diane Vaughan described what she saw as a repeated sequence of events where the Shuttle program identified an issue, acknowledged the risk, reviewed the data, accepted the risk "indicating the normalization of deviance", and then launched.[104] She attributed the normalization of deviance to a "work group culture" that was formed to respond to the O-ring issue and would dictate decision making for each occurrence of the anomaly.[105] This culture established and rigorously followed the "rules" that it made.[106]

Although near-miss bias and normalization of deviance caused NASA to continue to use the poor design of the SRB field joint, there were some significant communications issues associated with the *Challenger* accident. The *Roger's Commission Report* of the investigation made it clear that there were significant communications issues impacting decision making including "the decision to launch 51-L based on incomplete and sometimes missing information, a conflict between engineering data and management judgements, and a NASA management structure that permitted internal flight safety problems to bypass key Shuttle managers."[107]

---

[102] McDonald, *Truth, Lies, and O-Rings*, 47.

[103] Vaughan, *The Challenger Launch Decision*, 156.

[104] Vaughan, *The Challenger Launch Decision*, 65.

[105] Vaughan, *The Challenger Launch Decision*, 65-66.

[106] Vaughan, *The Challenger Launch Decision*, 65-66.

[107] *Report on the Presidential Commission of the Space Shuttle Challenger Accident*, 83.

However, the communications issues began long before the STS 51-L accident. Early in the Shuttle development, Marshall Space Flight Center solid rocket propulsion engineers pointed out issues with the joint design in at least two official memos, but the Rogers Commission could find no evidence that these memos were received by Thiokol.[108] Hence, Shuttle was plagued with communications issues almost from the beginning. O-ring erosion was observed as early as the second Shuttle mission, STS-2.[109] The primary vehicle for communicating hardware issues that might impact the next mission was the Flight Readiness Review (FRR) where readiness to launch the next Shuttle is reviewed and approved by multiple levels of Shuttle management.[110] Despite the significance of this finding, the STS-2 O-ring erosion was not reported in the FRR for the next flight, STS-3.[111] The issue was not covered in an FRR until the one for STS 41-C, about three years later![112] Even at that FRR, MSFC officials deemed the erosion “acceptable.”[113] The Rogers Commission concluded that NASA and Thiokol engineers “did not fully understand the mechanism by which the joint sealing action took place.”[114] There was no mention of the O-ring concern in the STS 51-L FRR.[115] The Rogers Commission also concluded that NASA’s method of tracking hardware issues and reporting them through the FRR was a failure.[116] Near-

---

[108] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 121.

[109] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 125.

[110] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 145.

[111] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 147.

[112] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 129, 147.

[113] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 147.

[114] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 148.

[115] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 84.

[116] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 148.

miss bias and normalization of deviance certainly were significant factors in the acceptance of a bad joint design and O-ring erosion, but poor communication made the problem worse.

The most well-known examples of communications failures from the *Challenger* accident center on some meetings that occurred the night before the launch. The following events have been documented many times, including depiction in at least two motion pictures. Although the events were critical in the decision to launch *Challenger*, there were the tip of the iceberg with respect to the communications issues surrounding the Shuttle program. On the day before launch, in the afternoon, engineers at Thiokol were concerned about the temperature forecast for launch day since it was much colder than their experience base and well below the temperature at which the joints were qualified for flight[117] Specifically, they were concerned that the O-ring in the SRB field joints would lose flexibility in the cold temperatures, in a similar manner that a piece of chewing gum becomes difficult to chew after placing it in ice water.[118] Space hardware is qualified for a very specific range of environments throughout its life. There is an unwritten rule in the agency that hardware should not be operated outside of its qualification limits unless there are special circumstances, and only if it can be proven that the hardware will not fail when exposed to the proposed conditions. It is important to note that Diane Vaughan, concluded that no flight rules were violated with the decision to launch Challenger.[119] Technically, she is correct, but the unwritten rule about operating hardware outside of its qualification limits was clearly violated on launch day.

---

[117] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 85-86.

[118] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 89-91.

[119] Vaughan, *The Challenger Launch Decision,* 56-58.

Thiokol engineers communicated their concerns to MSFC SRB Project Management in two separate teleconferences in the evening before the launch in a prolonged discussion that continued late into the evening.[120] During the second teleconference, it was clear that the MSFC SRB Project Manager did not agree with the Thiokol position and was reported as saying that he "was appalled that (Thiokol) would make such a recommendation."[121] He thought that the data was inconsistent, showing significant O-ring damage on both warm and cold days.[122] Thiokol managers asked to pause the teleconference so they could caucus amongst themselves.[123] During that sidebar, the Thiokol Vice-President for Engineering was asked to "take off his engineering hat and put on his management hat."[124] Feeling the pressure, Thiokol managers overrode their engineers and said they were "go" for launch.[125] Allan McDonald, a Thiokol SRB project manager described not only production pressure at Thiokol, but also constant talk that the government was seeking to recompete the SRB contract.[126] It is possible that these pressures motivated the Thiokol managers to reconsider their position. The concerns of the Thiokol engineers never reached the Shuttle Mission Management Team (MMT), which was responsible for the go/no-go decision, since MSFC project management did not communicate the Thiokol concern to the team.[127] I found no evidence that Thiokol engineers directly contacted the MMT,

[120] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 86-89.

[121] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 94.

[122] Chiles, *Inviting Disaster,* 66.

[123] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 94.

[124] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 94.

[125] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 92-94.

[126] McDonald, *Truth, Lies, and O-Rings*, 10-11.

[127] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 87-88.

but it is likely they would have not strayed out of their established chain of communication. One of the Thiokol engineers seems to confirm this when he testified to the Senate that he gave his input and would not take away the manager's "right to take the input of an engineer and then make a decision based on that input […]."[128] He said that he felt "badly defeated" and that he did all he could "to stop the launch."[129] This is an example of a serious communications issue, when people with dissenting or unpopular opinions are ignored or intentionally silenced. The tragic result is that the top-level Shuttle Managers in MMT did not have all of the information they needed to make a sound decision.

There was another communications breakdown during the Challenger launch decision that was more subtle, yet has significant and sobering implications for engineers today. According to the Rogers Commission, if NASA or Thiokol had performed a thorough analysis of the O-Ring erosion data, the correlation between ambient temperature and launch, and O-ring damage would have been much clearer.[130] Edward Tufte, a statistician and Professor Emeritus of Yale University conducted an evaluation of the charts that Thiokol engineers provided at the second telecon conducted on the evening before the launch. His assessment is compelling, stating that there was a "[…] proximal cause (of the accident): an inability to assess the link between cool temperature and O-ring damage on earlier flights."[131] According to Tufte, the charts had significant weaknesses including no authors on the title page, indicating lack of responsibility for the content, too much detail in some charts, and not enough or relevant detail in

---

[128] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 93.

[129] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 93.

[130] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 148.

[131] Edward R. Tufte, *Visual Explanations: Images and Quantities, Evidence and Narrative* (Cheshire: Graphics Press, 1997), 40.

others.[132] The most compelling flaw he pointed out was the limited data set that the engineers included regarding O-ring damage.[133] The data as shown did not show a real correlation between joint temperature and O-ring damage, and even included a data point where damage occurred on a launch day when the temperature was 75 degrees Fahrenheit.[134] If Thiokol had shown a plot of the O-ring condition for all launches, it would have shown an undeniable correlation between damage and temperature.[135] A data plot including all launches would have addressed the lack of correlation in the limited data set pointed out by MSFC SRB Project Manager. Data analysis must be thorough and communicated in a clear way that supports an engineer's position. Although it is tempting to criticize the Thiokol engineers for their poor communication skills, one consideration that must be taken into account, was the rush in the evening before the 51-L launch, to make a launch recommendation based on the cold weather. These were the days before Microsoft Excel and PowerPoint, when Thiokol engineers did not have the desktop computing resources to conduct a quick data analysis and effective display. They did their best within the time constraints given, but mistakenly assumed that the data they were showing would be so evident that everyone would agree with them without question.[136] Not only is this a compelling example of failed written and verbal communication, it is also an example of a faulty assumption that communication had taken place when it in fact it had not.

[132] Edward R. Tufte, *Visual Explanations*, 40-41.

[133] Edward R. Tufte, *Visual Explanations*, 44.

[134] Edward R. Tufte, *Visual Explanations*, 44-45.

[135] Edward R. Tufte, *Visual Explanations*, 45.

[136] *Report on the Presidential Commission of the Space Shuttle Challenger Accident*, 91.

Engineers at Thiokol were not the only ones who were concerned about launch that day. Engineers at Rockwell International, the company that made the Shuttle Orbiter, were also concerned about the cold temperatures.[137] They were concerned that the outside temperature was lower than any temperature in which they had previously launched.[138] It was possible that large amount of ice that had formed on the pad and the mobile launch platform could come loose during the firing of the SSMEs and SRBs and be directed toward the Orbiter, causing damage to the thermal protection tiles.[139] Unlike the SRB O-ring concern, the Rockwell concern was discussed with the Mission Management Team.[140] However, Rockwell's launch position was very vague, and did not clearly indicate they were "no-go".[141] Furthermore, the Rogers Commission was concerned that NASA had not "appropriately considered Rockwell's concern about the ice."[142] NASA had put both Thiokol and Rockwell into the awkward position of stating that their hardware was not safe for launch.[143] Once again poor, and perhaps intentionally vague, communication from a contractor, in this case Rockwell, became a flight safety failure.

---

[137] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 114-117.

[138] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 114-117.

[139] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 114-117.

[140] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 114-117.

[141] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 114-117.

[142] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 117.

[143] *Report on the Presidential Commission of the Space Shuttle Challenger Accident,* 118.

The STS-107 *Columbia* Accident

The Space Shuttle *Columbia*, Mission STS-107 launched on January 16, 2003.[144] About eighty-one seconds into ascent, a piece of insulation from the ET broke off and struck the leading edge of the Orbiter wing creating a hole.[145] On February 1, 2003, the Orbiter Columbia broke up during re-entry.[146] The Orbiter thermal protection system was designed to protect it from the superheated air that surrounds it during re-entry.[147] However, the air was allowed to enter the interior of the wing due to the hole in the leading edge.[148] The hot gas melted the interior of the wing, destroying it, and ultimately caused the break up of the entire Orbiter.[149]

After the STS-107 launch, the Shuttle management team was confronted with imagery that indicated the possibility that the Orbiter wing had been struck by a piece of foam debris on ascent. There was no clear view of the wing to determine if it had been damaged. Anchoring bias was a significant factor that led to decision makers deciding not to pursue imagery of Columbia's wing after it was determined that foam had struck it.[150] NASA gave preference to an early United Space Alliance opinion that the material on the leading edge of the wing was resilient to impact damage.[151] Due to anchoring on the early United Space Alliance report, Shuttle management team seemed almost blind to the concerns of engineers regarding potential

---

[144] *Columbia Accident Investigation Report*, 11.

[145] *Columbia Accident Investigation Report*, 11.

[146] *Columbia Accident Investigation Report*, 12.

[147] *Columbia Accident Investigation Report*, 12.

[148] *Columbia Accident Investigation Report*, 12.

[149] *Columbia Accident Investigation Report*, 12.

[150] *Columbia Accident Investigation Report*, 141.

[151] *Columbia Accident Investigation Report*, 141.

damage to the orbiter.[152] The Columbia Accident Investigation Board stated that this may have "contributed to the mindset that hitting the RCC was not a concern."[153] This anchoring seemed to set up confirmation bias observed in the events leading up to the *Columbia* accident, where Shuttle decision makers might have focused on this opinion which made them less receptive to differing opinions. Stephen Waring pointed out that the Mission Management Team considered the foam strike as an "in family" occurrence and held the position that it was maintenance concern, not a safety of flight issue.[154] When presented the results from CRATER, the model used to assess potential damage to *Columbia*'s wing, they interpreted the results as "rigorous confirmation of their optimism."[155] Mission managers gave preference to "optimistic scenarios and ignored pessimistic ones."[156] This confirmation bias caused mission managers to disapprove three requests from engineers to use Department of Defense assets to get imagery of the wing.[157]

Near-miss bias played a significant role in the *Columbia* accident. Since the first Shuttle mission, thermal insulating foam from the ET had broken off during ascent and at times, struck various elements of the Shuttle stack.[158] This was in violation of NASA requirement that the Shuttle "shall be designed to preclude the shedding of ice and/other debris[…]", yet the

---

[152] *Columbia Accident Investigation Report*, 141.

[153] *Columbia Accident Investigation Report*, 141.

[154] Waring, "Losing the Shuttle (or Nearly), 228.

[155] Waring, "Losing the Shuttle (or Nearly), 229.

[156] Stephen Waring, "Losing the Shuttle (or Nearly), 228.

[157] *Columbia Accident Investigation Report*, 37-38.

Waring, "Losing the Shuttle (or Nearly), 228.

[158] Cabbage and Harwood, *Comm Check*, 56-57.

requirement was never enforced.[159] ET foam loss had not resulted in a significant failure of the Shuttle, and thus it was repeatedly accepted and considered more of a turn-around/Orbiter maintenance issue.[160] Again, anomalous performance of the hardware, in this case the ET foam, did not lead to a mishap, and thus was deemed acceptable up to fly.

Early in the *Columbia* accident investigation, the Manager of the Space Shuttle Program brought a piece of ET foam roughly the same size as the one that hit the *Columbia*'s wing, to a daily press briefing.[161] He stated that foam shedding was a maintenance issue that they "were comfortable with" and dismissed it as a potential cause of the accident.[162] He was not the only person at NASA who shared this opinion. We discussed the accident in my office area and no one could believe that a piece of lightweight foam could pierce the tough Reinforced Carbon-Carbon (RCC) material on the leading edge of the wing. Many of us were shocked when we eventually saw the video of the "chicken gun" firing foam test pieces at a section of RCC and seeing the resulting hole. Over time, NASA increased the size of the foam strikes deemed acceptable and foam strikes over time were considered "in family."[163] NASA have moved considerably from the original position of not permitting the shedding of debris from the Shuttle. Diane Vaughan drew a parallel between the normalization deviance with respect to the field joint issue that took *Challenger*, to the acceptance of ET foam shedding that ultimately caused

---

[159] Cabbage and Harwood, *Comm Check*, 56-57.

[160] *Columbia Accident Investigation Report*, 130.

[161] Vaughan, *The Challenger Launch Decision*, xv.

[162] Vaughan, *The Challenger Launch Decision*, xv.

[163] Cabbage and Harwood, *Comm Check*, 59.

Columbia's demise.[164] She asserted that the organizational issues that caused the *Challenger* accident were not fixed and that both accidents were the result of many "interacting factors" including political and economic environment, structure of the organization, and "layered cultures that affected how people making technical decisions defined and redefined risk."[165] In addition, having anomalies themselves was considered normal, which desensitized NASA to issues that posed danger to the Shuttle and its crews.[166] Although the examination of the NASA organization itself was not part of the scope of this paper, it is clear that there was a direct connection between the normalization of deviance observed and the organization and culture of NASA.

An examination of the events that took place after launch and while Columbia was on-orbit reveal some significant communications issues. A day after the launch, after looking at the high-resolution footage of the ascent, the Inter Center Working Group discovered the foam strike on the Orbiter.[167] They requested that NASA contact the Department of Defense to gain imagery of the Orbiter wing that they believed had been struck by the foam.[168] A Debris Assessment Team (DAT) was also formed to assess the potential damage to the wing and make

---

[164] Vaughan, *The Challenger Launch Decision*, xv.

[165] Diane Vaughan, "NASA Revisited: Theory, Analogy, and Public Sociology," *American Journal of Sociology*, Volume 112, Number 2 (September 2006), 361.

Diane Vaughan, "System Effects: On Slippery Slopes, Repeating Negative Patterns, and Learning from Mistake," *Organization at the Limit: Lessons from the Columbia Disaster*, eds. William H. Starbuck and Moshe Farjoun (Malden: Blackwell Publishing, 2005), 41.

[166] Diane Vaughan, "System Effects," 41.

[167] *Columbia Accident Investigation Report*, 37.

[168] *Columbia Accident Investigation Report*, 37.

recommendations.[169] After the first imagery request was turned down by upper level Shuttle management, the DAT began modeling of the potential damage with an analytical tool called CRATER.[170] Given that the model was not written to analyze the type of damage the team was assessing, the team communication of the results was not one exuding confidence.[171] After hearing a summary of the results, the MMT concluded that the strike was not a safety issue, but more of a refurbishment issue on the ground.[172] Once again, less than optimal communication through a presentation in a meeting impacted the decision making process.

Without communicating with the NASA DAT, a United Space Alliance Thermal Protection System Subsystem Area Manager circulated an email that the Reinforced Carbon-Carbon material on the leading edge of the Orbiter wing was "extremely resilient" to impact damage and that the foam likely struck the RCC and "broke apart."[173] As discussed earlier, this communication heavily influenced the Mission Management Team. In general, the discussion of the potential damage was never discussed within the integrated Shuttle community, only within certain isolated groups, a phenomenon known as communications silos.[174] There seemed to be no clear lines of communication between the engineers evaluating the potential damage and the managers tasked with making safety decisions. As a result, two more requests for imagery would be made and disapproved.[175]

---

[169] *Columbia Accident Investigation Report*, 37.

[170] *Columbia Accident Investigation Report*, 38.

[171] *Columbia Accident Investigation Report*, 38.

[172] *Columbia Accident Investigation Report*, 38.

[173] *Columbia Accident Investigation Report*, 38.

[174] *Columbia Accident Investigation Report*, 38.

[175] *Columbia Accident Investigation Report*, 140.

The CAIB determined that in addition to the three denied imagery requests, there were at least eight missed opportunities over the course of a sixteen-day mission when the right action could have led to the discovery of the damage on *Columbia*'s wing.[176] The *Columbia* accident was not directly caused by poor communication. However, poor communication prevented the Shuttle team from properly assessing the damage to the wing. There were assumptions that communication had taken place when it didn't, discussions that were happening in isolated silos, and the concerns of DAT that were not conveyed effectively to the Shuttle MMT decision makers. After the accident, managers stressed that any engineer with a safety concern could have voiced that concern to a manager.[177] The CAIB pointed out that it was the managers' responsibility to also seek out the technical opinions of the engineers and to ensure that the engineers knew the communications paths available to them.[178] Karl Weick concluded that the complex bureaucratic structure impeded and even prevented communication between the decision makers and the people who held the technical expertise.[179]

The discussion of communication ultimately leads one to ask the question, had the Shuttle team discovered the significant damage to *Columbia*'s wing, could the crew have been saved? *Columbia* was not in the same orbital inclination angle as the International Space Station (ISS) and there was not enough propellant, even on a fully fueled Orbiter, to make an orbit change needed to seek refuge on the ISS. The CAIB tasked NASA with investigating potential

---

[176] *Columbia Accident Investigation Report*, 140.

[177] *Columbia Accident Investigation Report*, 169.

[178] *Columbia Accident Investigation Report*, 169.

[179] Karl E. Weick, "Making Sense of Blurred Images: Mindful Organizing in Mission STS-107," *Organization at the Limit: Lessons from the Columbia Disaster*, eds. William H. Starbuck and Moshe Farjoun (Malden: Blackwell Publishing, 2005), 175.

rescue scenarios to see if the crew could have been saved.[180] NASA looked at a wing repair scenario as well as an accelerated rescue mission with the Shuttle *Atlantis*.[181] Both scenarios were deemed risky but feasible.[182] Unfortunately, due to poor communication, NASA did not have the opportunity to explore either of these rescue options.

Conclusion

The space hardware did not perform as intended in the case of all three space accidents. The failure of hardware can arise from problems with manufacturing and workmanship. Many hardware failures are due to known or latent design issues. However, in the case of many engineering accidents, human "failure" was as much a causal factor as design, manufacturing, and workmanship issues. In the case of the three U.S. space program accidents there were three key factors, cognitive bias, normalization of deviance, and most of all, communication breakdown, that led to poor decision making which was a significant contribution to the three U.S. space accidents. Cognitive bias played a role in all three accidents, although to varying degrees. Anchoring bias was a significant factor that impacted the decision not to obtain imagery of *Columbia*'s wing following the launch. All three accidents were impacted by confirmation bias, where decision makers tended to accept the information that was consistent with their opinions. All three accidents were heavily influenced by near-miss bias as evidenced by the acceptance of flawed hardware since there had been no accidents involving that hardware in the past. Normalization of deviance played a significant role in all three accidents. Known

---

[180] *Columbia Accident Investigation Report*, 173.

[181] *Columbia Accident Investigation Report*, 173.

[182] *Columbia Accident Investigation Report*, 173.

hardware issues and the resulting issues with performance, were dismissed as "normal" with time. The greatest factor in all three accidents was flawed communication. The hardware and data provided warnings that were ignored, dismissed, or intentionally not communicated. Engineers communicated warnings verbally and by memo prior to all three accidents, yet the warnings were not heeded.[183] Communications issues resulted from poor chain of command structure, inadequate presentation of data, suppression of dissenting opinions, and not having the right personnel in a room. Had communication been better, all three of these accidents might have been prevented. The Apollo Command Module would not have been accepted as-is, the *Challenger* would not have launched, and flight controllers would have known that Columbia had significant damage that put the astronauts in jeopardy. Some say that *Columbia*, once in space, could not have been repaired to the point of saving the crew and vehicle. Unfortunately, we will never know if an Apollo 13 style repair in space would have worked.

It has been mentioned that spacecraft and launch vehicles are extremely complicated machines. We cannot always predict or prevent hardware failures because it is difficult to anticipate every way that a complicated system will fail. However, we as engineers can take responsibility for what we can control and that is the non-technical human factors that lead to space accidents. As an engineer working in the field, I have learned that the moment you think you are not biased, that is the moment when you are most vulnerable. Addressing cognitive bias requires education and diligence to prevent, and complacency is an ever-present threat to that diligence. After these three accidents, we should be more aware of the dangers of cognitive bias and normalization of deviance, but there are still engineers who have not been exposed to material discussing them. Vaughan stressed that the causes of both U.S. Shuttle accidents were

---

[183] Chiles, *Inviting Disaster*, 147.

both "patterned and systemic."[184] James Chiles made the point that the space vehicles can become "prisoners of the many promises made to get them built, promises of safety, low cost, on-time performance, and solid technology."[185] He also offered that the people involved with disasters are often so focused on a goal, such as the Moon in a decade, that they become blind to the warning signs around them.[186] These statements resonated with me because of the many pressures put on NASA, particularly political, funding, and schedule, that can make an already difficult task all the more challenging, and saying "it can't be done" is not an option. These pressures seemed to set up, or at least re-enforce, the cognitive biases and normalization of deviance observed in connection with all three accidents.

Engineers are often criticized for not being effective communicators, either in verbal or written form. Although there are many exceptions, there is a great deal of truth in that stereotype. Engineering curriculums must include so many technical courses, that it is a challenge to fit liberal arts courses into a four-year program. Add cost, schedule, political, and other pressures to the mix, then effective communication becomes even more of a challenge. Something as simple as how data is presented to decision makers can have a tremendous impact. Communication skills are something that can be acquired with diligent practice, and thus a factor that engineers can control. We have learned from this study that communications or lack of it, can make a significant difference in the outcome of a space mission. Although the agency, and my company, are starting to require good communication skills from applicants, we still have a long way to go in mitigating the risk posed by lack of communication. The missions will go on

[184] Diane Vaughan, "System Effects", 41.

[185] Chiles, *Inviting Disaster*, 92.

[186] Chiles, *Inviting Disaster*, 142.

and so must we, keeping in mind that missions are not just the hardware, but the people who design, test, build, and operate it.

Epilogue: The *Soyuz I* Accident

The United States was not the only nation to experience tragedy in its space program. Russia, or at the time the Soviet Union, suffered two significant accidents resulting in the deaths of one and three cosmonauts respectively. I chose to focus on the first one, the *Soyuz I* accident, because it happened not long after the Apollo I fire. Two nations were locked in a Cold War race to gain superiority in space and this rush to space came with a cost for both sides. Ultimately, the *Soyuz I* would be the casualty of some of the same non-technical issues that doomed Apollo I, including failed communication.

The challenge with researching and writing about the Soviet space program is the limited number of sources. Most are secondary sources and much of what has been written about Soviet space accidents came out after the end of the Cold War. The only primary sources I could locate were ones from NASA personnel expressing sympathy following the accident. Even with limited sources, one can see a glimpse of some of the issues that their programs experienced.

The *Soyuz I* launched, carrying Cosmonaut Vladamir Komarov, on April 23, 1967 from Baikonur Cosmodrome in what is now modern-day Kazakhstan.[187] This was the first launch of a crewed *Soyuz* spacecraft.[188] The original plan was to launch a second *Soyuz* in order to have a rendezvous and docking of the two spacecraft in orbit as well as an extravehicular activity, or

[187] Douglas Hart, *The Encyclopedia of Soviet Spacecraft* (New York: Exeter Books, 1987), 88.

[188] Bryan Harvey, *Soviet and Russian Lunar Exploration* (New York: Springer Books, 2007), 130.

spacewalk.[189] However, after launch a series of failures occurred. When *Soyuz I* reached orbit, at least one of the solar panels, which provided power to the spacecraft did not deploy.[190] The lack of power caused the guidance system needed for navigation to not function properly.[191] There were also issues with the spacecraft communications, propulsion, and thermal control systems.[192] The launch team considered launching the second *Soyuz* as a rescue mission but a storm that passed over the launch complex caused problems with its electrical system.[193] Given the many technical issues with the first *Soyuz*, launching the second one would have been a high risk operation, since the same technical issues could have happened to the second spacecraft. The launch team decided to abort the mission and bring *Soyuz 1* home.[194] Even with a failed navigation system, Komarov was able to pilot the Soyuz and achieve the correct alignment for de-orbit.[195] He was quoted as saying, "This devil ship, nothing I lay my hands on works properly."[196] Komarov was able to successfully de-orbit and re-enter the Earth's atmosphere but unfortunately, the parachute for the capsule did not deploy properly and Komarov was killed on impact when the *Soyuz* hit the ground at 400 miles per hour.[197]

---

[189] Harvey, *Soviet and Russian Lunar Exploration*, 130.

[190] Harvey, *Soviet and Russian Lunar Exploration*, 131.

[191] Harvey, *Soviet and Russian Lunar Exploration*, 131.

[192] Harvey, *Soviet and Russian Lunar Exploration*, 131.

[193] Harvey, *Soviet and Russian Lunar Exploration*, 131.

[194] Harvey, *Soviet and Russian Lunar Exploration*, 131.

[195] Harvey, *Soviet and Russian Lunar Exploration*, 131.

[196] Piers Bizony and Jamie Doran, *Starman: The Truth Behind the Legend of Yuri Gagarin* (New York: Walker & Company, 2011), 199.

[197] Harvey, *Soviet and Russian Lunar Exploration*, 131.

Shepard and Slayton, *Moon Shot*, 219.

The *Soyuz I* accident happened approximately three months after the Apollo I fire. An examination of the events leading to the launch reveal some haunting similarities between the Apollo I and *Soyuz 1* accidents. Both spacecraft were riddled with technical issues. There were three failed tests of the *Soyuz* before Komarov's launch, one ground failure and two failed un-crewed flight tests.[198] According to Bryan Harvey, the consensus of the team was that the launch was rushed before approximately 203 known technical issues with the *Soyuz* were fixed.[199] Why was there such a rush? According to Pier Bizony and Jamie Doran, political pressure was the main cause.[200] They asserted that Leonid Brezhnev wanted the two Soyuz spacecraft to dock on May Day which on that year would have been the fiftieth anniversary of the Russian Revolution.[201] Unfortunately, the potential pressure to launch Apollo I and *Soyuz I* is difficult to prove. However, given that these two nations were engaged in a space race with their perceived national security and prestige at stake, political pressure was a strong possibility.

Was there evidence of cognitive bias, normalization of deviance, or communications issues connected with the *Soyuz* accident? Without additional sources, it would be a challenge to identify cognitive bias in connection with the accident. However, the team knew about 203 issues with the spacecraft and experienced three failed tests prior to the *Soyuz* flight, so it is unlikely that they were subject to near-miss bias. While under pressure, they were willing to accept and fly crewed hardware with known technical issues, so one could say that normalization of deviance was present. The one issue that was absolutely present, according to the sources,

[198] Harvey, *Soviet and Russian Lunar Exploration*, 133.

[199] Harvey, *Soviet and Russian Lunar Exploration*, 131-132.

[200] Bizony and Doran, *Starman*, 194.

[201] Bizony and Doran, *Starman*, 194.

was broken communication channels. The problems with the spacecraft were well known both to the engineers and the cosmonauts. Komarov confided in a friend that he would not survive the mission.[202] When asked why he didn't refuse to fly, he replied that his friend Yuri Gagarin would be sent in his place and he wanted to protect Gagarin.[203] Following that conversation, a team of cosmonauts and engineers led by Gagarin compiled a memo describing all of the problems with the *Soyuz*, with the hope of stopping the launch.[204] The memo was taken to two officials. The first refused to read it and the second attempted to bribe the messenger with a promotion.[205] The second official kept the memo and never passed it on Leonid Brezhnev, whom he knew, because he knew his career would be ruined.[206] This was a case where everyone knew there was a problem but felt powerless to stop the launch. Even when an attempt was made to elevate the problem to a higher authority, the engineers and cosmonauts were silenced.

Once again, non-technical factors impacted a space accident. Although it was difficult to tell if cognitive bias was involved, there might have been some aspects of normalization of deviance present when flawed hardware was accepted for crewed flight. Broken communication was the most significant non-technical issue leading to the *Soyuz 1* space accident. In this case, many were afraid to speak up, and the ones who had the courage to come forward were abruptly silenced. The *Soyuz* spacecraft had many technical issues that likely made it impossible to fly successfully. There was pressure certainly pressure to launch the *Soyuz 1* mission, just as there

[202] Bizony and Doran, *Starman*, 196.

[203] Bizony and Doran, *Starman*, 196.

[204] Bizony and Doran, *Starman*, 196-197.

[205] Bizony and Doran, *Starman*, 196-197.

[206] Bizony and Doran, *Starman*, 197.

had been pressure to test and launch Apollo 1. In the case of both, properly functioning communications channels would have prevented both accidents. The timing of the accidents indicates that both sides were feeling pressure in the space race, and ironically, they both had significant failures within three months of each other.

Bibliography

<u>Primary Sources:</u>

AS-204 Plugs Out Test Audio, YouTube, https://www.youtube.com/watch?v=274lQSbpkRg.

Columbia Accident Investigation Board Report. Washington: U.S. Government Printing Office, 2003.

Report of the Apollo 204 Review Board to the Administrator National Aeronautics and Space Administration. Washington: U.S. Government Printing Office, 1967.

Report on the Presidential Commission of the Space Shuttle Challenger Accident. Washington: U. S. Government Printing Office, 1986.

U.S. Congress. House. Subcommittee on Science, Technology, and Space. *The Space Shuttle and Future Launch Vehicles: Hearing before the Subcommittee on Science, Technology, and Space*. 108th Cong. 2nd sess, May 5, 2004.

U.S. Congress. Senate. Committee on Aeronautical and Space Sciences. *AS204 Accident*. S. Rep. 956. 90th Cong. 2nd sess, 1968.

U.S. Congress. Senate. Committee on Aeronautical and Space Sciences. *Hearing Before the Committee on Aeronautical and Space Sciences on a Review of Background Information and Systems Decisions Preceding the Apollo Accident of January 27, 1967*. Washington: U.S. Government Printing Office, 1967.

Secondary Sources:

Bizony, Piers and Jamie Doran. *Starman: The Truth Behind the Legend of Yuri Gagarin.* New York: Walker & Company, 2011.

Cabbage, Michael and William Harwood. *Comm Check…The Final Flight of Shuttle Columbia*. New York: Simon and Schuster, 2004.

Chiles, James R. *Inviting Disaster: Lessons from the Edge of Technology*. New York: Harper Collins Publishers, 2001.

Dillon, Robin, Edward Rogers and Catherine Tinsley. “The Near-Miss Bias in Decision Making.” IEEEAC. Paper Number 1201 (October 25, 2005): 1-6.

Hart, Douglas. *The Encyclopedia of Soviet Spacecraft.* New York: Exeter Books, 1987.

Harvey, Bryan. *Soviet and Russian Lunar Exploration*. New York: Springer Books, 2007.

Kahneman, Daniel, Paul Slovic and Amos Tversky, "Judgement Under Uncertainty: Heuristics and Biases." *Science* 185, No. 4157 (Sep. 27, 1974) 1124-1131.

Kahneman, Daniel. *Thinking Fast and Slow.* New York: Farrar, Straus, and Giroux, 2011.

Launius, Roger D. and John Krige, James I. Craig, eds. *Space Shuttle Legacy: How We did It and What We learned*. Washington: American Institute of Aeronautics and Astrodynamics, 2013.

McDonald, Allan J. and James R. Hansen. *Truth, Lies, and O-Rings: Inside the Space Shuttle Challenger Disaster*. Tallahassee: University Press of Florida, 2009.

Perrow, Charles. *Normal Accidents: Living with High-Risk Technologies*. Princeton: Princeton University Press, 1999.

Shepard, Alan and Deke Slayton. *Moon Shot: The Inside Story of America's Race to the Moon*. Atlanta: Turner Publishing, 1994.

Starbuck, William H. and Moshe Farjoun. *Organization at the Limit: Lessons from the Columbia Disaster*. Malden: Blackwell Publishing, 2005.

Tufte, Edward R. *Visual Explanations: Images and Quantities, Evidence and Narrative*. Cheshire: Graphics Press, 1997.

Vaughan, Diane. *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA.* Chicago: University of Chicago Press, 2016.

Vaughan, Diane. "NASA Revisited: Theory, Analogy, and Public Sociology." *American Journal of Sociology* 112, No. 2 (September 2006): 353-393.

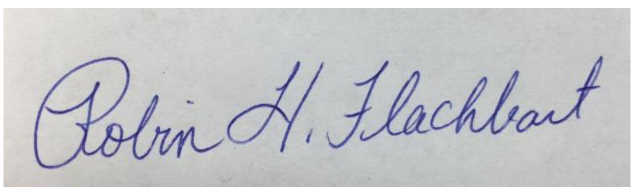
Honors Thesis Copyright Permission

This form must be signed by the student and submitted as a bound part of the thesis.

In presenting this thesis in partial fulfillment of the requirements for Honors Diploma or Certificate from The University of Alabama in Huntsville, I agree that the Library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by my advisor or, in his/her absence, by the Chair of the Department, Director of the Program, or the Dean of the Honors College. It is also understood that due recognition shall be given to me and to The University of Alabama in Huntsville in any scholarly use which may be made of any material in this thesis.

Robin Holt Flachbart____________

Student Name (printed)



____

Student Signature

5/1/2020___

Date