Challenger Triumphs:

Exploring the Reaches of Tragedy

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Historical Paper

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> "I didn't wish those tragedies upon the people who played them out. It was certainly tragic for them, but not for me. All of those things brought me to where I am. Without those things, I couldn't be who I am, I wouldn't be here." -Story Musgrave[1]

The human race has always looked to the stars. Regardless of the dangers, we are willing to risk exploring them. After successfully entering space fifty-five times over twenty-five years, safe returns were taken for granted; the Space Shuttle Challenger shattered those expectations.[2] The Challenger met disaster on January 28, 1986, at an altitude of 65,000 feet above Kennedy Space Center in Cape Canaveral, Florida. This horrific accident resulted in the death of seven astronauts, and the grounding of the shuttle program for nearly three years. Despite the tragedy of the Challenger, it offered a final triumph in the form of much-needed safety measures. Today, the National Aeronautics and Space Administration (NASA) prioritizes safety due to the great sacrifice represented by the Challenger disaster.

Since World War II the US has aspired to global dominance and could not pass up the challenge presented by the Soviets' space program, which began in the midst of the Cold War.[3] The driving force behind the creation of NASA was the launch of the Soviet satellite Sputnik on October 4, 1957.[4]

Sputnik, the world's first man-made satellite, took ninety-eight minutes to orbit the Earth, capturing the fear of America. The United States launched its first satellite, Explorer, on January

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[1]Roylance, Frank "'Right stuff' old stuff to him 'I love space': A 29-year astronaut, Dr. Story Musgrave at 61 will be the oldest human to fly in space when Columbia takes off in November." The Baltimore Sun, 1996. https://www.baltimoresun.com/news/bs-xpm-1996-04-26-1996117050-story.html Accessed 22 January 2019 Story Musgrave, the only person to fly on all 5 shuttles.

[2]Magnuson, Ed. "Space: They Slipped the Surly Bonds of Earth to Touch the Face of God" Time, content.time.com, 10 February 1986, http://content.time.com/time/magazine/article/0,9171,960596,00.html. Accessed 9 October 2018. After 25 years the excitement of space had worn off and many people had lost interest and assumed that everyone would return safely.

[3] Dick, Steven. "The Birth of NASA" NASA, nasa.gov, 28 August 2008, https://www.nasa.gov/exploration/whyweexplore/Why_We_29.html. Accessed 17 December 2018.

[4] Obery, James "Space Exploration" World Book Chicago: World Book 2000. 695-729. Print.

31, 1958, discovering the magnetic radiation belts that surround the Earth. On November 3, 1957, the Soviet Union launched Sputnik II, which carried a dog named Laika.[5] Thus began the race for space.

In response to the Soviet Union's achievements, the United States government initiated development of an agency to combat the possible threat of the Soviet space program. On November 25, 1957, Lyndon B. Johnson began Congressional hearings,[6] which lead to the creation of a Senate Special Committee on Space and Aeronautics on February 6, 1958.[7] After weeks of hearings, Congress passed the National Aeronautics and Space Act on July 29, 1958.[8] An excerpt from the act summarizes the nation's goals: "major objectives of a civil space research program are scientific research in the physical and life sciences, advancement of space flight technology, development of manned space flight capability, and exploitation of space flight for human benefit."[9]

T. Keith Glennan was sworn in as the first administrator of NASA on August 19, 1958.[10] Dwight Eisenhower commented in a letter about the creation of NASA: "These opportunities reinforce my conviction that we and other nations have a great responsibility to promote the

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[5] Garber, Steve. "Sputnik and the Dawn of the Space Age" NASA, nasa.gov, 10 October 2007. https://www.history.nasa.gov/sputnik/ Accessed 8 January 2019

[6] Dick, Steven. "The Birth of NASA" NASA, nasa.gov, 28 August 2008, https://www.nasa.gov/exploration/whyweexplore/Why_We_29.html. Accessed 17 December 2018.

[7] Dick, Steven. "The Birth of NASA" NASA, nasa.gov, 28 August 2008, https://www.nasa.gov/exploration/whyweexplore/Why_We_29.html. Accessed 17 December 2018.

[8] Garber, Steve "National Aeronautics and Space Act of 1958 (Unamended)" NASA, nasa.gov, 29 July 1958. https://history.nasa.gov/spaceact.html Accessed 2 February 2019
The NASA Act highlights the purpose, objectives, functions, guidelines, and other topics that the space agency should oversee.

[9] "Special Committee on Space Technology Report, 1958" NASA, nasa.gov, 1958. https://www.hq.nasa.gov/office/pao/History/report58.html Accessed 6 February 2019.

[10] Dick, Steven. "The Birth of NASA" NASA, nasa.gov, 28 August 2008, https://www.nasa.gov/exploration/whyweexplore/Why_We_29.html. Accessed 17 December 2018.

peaceful use of space and to utilize the new knowledge obtained from space science and technology for the benefit of all mankind."[11]

After the establishment of NASA, the program underwent many stages before space shuttles were developed.[12] In the 1950s Wernher Von Braun created the Von Braun Paradigm, the first time a space shuttle was mentioned.[13] In the 1960s, NASA focused on lunar exploration and landings, while the 1970s focused on using renewable resources and satellites.[14] The shuttle era began with the first space shuttle launch in 1981.[15] Five years later the first space shuttle accident occurred when Challenger plunged into the Atlantic, suspending shuttle launches for almost three years.[16]

From the first launch of Columbia on April 12, 1981, to the last landing of Atlantis on July 21, 2011, the space shuttle program proved to be a key component of NASA's mission.[17] The fleet, comprised of Enterprise, Columbia, Challenger, Discovery, Atlantis, and Endeavor flew a total of 135 missions and helped construct the International Space Station over the thirty-year space shuttle reign. The fleet had many triumphs, such as carrying people into space; launching, recovering, and repairing satellites; conducting research; and building the largest

[11] Eisenhower, Dwight "Letter From President Dwight D. Eisenhower" NASA, nasa.gov, 26 March 1958. https://www.nasa.gov/50th/50th_magazine/ikeLetter.html Accessed 23 January 2019
[12]"NASA Glenn's Historical Timeline" NASA, nasa.gov, 10 July 2018. https://www.nasa.gov/centers/glenn/about/history/timeline.html Accessed 10 January 2019.
[13]Wall, Mike. "How the Space Shuttle Was Born" Space, space.com, 28 June 2011. https://www.space.com/12085-nasa-space-shuttle-history-born.html. Accessed 18 December 2018
[14]"Centaur: America's Workhorse in Space" NASA, nasa.gov, 12 December 2012. https://www.nasa.gov/centers/glenn/about/history/centaur.html. Accessed 21 January 2019
[15] "NASA Glenn's Historical Timeline" NASA, nasa.gov, 10 July 2018. https://www.nasa.gov/centers/glenn/about/history/timeline.html Accessed 10 January 2019.
[16]Garber, Steve and Roger Launius. "A Brief History of NASA" NASA, nasa.gov. https://history.nasa.gov/factsheet.htm Accessed 25 September 2018.
[17] Loff, Sarah "Space Shuttle Era" NASA, nasa.gov, 3 August 2017. https://www.nasa.gov/mission_pages/shuttle/flyout/index.html Accessed 18 September 2018.

space structure. The shuttles broke the boundaries of what was thought possible by becoming the first reusable spacecraft but not without sacrifice, as Gus Grissom knew.[18]

> If we die we want people to accept it. We are in a risky business, and we hope that if anything happens to us, it will not delay the program. The conquest of space is worth the risk of life. Our God-given curiosity will force us to go there ourselves because in the final analysis, only man can fully evaluate the moon in terms understandable to other men.–Gus Grissom[19]

Sadly, Grissom's foresight came true on the Apollo 1 mission, the biggest tragedy before the Challenger. On January 27, 1967, during the Apollo-Saturn mission,[20] a flash fire broke out inside the capsule, killing all three astronauts aboard: Gus Grissom, Ed White, and Roger Chaffee. The Apollo program didn't return to flight until October of 1968.

The Apollo 13 flight nearly became a similar disaster. After multiple systems ruptured causing damage to necessary supplies, Jim Lovell, Jack Swigert, and Fred Haise were stranded in space until engineers could devise a method to bring them down.[21] Apollo 13 Engineer, Gene Kranz, declared: "To recognize that the greatest error is not to have tried and failed, but that in trying, we did not give it our best effort."[22]

The space shuttles became a reality in 1981 when Columbia was launched; Challenger followed soon after. The Challenger was first used as a Structural Testing Vehicle, STA-099.[23] On January 1, 1979 STA-099 was ordered to be converted into the Space Shuttle Challenger,

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[18] Wall, Mike. "How the Space Shuttle Was Born" Space, space.com, 28 June 2011. https://www.space.com/12085-nasa-space-shuttle-history-born.html. Accessed 18 December 2018
[19] Barbour, John, et. al "Footprints on the Moon" The Associated Press, 1969. Accessed 6 February 2019.
[20] Barry, Bill and Steve Garber "A Chronology of Defining Events in NASA History" NASA, nasa.gov 3 January 2012. https://history.nasa.gov/40thann/define.htm Accessed 9 January 2019
[21] Wall, Mike. "How the Space Shuttle Was Born" Space, space.com, 28 June 2011. https://www.space.com/12085-nasa-space-shuttle-history-born.html. Accessed 18 December 2018
[22] Kranz, Gene "Failure is not an Option" Simon and Schuster, 2009. Accessed 6 February 2019
[23] Ryba, Jeanne. "Space Shuttle Overview: Challenger (OV-099) NASA, nasa.gov 12 April 2013. https://www.nasa.gov/centers/kennedy/shuttleoperations/orbiters/challenger-info.html. Accessed 13 October 2018

named after the HMS Challenger, a British naval vessel.[24] Exactly seven years before the tragedy, construction began. The shuttle was finished on October 21, 1981.

Challenger completed nine other missions before the disaster. The maiden voyage, STS-6,[25] was on April 4, 1983, when Story Musgrave, the only person to fly on every shuttle, reached space.[26] After the seventeenth space shuttle mission, engineers discovered both the primary and secondary O-rings were charred or burned through. Engineers decided that since the charred O-rings had not posed a threat to the mission, the only action necessary was to replace them and continue with missions. (See Appendix A)

The Challenger was carrying seven astronauts when it plunged into the Atlantic Ocean on January 28, 1986. Commander Francis Scobee, Pilot Mike Smith, Mission Specialist Judith Resnik, Mission Specialist Ronald McNair, Mission Specialist Ellison Onizuka, Payload Specialist Christa McAuliffe, and Payload Specialist Gregory Jarvis were tragically lost. After the disaster, Buzz Aldrin stated: "As we reflect back upon the tragic loss of Challenger and her brave crew of heroes who were aboard that fateful day, I am reminded that they truly represented the best of us, as they climbed aloft on a plume of propellant gasses, reaching for the stars, to inspire us who were Earthbound."[27]

Francis "Dick" Scobee had been an astronaut for seven years. He served as a fighter pilot

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[24] Ryba, Jeanne. "Space Shuttle Overview: Challenger (OV-099) NASA, nasa.gov 12 April 2013. https://www.nasa.gov/centers/kennedy/shuttleoperations/orbiters/challenger-info.html. Accessed 13 October 2018

[25] Almeida, Andres "Behind the Shuttle Mission Numbering System" NASA, nasa.gov, 5 December 2016. https://www.nasa.gov/feature/behind-the-space-shuttle-mission-numbering-system Accessed 2 February 2019. STS stands for Space Transportation System.

[26] Gebhardt, Steve. "1983-1986 The Missions and History of the Space Shuttle Challenger" NASA, nasaspaceflight.comhttps://www.nasaspaceflight.com/2011/01/1983-1986-missions-history-space-shuttle-challenger / Accessed 24 November 2018

[27] Aldrin, Buzz "In Memoriam- A Rededication to Space" The Huffington Post, 2011. https://www.huffingtonpost.com/buzz-aldrin/n-memoriam-a-rededication_b_815519.html Accessed 18 January 2019

in Vietnam and had a degree in aerospace engineering.[28] Michael Smith became an astronaut in 1981 and flew for the United States Navy.[29] Judith Resnik had been training for seven years, held two degrees in electrical engineering and previously worked as a biomedical engineer.[30] Before NASA employed Ronald McNair in 1979, he worked as a laser radiation scientist.[31] Ellison Onizuka was an astronaut for seven years, was enrolled in active duty with the United States Air Force, and was a distinguished military graduate.[32] Gregory Jarvis was an electrical engineer and had worked in the Air Force previously.[33]

However important these people were, Christa McAuliffe was the star of the show. Never before had anyone heard of a teacher in space.[34] She was chosen from over 1,000 candidates for NASA's Teacher In Space program. The lessons she would have taught in space are still available for teachers today and were taught by Barbara Morgan, McAuliffe's replacement on STS-118, which launched August 8, 2007.[35] Christa McAuliffe famously said, "I touch the future. I teach,"[36] proving McAuliffe's commitment to the education of today's youth.

Challenger had three days of delays due to weather concerns before take-off. The night

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[28] "Biographical Data: Francis Scobee" NASA, nasa.gov, May 2013. https://www.nasa.gov/sites/default/files/atoms/files/scobee_francis.pdf Accessed 22 January 2019.
[29] "Biographical Data: Michael Smith" NASA, nasa.gov, December 2003. https://www.nasa.gov/sites/default/files/atoms/files/smith_michael.pdf Accessed 22 January 2019.
[30] "Biographical Data: Judith Resnik" NASA, nasa.gov, December 2003. https://www.nasa.gov/sites/default/files/atoms/files/resnik_judith.pdf Accessed 22 January 2019.
[31] "Biographical Data: Ronald McNair" NASA, nasa.gov, December 2003. https://www.nasa.gov/sites/default/files/atoms/files/mcnair_ronald.pdf Accessed 22 January 2019
[32] "Biographical Data: Ellison Onizuka" NASA, nasa.gov, January 2007. https://www.nasa.gov/sites/default/files/atoms/files/onizuka_ellison.pdf Accessed 22 January 2019.
[33] "Biographical Data: Gregory Jarvis" NASA, nasa.gov, December 2003. https://www.nasa.gov/sites/default/files/atoms/files/jarvis.pdf Accessed 22 January 2019.
[34] "Biographical Data: Christa McAuliffe" NASA, nasa.gov, April 2007. https://www.nasa.gov/sites/default/files/atoms/files/mcauliffe.pdf Accesed 22 January 2019
[35] "STS-118" NASA, nasa.com, https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-118.html Accessed 6 February 2019.
[36] "Christa McAuliffe Quotes" https://www.brainyquote.com/quotes/christa_mcauliffe_134582 Accessed 24 January 2019

before the launch Morton Thiokol, the company that built the solid rocket boosters (SRB) and O-rings, expressed concerns about the effect of the cold temperatures on the SRB seals.[37] (See Appendix B) At the time, NASA engineers assessed all the data and concluded that the evidence of cold affecting O-ring seals was not strong enough to cause a delay in the launch.[38] (See Appendix C) Alan McDonald, a Morton Thiokol engineer, stated after the disaster: "Don't assume that if it's really critical other people will always do their job."[39]

The Challenger accident was a defining moment in the history of space. On January 28, 1986, the crew was ready for takeoff until ice on the launch pad caused a few hours delay. Finally, at 11:38 AM the crew prepared for takeoff. At seventy-three seconds into the flight, a fiery ball engulfed the shuttle. The crowd kept cheering, not knowing what had happened. Once debris began falling out of the sky, the onlookers realized that something was wrong. First Lady Nancy Reagan reacted in horror to the disaster, "Oh my God, no!"[40]

The tragedy was a huge shock, prompting a Presidential Commission to create the Rogers Commission Report. After investigating eight possible faults, they determined the right solid rocket booster and O-rings caused the accident.[41] O-ring deterioration had caused hot gasses to leak through the joint during the propellant burn of the rocket motor.

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[37] "The Space Shuttle Challenger Disaster" Engineering, engineering.com. 24 October 2006, https://www.engineering.com/Blogs/tabid/3207/ArticleID/170/categoryId/7/The-Space-Shuttle-Challenger-Disaster.aspx. Accessed 22 January 2019

[38] "Challenger Disaster: The 24 hours of prelaunch debate that could have prevented a tragedy" latimes.com 10 June 1986. https://www.latimes.com/science/la-sci-challenger-24-hours-pre-launch-debate-20160128-htmlstory.html Accessed 14 January 2019.

[39] McDonald, Allan "Truth, Lies, and O-rings, Inside the Space Shuttle Challenger Disaster" University Press of Florida, 2009.
Allan McDonald was Morton Thiokol's top official at the launch site of the Challenger.

[40] Magnuson, Ed "Space: They Slipped the Surly Bonds of Earth to Touch the Face of God" Time Magazine. 10 February 1986. http://content.time.com/time/magazine/article/0,9171,960596,00.html Accessed 9 October 2018.

[41] "Rogers Commission Report" NASA, nasa.gov. 6 June 1986. https://spaceflight.nasa.gov/outreach/SignificantIncidents/assets/rogers_commission_report.pdf Accessed 14 January 2019

The events that caused the disaster began almost immediately after the flight commenced. At .678 seconds into the flight, black puffs of smoke originated from the right booster, indicating that hot propellant gasses had burned through joints, grease, and O-rings. The first small flame occurred at 58.788 seconds, and a pressure difference was detected between the right and left rocket boosters at approximately 60.00 seconds. The flames continued growing towards the external tank. At 64.660 seconds, the smoke changed colors, confirming that the fire had breached the fuel tank. Pilot Michael Smith's last recorded words were: "Uh oh."[42]

At seventy-two seconds, many events occurred rapidly that resulted in tragedy. First, the rocket booster and the external tank pulled away, causing the structural failure of the hydrogen tank. Once the hydrogen tank collapsed, tons of liquid hydrogen escaped, creating a sudden forward thrust of 2.8 million pounds, pushing the hydrogen tank into the internal structure. At the same time, the right solid rocket booster hit the intertank structure and the oxygen tank, causing them to fail.[43]

The shuttle crew was most likely conscious until hitting the Atlantic Ocean. This wasn't publicized until years after the disaster, as the crew's families hadn't been informed at the time the report came out.[44] The shuttle disintegrated around the crew cabin, leaving the cabin almost wholly intact. The cabin sailed upwards for three miles, until momentum gave out, plunging the

[42] Almeida, Andres "Behind the Shuttle Mission Numbering System" NASA, nasa.gov, 5 December 2016. https://www.nasa.gov/feature/behind-the-space-shuttle-mission-numbering-system Accessed 2 February 2019.
[43] Rogers, William, et al. "Report to the President By the Presidential Commission On the Space Shuttle Challenger Accident" NASA, nasa.gov 6 June 1986. https://spaceflight.nasa.gov/outreach/SignificantIncidents/assets/rogers_commission_report.pdf Accessed 11 January 2019
Summarization of a longer report.
[44] Scocca, Tom. "Thirty Years Ago, the Challenger Crew Plunged Alive and Aware to Their Deaths" gawker.com. 28 January 2016. https://gawker.com/thirty-years-ago-the-challenger-crew-plunged-alive-and-1755727930. Accessed 18 January 2019

astronauts twelve miles into the sea at 200 miles per hour.[45] The horrifying descent lasted two and a half minutes.[46]

The whole nation was in shock for many days. Never before had we lost seven people from our own country in such a tragic, public disaster. (See Appendix D) President Reagan spoke later that night on television, and three days later at a memorial ceremony, addressing each of the astronauts and their accomplishments: "[they] slipped the surly bonds of Earth to 'touch the face of God.'"[47]

NASA made over one hundred improvements to the space shuttle over the years of service, many a direct result of the Challenger and Columbia disasters.[48] Although all shuttles were grounded until 1989, the space shuttle program triumphed for years after the Challenger tragedy.[49] The right solid rocket booster underwent many changes after the accident. Engineers redesigned the motor, and many new safety features were added. The joint sealing system's redesign included improved metal hardware and a third O-ring. Sally Ride commented: "After the Challenger accident, NASA put in a lot of time to improve the safety of the space shuttle to fix the things that had gone wrong."[50] The aft skirt was modified to increase structural safety, and the attachment ring was redesigned from a 270 degree to a full 360-degree ring. Landing safety

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[45] Bergin, Chris "Remembering the mistakes of Challenger" 28 January 2007. NASA, nasaspaceflight.com https://www.nasaspaceflight.com/2007/01/remembering-the-mistakes-of-challenger/ Accessed 16 February 2019

[46] Scocca, Tom. "Thirty Years Ago, the Challenger Crew Plunged Alive and Aware to Their Deaths" gawker.com. 28 January 2016. https://gawker.com/thirty-years-ago-the-challenger-crew-plunged-alive-and-1755727930. Accessed 18 January 2019

[47] Reagan, Ronald "Explosion of the Space Shuttle Challenger Address to the Nation" NASA, nasa.gov 28 January 1986. https://history.nasa.gov/reagan12886.html Accessed 25 January 2019.
Paraphrased from poem by John Magee, High Flight.

[48] Wright, Mike and Jim Owen "Shuttle Saw Many Improvements Over the Years" NASA, nasa.gov. 14 April 2011. https://www.nasa.gov/centers/marshall/about/star/shuttle_110803.html Accessed 22 January 2019.

[49] Grady, Monica "What the Challenger Disaster Meant for the Race into Space" BBC, 28 January 2016. http://www.bbc.com/future/story/20160128-what-the-challenger-disaster-meant-for-the-race-into-space Accessed 29 November 2018.

[50] Ride, Sally "Sally Ride Interview" Scholastic, 1998. http://teacher.scholastic.com/space/sts7/interview.htm Accessed 8 January 2019

was improved by adding orbiter brakes and nose wheel steering. Also, new crew escape systems were put in place. Engineers added a third O-ring and improved the case field joint. They included a J-leg, a rubber J-shaped piece, to add additional erosion and thermal protection around the O-ring.[51]

After the accident, research began into why the shuttle launched when engineers were adamantly against it. Studies found that management pressure to keep the shuttle program on schedule could have contributed to the minimization of the engineer's concerns.[52] Diane Vaughan believed the main issue was, as she called it, "Normalization of Deviance" in which unacceptable acts slowly become acceptable.[53] In previous launches, erosion of O-rings had not posed a threat to the mission, so there was no reason they should now. The teleconference between NASA and Morton Thiokol brought about many questions of management powers. Morton Thiokol senior official Jerald Mason, who voted for the launch, told a colleague considering a vote against the launch to "take off your engineering hat and put on your management hat."[54]

The disaster not only improved shuttle safety but also NASA's culture and communication standards.[55] There was improved communication between the centers and a plan to make the flight commander part of the flight review process. NASA opted to change the management structure to eliminate the tendency for management isolation. Many other new

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[51] "Sucess Legacy of the Space Shuttle Program" NASA, nasa.gov. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100030545.pdf Accessed 25 January 2019

[52]Prusak, Larry "25 Years After Challenger, Has NASA's Judgement Improved?" Harvard Business Review, hbr.org. 28 January 2011. https://hbr.org/2011/01/25-years-after-challenger-has Acessed 23 January 2019

[53] "Challenger Launch Decision" 27 January 2016. Aerossurance. http://aerossurance.com/safety-management/challenger-launch-decision-30/ Accessed 27 February 2019.

[54]"The Space Shuttle Challenger Disaster" engineering.com 24 October 2006. https://www.engineering.com/Blogs/tabid/3207/ArticleID/170/categoryId/7/The-Space-Shuttle-Challenger-Disaster.aspx Accessed 23 January 2019

[55] Prusak, Larry "25 Years After Challenger, Has NASA's Judgement Improved?" Harvard Business Review, hbr.org. 28 January 2011. https://hbr.org/2011/01/25-years-after-challenger-has Accessed 23 January 2019

positions and procedures ensured smoother communication.[56] For example, NASA placed retired astronauts in management positions to guarantee understanding.[57]

> Ironically, it is only when disaster strikes that the shuttle makes the headlines. Its routine flights attracted less media interest than unmanned probes to the planets or the images from the Hubble Telescope. The fate of Columbia (like that of Challenger in 1986) reminded us that space is still a hazardous environment. -Martin Rees[58]

The STS-199 launch proves that NASA has become much more careful. The launch of Discovery was scheduled for February 19, 2009, and didn't launch until a month later because of safety concerns.[59] NASA now brings in various experts, conducts polls, and looks at all potential dangers and outcomes as well as attempts to involve all workers and opinions for all missions, manned and unmanned.[60]

The Challenger disaster proved that there were many improvements and changes to be made at NASA. From its inception, NASA strove to advance space travel and technology. By initiating the space shuttle program, NASA created a new, unique method of space travel. The Challenger accident was a tragic setback, but caused NASA to rebound and improve, triumphing both in safety standards and culture within the workspace. As the human race looks to the stars, we must remember those who have fallen for our shared cause.

> "The Challenger crew was pulling us into the future, and we'll continue to follow them."
>
> -President Ronald Reagan[61]

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[56] Crane, Rachel and Bryce Urbany. "30th Anniversary: How the Challenger Disaster Changed NASA" CNN Business, 28 January 2016. https://www.cnn.com/2016/01/28/tech/challenger-disaster-space-shuttle-anniversary/index.html Accessed 29 November 2018.

[57] "Success Legacy of the Space Shuttle Program" NASA, nasa.gov. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100030545.pdf Accessed 25 January 2019

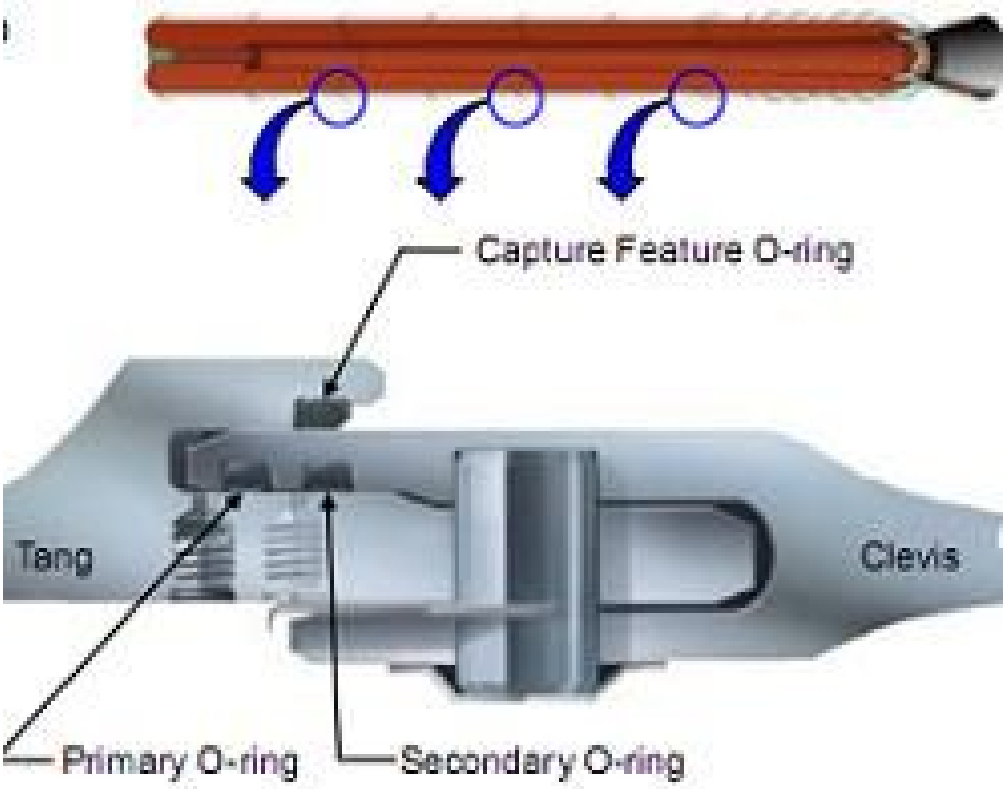
[58] Rees, Martin "This Mission is brought to you by…" The Guardian, 2003. https://www.theguardian.com/science/2003/jul/10/lastword.spaceexploration Accessed 14 December 2018

[59] Prusak, Larry "25 Years After Challenger, Has NASA's Judgement Improved?" Harvard Business Review, hbr.org. 28 January 2011. https://hbr.org/2011/01/25-years-after-challenger-has Accessed 23 January 2019

[60] "Success Legacy of the Space Shuttle Program" NASA, nasa.gov. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100030545.pdf Accessed 25 January 2019

[61] https://history.nasa.gov/reagan12886.html Accessed 24 January 2019

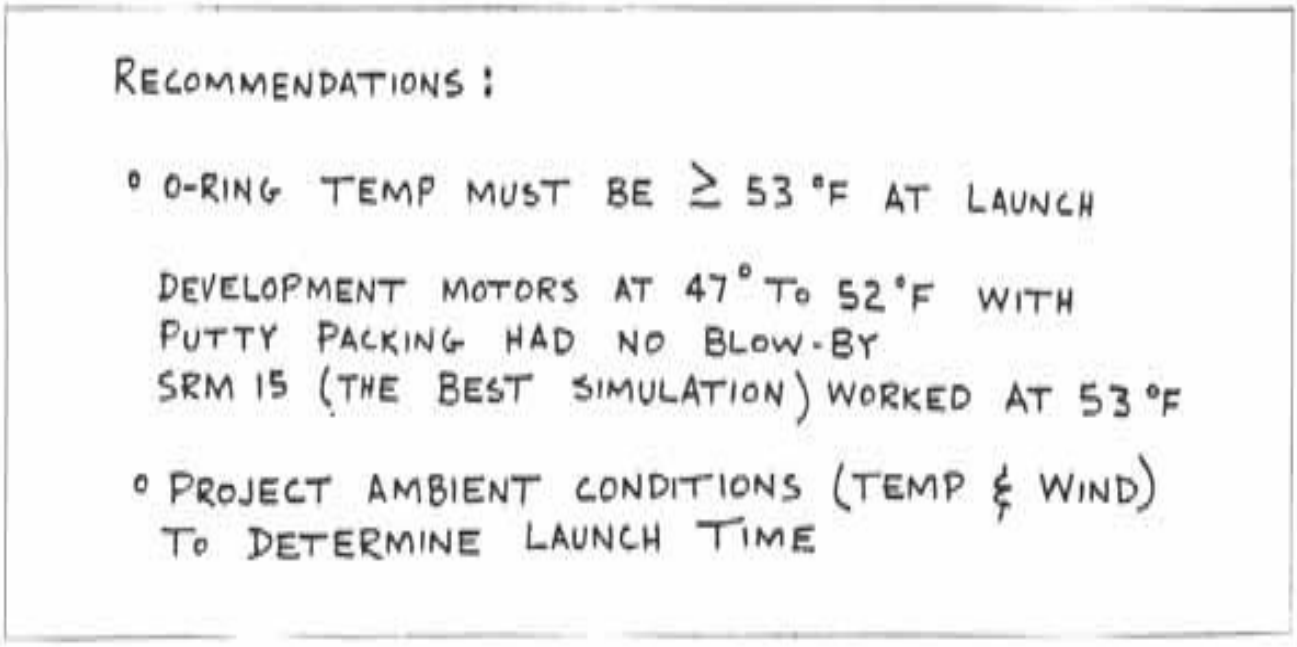
Appendix A



Gebhardt, Chris. “1983-1986 “The Missions and History of the Space Shuttle Challenger” NASA, nasa.gov, https://www.nasaspaceflight.com/2011/01/1983-1986-missions-history -space-shuttle-challenger/ Accessed 3 December 2018

This was an article of all the Challenger’s triumphs before the disaster. The image shows an O-Ring feature and how it should look. This was used as an appendix to show an O-Ring configuration and how it normally looks.

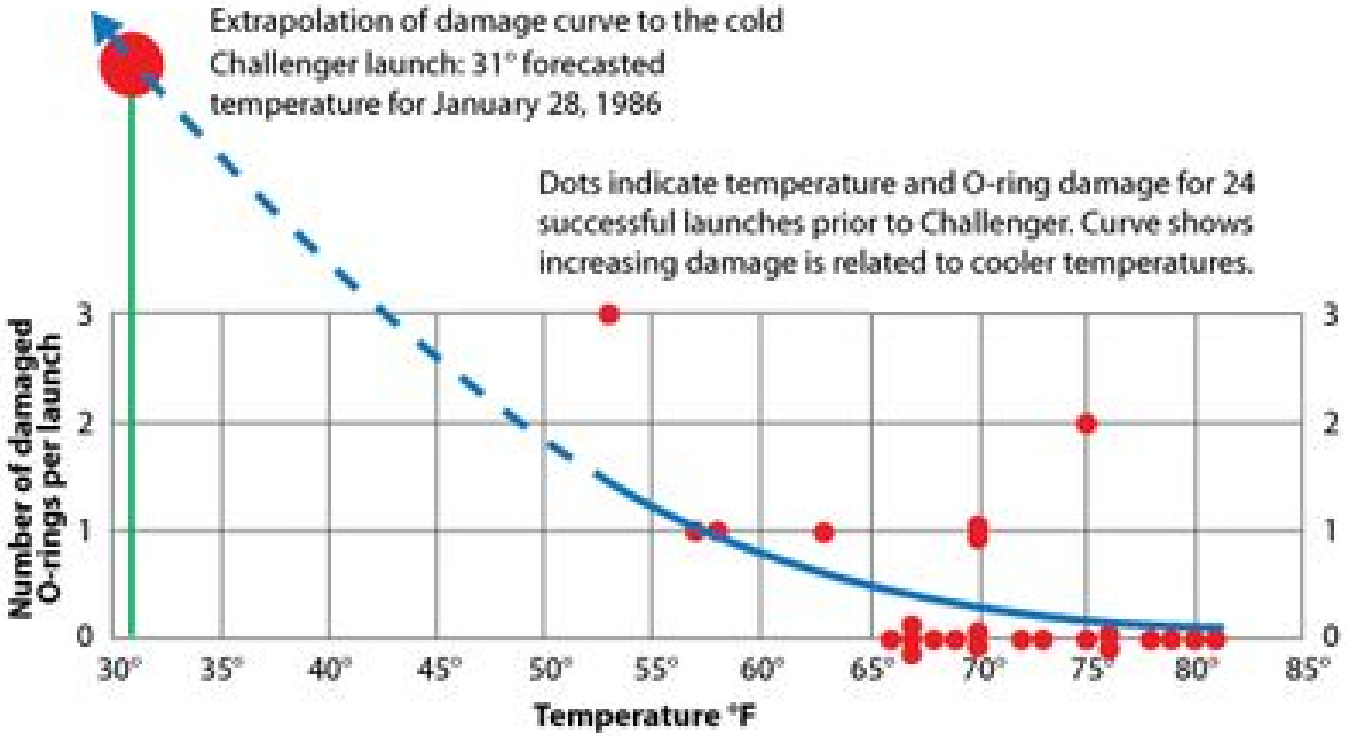
Appendix B



"Challenger Launch Decision" 27 January 2016. Aerossurance. http://aerossurance.com/safety-management/challenger-launch-decision-30/ Accessed 27 February 2019.

This photo specifically shows Morton Thiokol recommendations for launches. This was written long before the debate over whether to launch. When Morton Thiokol created the O-Rings this was their initial launch recommendation. I used this to show that there were cautions against launching in cold weather before the Challenger launch.

Appendix C



Tufte, Edward "Tufte-Challenger Space Shuttle Graph" groups.nceas.ucsb.edu, 28 August 2009 https://groups.nceas.ucsb.edu/monitoring-kb/dot/graphics/Tufte%232ChallengerSpaceShuttleGraph.png/view Accessed 27 January 2019

This was a graph on the Challenger disaster and the air temperature compared to O-ring failures. It shows that O-Rings were less likely to be damaged in warmer weather. I used this to show how the launch should have been postponed because there was no data available to show the effects on the seals.

Appendix D

The New York Times

Late Edition

NEW YORK, WEDNESDAY, JANUARY 29, 1986

THE SHUTTLE EXPLODES

6 IN CREW AND HIGH-SCHOOL TEACHER ARE KILLED 74 SECONDS AFTER LIFTOFF

11:39:13 A.M.

11:39:17 A.M.

Thousands Watch A Rain of Debris

From the Beginning to the End

How Could It Happen? Fuel Tank Leak Feared

After the Shock, a Need to Share Grief and Loss

Reagan Lauds 'Heroes'

Broad, William "The Shuttle Explodes" New York Times. 28 January 1986. http://archive.nytimes.com/www.nytimes.com/learning/general/onthisday/big/0128.html#article Accessed 15 November 2018.

This was a newspaper article from the day of the disaster. The article discussed the astronauts and statistics about the disaster. No cause had been determined at the time of this article. I used this article to show what the time was like and how people were reacting to the disaster.

Annotated Bibliography

Primary Sources

Aldrin, Buzz "In Memoriam- A Rededication to Space" The Huffington Post, 2011. https://www.huffingtonpost.com/buzz-aldrin/n-memoriam-a-rededication_b_815519.html Accessed 18 January 2019

This was an article that Buzz Aldrin wrote in remembrance of the Challenger astronauts. I learned more about the loss of the Challenger and how people reacted to it. I used a quote about remembering them and their sacrifices to show how other astronauts reacted to the disaster.

"Special Committee on Space Technology Report, 1958" NASA, nasa.gov, 1958. https://www.hq.nasa.gov/office/pao/History/report58.html Accessed 6 February 2019.

This was a report on space and creating a space agency from the time NASA was established. I learned about the NASA Act and what they wanted to be accomplished by this agency. I used a quote from this paper that highlighted the goals of such an agency. I chose this quote because it ties in the space shuttles to the NASA dream of space travel.

Broad, William "The Shuttle Explodes" New York Times. 28 January 1986. http://archive.nytimes.com/www.nytimes.com/learning/general/onthisday/big/0128.html#article Accessed 15 November 2018.

This was a newspaper article from the day of the disaster about the disaster. This article helped me to understand the tragedy that our country went through. I used this article mostly for background knowledge but I also used the image of the front page for an appendix. I used this image as an appendix because it shows what our country was going through at the time.

Barbour, John, et. al "Footprints on the Moon" The Associated Press, 1969. Accessed 6 February 2019.

This book was by John Barbour, a reporter. I used a quote from it in my paper to highlight the astronaut's thoughts of death during the space program. The quote I used was by Gus Grissom, an astronaut who died in the space program.

Eisenhower, Dwight "Letter from President Dwight D. Eisenhower" NASA nasa.gov, 26 March 1958. https://www.nasa.gov/50th/50th_magazine/ikeLetter.html Accessed 23 January 2019

This source was a letter from President Eisenhower on the creation of NASA. I learned how the president felt about the creation of NASA and what he hoped would be accomplished by NASA. I used a quote that discusses President Eisenhower's vision for space. I chose this quote because it showed what the United States hoped to gain from space.

Garber, Steve "Transcript of the Challenger Crew Comments From the Operational Recorder" NASA, nasa.gov, 3 February 2003. https://www.hq.nasa.gov/office/pao/History/transcript.html Accessed 2 February 2019

This was the official transcript of all that was said between headquarters and the Challenger the day of the disaster. I used it to learn more of what went on directly prior to the disaster. I used a quote from it that was the last words of Pilot Michael Smith. I chose this quote because it proves that nothing was planned to happen and the crew was also completely unprepared, which helps us today understand the disaster better.

Garber, Steve "National Aeronautics and Space Act of 1958 (Unamended)" NASA, nasa.gov, 29 July 1958. https://history.nasa.gov/spaceact.html Accessed 2 February 2019

This was the NASA act of 1958 that authorized the creation of NASA. I used it to learn About the creation of NASA and the conditions on which it was created. This was used in my paper to talk about the creation of NASA.

Kranz, Gene "Failure is not an Option" Simon and Schuster, 2009. Accessed 6 February 2019

This was a book by Gene Kranz. I used a quote from Gene Kranz in the book to show an engineers opinion on working inside NASA, especially after Kranz worked on the Apollo mission. I learned more about what it would be like to work with NASA and an engineers view on what goes on inside NASA.

Roylance, Frank "'Right stuff' old stuff to him 'I love space': A 29-year astronaut, Dr. Story Musgrave at 61 will be the oldest human to fly in space when Columbia takes off in November." The Baltimore Sun, 1996. https://www.baltimoresun.com/news/bs-xpm-1996-04-26-1996117050-story.html Accessed 22 January 2019

This was an article about Story Musgrave, the only man to fly on every shuttle. I learned about how the tragedy affected other astronauts. I used this quote in my paper to show how others felt about the disaster. The quote was about how tragedy helped to propel others.

Ride, Sally "Sally Ride Interview" Scholastic, 1998. http://teacher.scholastic.com/space/sts7/interview.htm Accessed 8 January 2019

This was an article where Sally ride answered reader questions. I learned about an astronaut's view of space and tragedies and other areas of work. I used a quote from her, that talked about the changes to shuttles after the disaster. I chose this quote because it helped to prove my point because an astronaut herself was saying the same thing I was.

Rees, Martin "This Mission is brought to you by…" The Guardian, 2003. https://www.theguardian.com/science/2003/jul/10/lastword.spaceexploration Accessed 14 December 2018

This article was about Martin Rees's perspective on space. I used it to learn of a different perspective of space and what NASA does. I used a quote from it that talked about space flight and disasters. I used this quote because it brings attention to how we never know what could happen.

Magnuson, Ed "Space: They Slipped the Surly Bonds of Earth to Touch the Face of God" Time Magazine. 10 February 1986. http://content.time.com/time/magazine/article/0,9171,960596,00.html Accessed 9 October 2018.

This was a newspaper article from the time of the disaster. I learned about how the public reacted to the disaster and how the disaster was dealt with. I used a quote of the first lady's reaction to show the reaction most people had. I also used the article for information within my paper.

McDonald, Allan "Truth, Lies, and O-rings, Inside the Space Shuttle Challenger Disaster" University Press of Florida, 2009.

This was a book written by Allan McDonald, the Morton Thiokol official. I used his quote about people doing their part in my paper to show that not everyone had an equal say in the launch decision.

Reagan, Ronald "Explosion of the Space Shuttle Challenger Address to the Nation" NASA, nasa.gov 28 January 1986. https://history.nasa.gov/reagan12886.html Accessed 25 January 2019.

This was President Reagan's address to the nation after the disaster. I learned more about what had happened from the perspective of the people. I used quotes from it about the shuttle crew and continuing the space race to show that many people were affected and that the US would rebound from the tragedy and keep moving forward.

Rogers, William, et al. "Report to the President By the Presidential Commission On the Space Shuttle Challenger Accident" NASA, nasa.gov 6 June 1986.

https://spaceflight.nasa.gov/outreach/SignificantIncidents/assets/rogers_commission_report.pdf Accessed 11 January 2019

This was the official report on the Challenger Accident. I used it to learn about the cause of the accident. I also learned about how management pressure was a part of the launch decision. I used it in my paper to write about the cause of the accident and management pressure.

Secondary Sources

Almeida, Andres "Behind the Shuttle Mission Numbering System" NASA, nasa.gov, 5 December 2016. https://www.nasa.gov/feature/behind-the-space-shuttle-mission-numbering-system Accessed 2 February 2019.

This article helped me to understand the way shuttle launches were organized. I used it to build background knowledge and learn more so I can answer questions more accurately. I used it in my paper to talk about launches of shuttles more accurately.

Barry, Bill and Steve Garber "A Chronology of Defining Events in NASA History" NASA, nasa.gov 3 January 2012. https://history.nasa.gov/40thann/define.htm Accessed 9 January 2019

This source was an article about the first 40 years of NASA. I used it to learn about other space disasters or near-disasters. I used this to write about how NASA rebounded from the other disasters and to show that there were other issues before Challenger.

Bergin, Chris "Remembering the mistakes of Challenger" 28 January 2007. NASA, nasaspaceflight.com https://www.nasaspaceflight.com/2007/01/remembering-the-mistakes-of-challenger/ Accessed 16 February 2019

This was an article on the decision to launch. I used it to learn more about the disaster from a NASA and Morton Thiokol prospective. I wrote about the management powers and how NASA changed dramatically in culture around the workspace.

"Biographical Data: Francis Scobee" NASA, nasa.gov, May 2013. https://www.nasa.gov/sites/default/files/atoms/files/scobee_francis.pdf Accessed 22 January 2019.

This was an article on Francis Scobee, captain of the Challenger. I learned about Scobee and his life before becoming an astronaut. I used it in my paper to write about him and his accomplishments before the disaster.

"Biographical Data: Michael Smith" NASA, nasa.gov, December 2003. https://www.nasa.gov/sites/default/files/atoms/files/smith_michael.pdf Accessed 22 January 2019.

This source was about biographical data on Michael Smith, the pilot. I learned about how he became an astronaut and ended up on that shuttle. I used it to write about how Smith got to where he was when the Challenger took off.

"Biographical Data: Gregory Jarvis" NASA, nasa.gov, December 2003. https://www.nasa.gov/sites/default/files/atoms/files/jarvis.pdf Accessed 22 January 2019.

This source was a biography on Gregory Jarvis. I learned about how he became part of NASA and what he had done before the Challenger. I wrote about how he became part of the Challenger crew and what he did before becoming an astronaut.

"Biographical Data: Judith Resnik" NASA, nasa.gov, December 2003. https://www.nasa.gov/sites/default/files/atoms/files/resnik_judith.pdf Accessed 22 January 2019.

This was biographical data on Judy Resnik. I used it to learn about her life before she became an astronaut. I wrote about how she came to NASA and what she worked on before she became an astronaut.

"Biographical Data: Ellison Onizuka" NASA, nasa.gov, January 2007. https://www.nasa.gov/sites/default/files/atoms/files/onizuka_ellison.pdf Accessed 22 January 2019.

This article was all about Ellison Onizuka. I learned about his previous accomplishments and how he became involved with NASA. I wrote about how he came to NASA and what he did before becoming an astronaut.

"Biographical Data: Ronald McNair" NASA, nasa.gov, December 2003. https://www.nasa.gov/sites/default/files/atoms/files/mcnair_ronald.pdf Accessed 22 January 2019

This source was an article about Ron McNair. I learned about McNair and what he did before becoming an astronaut. I wrote about his previous experiences and what he did before coming to work with NASA.

"Biographical Data: Christa McAuliffe" NASA, nasa.gov, April 2007. https://www.nasa.gov/sites/default/files/atoms/files/mcauliffe.pdf Accessed 22 January 2019

This was a biography on Christa McAuliffe. I used it to learn about who McAuliffe was before she became part of NASA's teacher in space program. I learned about where she went to school and how she became part of NASA.

"Centaur: America's Workhorse in Space" NASA, nasa.gov, 12 December 2012. https://www.nasa.gov/centers/glenn/about/history/centaur.html. Accessed 21 January 2019

This source was about the rocket that the Challenger flew on. It helped me learn about rockets and how they are used and improved. I used it to write about the background and how Challenger was linked to earlier developments.

"Challenger Disaster: The 24 hours of prelaunch debate that could have prevented a tragedy" latimes.com 10 June 1986. https://www.latimes.com/science/la-sci-challenger-24-hours-pre-launch-debate-20160128-htmlstory.html Accessed 14 January 2019.

This article contained all the information necessary about the debate of whether to launch. I learned more about how management staff overruled the concerns of the engineers. I used this in my paper when talking about the different culture and the activity that went on before launch.

"Challenger Launch Decision" 27 January 2016. Aerossurance. http://aerossurance.com/safety-management/challenger-launch-decision-30/ Accessed 27 February 2019.

This article discusses the decision to launch and why the NASA managers went ahead with the launch. I learned about unfair ideas and dominating positions. I used it to argue my point of why the managers agreed even with the risks.

Crane, Rachel and Bryce Urbany. "30th Anniversary: How the Challenger Disaster Changed NASA" CNN Business, 28 January 2016. https://www.cnn.com/2016/01/28/tech/challenger-disaster-space-shuttle-anniversary/index.html Accessed 29 November 2018.

This was an article on how the Challenger affected NASA. I used it to learn more about the disaster and how it changed the way we look at space. I used it in my paper to show how NASA changed the structure of communication and jobs and many other areas so that a disaster like Challenger can be prevented.

Dick, Steven. "The Birth of NASA" NASA, nasa.gov, 28 August 2008, https://www.nasa.gov/exploration/whyweexplore/Why_We_29.html. Accessed 17 December 2018.

This was an article on the creation of NASA. I learned about what sparked NASA to be created and why it was created in such a hurry. I used this for background knowledge. I wrote about the creation of NASA and Sputnik in my paper using this and some other resources.

Garber, Steve. "Sputnik and the Dawn of the Space Age" NASA, nasa.gov, 10 October 2007. https://www.history.nasa.gov/sputnik/ Accessed 8 January 2019

This source was all about how the creation of a Russian satellite spurred the creation of NASA. I learned about Sputnik and its launches and how the US was scared because of it. I used this article in my paper to write about Sputnik and how it impacted the USA and what our vision was for a space program.

Garber, Steve, and Roger Launius. "A Brief History of NASA" NASA, nasa.gov. https://history.nasa.gov/factsheet.htm Accessed 25 September 2018.

This was an article about NASA and what they do. I learned about major events that caused NASA to advance more and other projects that were undertaken in the years of NASA. I used this in my paper to talk about NASA history and also to talk about the space shuttles and what they meant for NASA in the years to come.

Gebhardt, Chris. "1983-1986 "The Missions and History of the Space Shuttle Challenger" NASA, nasa.gov, https://www.nasaspaceflight.com/2011/01/1983-1986-missions-history -space-shuttle-challenger/ Accessed 3 December 2018

This was an article of all the Challenger's triumphs before the disaster. I learned a lot more about the space shuttle and what it was doing before the disaster. I used this to write about the transition from a testing vehicle to a shuttle. I also used a photo from this article as an appendix. I chose this photo of an O-Ring structure because it helps to show how and what an O-ring looks like and works.

Grady, Monica "What the Challenger Disaster Meant for the Race into Space" BBC, 28 January 2016. http://www.bbc.com/future/story/20160128-what-the-challenger-disaster-meant-for-the-race-into-space Accessed 29 November 2018.

This was an article on how the disaster impacted space travel. I learned about what the Challenger meant for the future of space travel and how NASA was rebounding and trying to learn and fix issues. I used this article to discuss how the shuttle program moved on after the tragedy.

Loff, Sarah “Space Shuttle Era” NASA, nasa.gov, 3 August 2017. https://www.nasa.gov/mission_pages/shuttle/flyout/index.html Accessed 18 September 2018.

This was an article on the space shuttle program and what it accomplished. I learned more about all the shuttles and what they had accomplished during their time. I used this to show how the shuttle had been a key part to NASA achieving their goals.

“NASA Glenn’s Historical Timeline” NASA, nasa.gov, 10 July 2018. https://www.nasa.gov/centers/glenn/about/history/timeline.html Accessed 10 January 2019.

This article was about what NASA did leading up to the 21st century. I learned a lot about activities within NASA and what NASA focused on before the space shuttles. I used this to write background on NASA and what went on before the shuttles so my paper allowed the reader to learn more about NASA overall.

Obery, James “Space Exploration” World Book Chicago: World Book 2000. 695-729. Print.

This was an encyclopedia article on space exploration. I learned about space in general and what had happened regarding space pre 21st century. I used this source to talk about the launch of Sputnik and what it meant for the USA and the race for space.

Prusak, Larry “25 Years After Challenger, Has NASA’s Judgement Improved?” Harvard Business Review, hbr.org. 28 January 2011. https://hbr.org/2011/01/25-years-after-challenger-has Accessed 23 January 2019

This was an article on everything that the Challenger changed at NASA. I learned about improvements to the shuttles and also improvements to the culture of the workplace. I used this to write about management pressure causing the shuttle to launch, new communication standards, and the later launch of Discovery.

Ryba, Jeanne. “Space Shuttle Overview: Challenger (OV-099) NASA, nasa.gov 12 April 2013. https://www.nasa.gov/centers/kennedy/shuttleoperations/orbiters/challenger-info.html. Accessed 13 October 2018

This was an article on the transition from a vehicle to a space shuttle. I learned about the Challenger and how it was transformed into the Challenger. I used this to write about the transition from a testing vehicle to a shuttle. This article was very useful because every change that was made on the Challenger was dated.

Scocca, Tom. “Thirty Years Ago, the Challenger Crew Plunged Alive and Aware to Their Deaths” gawker.com. 28 January 2016.

https://gawker.com/thirty-years-ago-the-challenger-crew-plunged-alive-and-1755727930. Accessed 18 January 2019

This article was about how the Challenger crew was conscious until impact. I learned about how the crew died and why most of the public does not know of this astounding detail. I used this to write about the explosion and aftermath and about the choices NASA made regarding the disaster.

"STS-118" NASA, nasa.com, https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-118.html Accessed 6 February 2019.

This was an article on the launch of STS-118 in which Barbara Morgan flew. I learned about McAuliffe's replacement and how the flight went. I used it to write about how NASA came back and still followed through with a teacher in space.

"Success Legacy of the Space Shuttle Program" NASA, nasa.gov. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100030545.pdf Accessed 25 January 2019

This was a slideshow about the improvements to the shuttles and NASA. I learned a lot about what exactly was improved after the Challenger and then after the Columbia disaster. I used this to prove that the disaster had not only an impact on safety measures but also cultural standards at NASA.

"The Space Shuttle Challenger Disaster" engineering.com 24 October 2006. https://www.engineering.com/Blogs/tabid/3207/ArticleID/170/categoryId/7/The-Space-Shuttle-Challenger-Disaster.aspx Accessed 23 January 2019

This article had overall information on the disaster. I learned more information about the disaster and the launch debate. I used the article to write about the people involved in the debate. I also used a quote about management staff dominating the decision and making other engineers change their vote. I used this to show the issues with how NASA was set up at the time.

Tufte, Edward "Tufte-Challenger Space Shuttle Graph" groups.nceas.ucsb.edu, 28 August 2009 https://groups.nceas.ucsb.edu/monitoring-kb/dot/graphics/Tufte%232ChallengerSpaceShuttleGraph.png/view Accessed 27 January 2019

This was a graph on the Challenger disaster and the temperature compared to O-ring failures. I learned that cooler temperatures are linked to O-Ring failures. I used this graph as an appendix to prove the data correlation between seals and cool temperatures.

Wall, Mike. “How the Space Shuttle Was Born” Space, space.com, 28 June 2011. https://www.space.com/12085-nasa-space-shuttle-history-born.html. Accessed 18 December 2018

This article was about the timeline of the space shuttle program. I learned about how the the shuttle was created and who helped in that vision. I used this to talk about the background on the shuttle program, the risks involved, and who was involved in creating the shuttle.

Wright, Mike, and Jim Owen “Shuttle Saw Many Improvements Over the Years” NASA, nasa.gov. 14 April 2011. https://www.nasa.gov/centers/marshall/about/star/shuttle_110803.html Accessed 22 January 2019.

This article was about the changes in the space shuttle throughout the years. I learned about improvements that were in direct correlation with the Challenger disaster. I used this to write about the changes and to prove my point that the Challenger improved NASA in many ways.