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Introduction

NASA's many successful launches of the Space Shuttle were defining moments for engineering and science during the 20th century. Fresh from the space race and the cold war, America's space program was a big source of pride and patriotism. A result of this enthusiasm was the design of the first semi-reusable spacecraft. The Columbia and Challenger Series were the first instalments of the space shuttle program, which first launched on April 12th 1981 (Sharp, 2017). The incentive for the US to continue launching spacecraft was high as it was allowing them to establish superiority over Russia in space and was keeping their citizens content after the Vietnam War. Although the shuttle was not flawless, it was one of the most iconic inventions of the 20th century and illustrated to the world the possibilities of space travel. The story behind its design and the tragic failure of The Challenger Shuttle contain fundamental lessons for engineers, leaders and all. Analysing these lessons under the lens of a 21st century engineer will aid in understanding how to avoid mistakes and help to stress the importance of following proper design protocol. Reflecting on these events and the various coursework I have completed over the past few months will compliment my journey in becoming an engineer and allow me to learn from my own and others' mistakes.

NASA's Space Shuttle

Needs

The engineering design process begins with identifying a problem and the needs of various stakeholders (Barrie, 2021). The engineers at NASA were given a barrage of needs to meet when designing the Space Shuttle; it was meant to be the ideal design that was the backbone to the USA's space program (Wild, 2013). The main aim of the Space Shuttle was to transport large payloads such as satellites and other equipment into orbit . The transportation of the Hubble Space Telescope and the construction of the International Space Station being two of the many feats achieved with the Space Shuttle (Wall, 2011). In addition to large payloads, NASA was tasked with establishing a dominant US presence in space- through multiple launches which wouldn't have been possible without the advent of reusable spacecraft. The US government needed proof that NASA could deliver results so were very lenient with their budgeting. This semi-reusability allowed NASA to save money and continue refuelling their relatively small budget back into the space program. Although the cost was reduced by reusing the spaceplane, the cost of developing a space shuttle was still immense- around \$3.2 billion per unit (Los Angeles Times, 1986). Although NASA had a budget, the US Government did not have anywhere to outsource their plans to. So reducing cost was more of a wish rather than a want in that regard.

Research, Brainstorming and Prototyping

There was not much research or ideating needed during the designing of the Space Shuttle. The idea of the aerospace-plane had already been fully developed during secret military reconnaissance projects between the US Air Force and NASA (Wall, 2011). The initial idea was found in Nazi documents, which were seized by the US after World War 2 (WW2), that planned to bomb New York. All that was left for NASA was to tweak the design, build it and

test it. Additionally, following the arms race's craze over ballistic missile based arms during WW2, there was not much decision making necessary when choosing the method of propulsion for the spaceplane. The Space Shuttle was therefore not used for its intended purpose and alternative ideas were not considered thoroughly. The Space Shuttle was an idea from the 1930s but the NASA engineers were placed under severe time constraints to produce a craft that could get the ambitious space plans of the USA into action. As a result, NASA hastily built the prototype Enterprise Shuttle which made several glide flights. After these test flights in 1977, NASA successfully launched the Columbia Space Shuttle into orbit during 1981 (Wall, 2021). No one knows how different space travel would be if the NASA engineers were given more time, funding and freedom to explore different ideas.

Implications

Placing the engineers under such pressure was not exactly ethical but the USA needed to prove its status as one of the world leaders after their loss during the Vietnam war and after Russia launched the first satellite and first successful manned space flight. Ultimately, being funded by the US government meant that their intense schedule, needs and wants held priority over a lengthy and thorough design process. The Space Shuttle could be argued to be a market pulled invention, where the US Government was the main stakeholder and customer, and NASA was the producer. In the end the harsh time restrictions and pressure placed on NASA resulted in the Challenger Space Shuttle crashing in 1986. Groupthink also played a large role in the crash; the desire to keep the excitement and joy of continual launches overrode the ethical judgement of many parties involved- causing the launch to go as planned even though warnings were evident (Teitel, 2021). Considering the time constraints placed on the engineers, it is understandable that the final design of the shuttle was not very sustainable or environmentally friendly. Reusing the shuttle itself did not save much as the majority of cost was in the boosters and main rockets which could only be used once. The NASA engineers initially planned to reuse the main engine but were restricted by time and finance. Instead of having a singular advanced engine that they could reuse, the engineers had to include the two solid boosters to the main engine which was what fundamentally led to the failure of the Challenger Shuttle. Using the additional boosters also meant that none of the propulsion systems could be reused; which severely decreased the sustainability of the Shuttle (Tate, 2016).

SpaceX's Starship

Comparing the Space Shuttle to a 21st century equivalent reveals how engineers approach the problem differently. SpaceX sought to design a spacecraft that could transport large payloads into orbit in a similar fashion to the space shuttle. Their response was the Starship. Separated into two stages, both the Starship and its booster are fully reusable- a similar set up to the one the NASA engineers initially wanted to make. Having the advantage of more developed computing, SpaceX is able to land their vehicles back on their launch pads or drone ships, which is more environmentally friendly and sustainable. The Starship is also severely cheaper than the Space Shuttle costing only \$750 million per unit (Mook, 2021). This results from further research into composites and other developments in space systems research. However, the majority of the financial sustainability lies within manufacturing of components; which SpaceX do by themselves. In addition to increased sustainability, a fully assembled Starship can transport more than 100 tonnes of payload to low earth orbit and, theoretically, beyond to the Moon or Mars (Berger, 2021). The Space Shuttle in comparison could only launch around 30 tonnes into orbit and likely not much

further (NASA, 2021). Through thorough testing of their software and hardware, SpaceX has been able to tweak the Starship numerous times. This is key to any successful space program or efficient design. More testing leads to a more refined end product. NASA did not have the privilege or freedom that SpaceX does. SpaceX does not need to meet many needs or wants as it is a private company. This means that external stakeholders and customers do not have much say in design and operations.

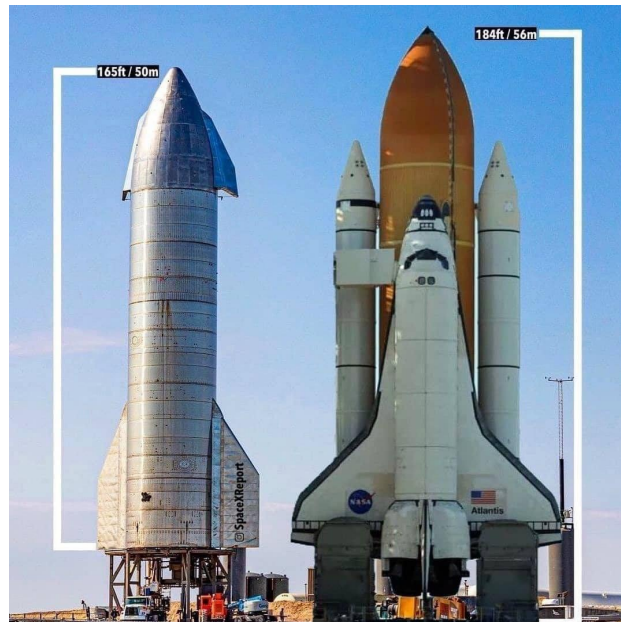


Figure 1: Side by side comparison of SpaceX's Starship and NASA's Space Shuttle

A result of the company almost going bankrupt numerous times, is them being very stringent with cost and stressing reusability (Vance, 2015). The majority of all their launches have been recovered and they continue to stress the importance of reusability in their Mission Statement. SpaceX has essentially been designing the Starship since its launch of the Falcon 1. The Starship is an amalgamation of the knowledge and testing that SpaceX has gained from years of success and failures in launching and landing their various vehicles (Berger, 2021).

Conclusion

The Space Shuttle achieved numerous feats while it was operational. Although its name was tarnished by the two crashes, it served its purpose and during the infancy of early space exploration, can be considered a somewhat successful design. SpaceX have shown the efficacy of the design process; given ample time, freedom and opportunity to test multiple designs, a refined design and protocol can be found. SpaceX has benefited from being a private company. The numerous crashes and failures during their early years have helped to make them the efficient leader of space flights that they are today (Berger, 2021). Having external stakeholders that have a large say in operations can hinder the design process. The design of the Space Shuttle and the subsequent crash of the Challenger illustrate the importance of not over restricting engineers, proper protocol and communication between engineers and their leaders.

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