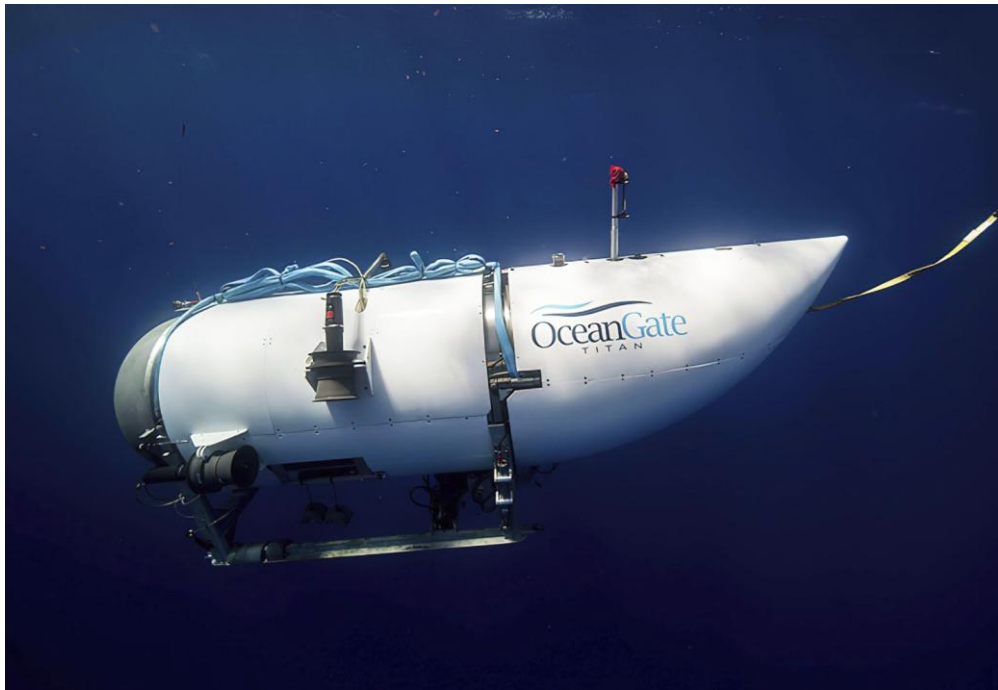


OceanGate Titan Submersible Implosion



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Abstract

Many people dream of exploring and expeditions to learn more about the great unknowns in our world. Stockton Rush was one of these men who dreamt of these great explorations and decided he was going to start pursuing his dream. Fascinated by the tragic sinking of The *Titanic*, a “British luxury passenger liner that sank on April 14–15, 1912, during its maiden voyage, en route to New York City from Southampton, England, killing about 1,500 passengers and ship personnel [10].” With that being said he started his own privately funded company OceanGate Inc in 2009. Their headquarters were located on the west-coast in Everett, Washington. Their company was successful for some time in the role of providing manned submarines for research, commercial, and industrial purposes. The company however ceased all operations on July 6th, 2023, until further notice, due to a catastrophic implosion that occurred involving their Titan I submersible. Tragically this incident claimed the lives of all five members on board the submersible at the time.

Introduction

OceanGate Inc was a company that specialized in the realm of deep-sea exploration. They provided access to manned submersibles for a multitude of reasons such as industrial, commercial, and research. The company was privately owned and was founded by Stockton Rush, a man who wanted to discover the undiscovered of the ocean. A very ambitious man he was, often pushing boundaries for these explorations yet at the cost of up-to-date safety standards and testing. Stockton’s background before swapping jurisdictions to the sea was the sky. He graduated from Princeton in 1984 with a degree in aerospace engineering and proceeded to earn his MBA from UC Berkeley in 1989 [13].

OceanGate had a submersible fleet of three total submersible pods, all capable of holding five crew members/passengers. The first submersible, Antipodes, was capable of traveling to only a depth of about 1,000 feet. Later on in 2012, Rush decided it was time to expand the OceanGate submersible and they proceeded to obtain Cyclops I. This submersible was also only capable of traveling to a depth of 1,640 feet, yet Cyclops I was meant to be a prototype for OceanGate’s main member [3]. Stockton proceeded to commission the construction of his newest project and his most ambitious one yet. He was obsessed with the shipwreck of the late *Titanic*, and wanted to create a submarine that he could use to take himself down to the wreckage. The *Titanic* remains lay almost 12,500 feet below sea level. A submersible attempting to reach these depths must be capable of withstanding the immense amount of pressure experienced when diving to those levels. Stockton’s newest toy, Titan, would be capable of making his dreams of reaching the wreckage a reality.

The Titan Submersible

The Titan submersible was composed of two titanium endcaps, one equipped with an acrylic window, held together on the ends of a filament wound carbon fiber reinforced epoxy hull. The inside cabin of the submersible was a very simplistic design. There were a couple monitors inside that were fed data and video footage from cameras installed on the outside of the vessel. The driving force for Titan came from 4 electronic thrusters placed on the outside of the vessel, that were ironically controlled using a Logitech F7 10 remote controller, which is primarily used for video gaming. Although not a major factor in the Titan’s downfall, it is still a cause for concern as the safety rating/testing standards simply are not comparable for a device being used to entertain humans while lounging at home and the other

to dive to depths of over 12,500 feet below sea level [4]. Titan was engineered to be capable of reaching depths over 13,000 feet below sea level, where it would experience nearly 6,000 pounds per square inch [3].

Although, Titan was not always a success, according to the New York Times, who referred back to old *GeekWire* articles, “The company first planned a voyage to the *Titanic* in 2018, according to the technology news site *GeekWire*, but the Titan sustained damage to its electronics from lightning. Then, in 2019, the voyage was postponed again because of a problem with complying with Canadian maritime law limitations on foreign flag vessels, according to *GeekWire*. Before the first successful trip to the *Titanic* in 2021, the Titan was “rebuilt,” according to *GeekWire*, after tests showed signs of “cyclic fatigue” that reduced the hull’s depth rating to 3,000 meters [3].” Eventually, the Titan submersible was a success! According to the OceanGate website, the final vessel ended up weighing 23,000 pounds, could dive to depths of up to 13,100 feet, and could support a five-man crew for up to 96 hours [5]. OceanGate who originally wanted to start sending commercial voyages to the *Titanic* in 2017 for the cost of \$105,129 per seat, finally started to run commercial tours using their newest vessel starting in 2021. Anybody who wanted to go, was able to go, if you could afford the massive price tag [10]. If it was not expensive enough before, shortly after sending the first voyages out, OceanGate quickly raised their prices and began charging upper-class civilians \$250,000 for a round trip in Titan to view the *Titanic* ship wreckage almost 12,500 feet below sea level [10]. OceanGate proceeded to attempt expeditions for the time being, however, many trips ended up coming up short, literally. Many of Titan’s attempts are canceled or aborted, a common trend amongst OceanGate, until Titan experienced a catastrophic failure on the morning of June 18th, 2023 [4].

Titan’s Final Voyage

Below, this section references the article ‘*Titan Submersible: Timeline of Vessel’s Voyage*’ written and published by The Guardian, which can be sourced through the reference section as number **11**. The article goes through the day Titan met its untimely fate that summer morning. Sadly, the wreck claimed all lives on board, those being Stockton Rush, the CEO himself, Hamish Harding, who was a British businessman, pilot, and space tourist, Paul-Henri Nargeolet, a French diver, and *Titanic* researcher, and the final two being a father-son duo, Shahzada Dawood, a British-Pakistani businessman, and his college aged son Suleman Dawood [7]. For context, the voyage begins with a trip on the *Polar Prince*, this vessel would transport the Titan Submersible from St. Johns, Newfoundland out to the wreck site, where the sub is offloaded and begins to commence its dive. The final Titan voyage timeline begins on...

Friday, June 16th, 2023: The Expedition sets off with OceanGate’s Titan submersible riding the back of the *Polar Prince*. The *Polar Prince* serves as the command center for Titan, as they transmit communications back and forth between the towing vessel and the sub during the dive.

Saturday, June 17th, 2023: Hamish Harding, one of the members set to embark on the unlucky dive posted to Facebook, “Due to the worst winter in Newfoundland in 40 years, this mission is likely to be the first and only manned mission to the *Titanic* in 2023. A weather window has just opened up and we are going to attempt a dive tomorrow [11].”

Sunday, June 18th, 2023:

8:00 AM: Scheduled start time of Titan’s dive to the ocean floor to view the shipwreck. According to US Coast Guard, the descent actually began around four hours later [11].

12:00 PM: Titan begins its nearly 12,500-foot dive [11].

1:45 PM: 1 hour and 45 minutes after beginning its descent, all communication between the command ship and the Titan submersible were lost [11].

7:00 PM: Scheduled resurface time for the Titan submersible, yet the sub is nowhere to be found [11].

9:40 PM: The first report of the missing vessel comes into the US Coast Guard. The call comes in from the command ship, which was around 900 nautical miles from Cape Cod [11].

Monday, June 19th,

2023:

Search and rescue operations begin. Both US and Canadian ships and planes were deployed to swarm the area looking for any signs of Titan. They even reached out to commercial ships to join in on the search and rescue efforts [11].

Tuesday, June 20th, 2023:

2:50 PM: France agrees to help and deploys Atalante, a ship with a deep-sea diving vessel, which is supposed to arrive to the search area late on Wednesday [11].

Throughout Day: A

Canadian P-3 Orion Aircraft, equipped with equipment to detect submarines, detects sounds over several hours [11].

Wednesday, June 21st, 2023: US Coast Guard, US Navy, Canadian Coast Guard, along with OceanGate take the reins and claim that they will handle the search [11].

6:00 AM: US Coast Guard confirms that sounds were detected underwater and that remote vehicles have been directed towards the sounds as well as sending the data to experts [11].

5:00 PM: US Coast Guard says more noises are heard. Search area has been determined to be 2 times the size of Connecticut [11].

Tuesday, June 22nd, 2023:

10 AM: Estimated deadline for air supply within the submersible. This was based on the claim that Titan had 96 hours of total air supply, made by OceanGate [11].

12:00 PM: 2 more remotely operated vehicles are deployed in the search effort [11].

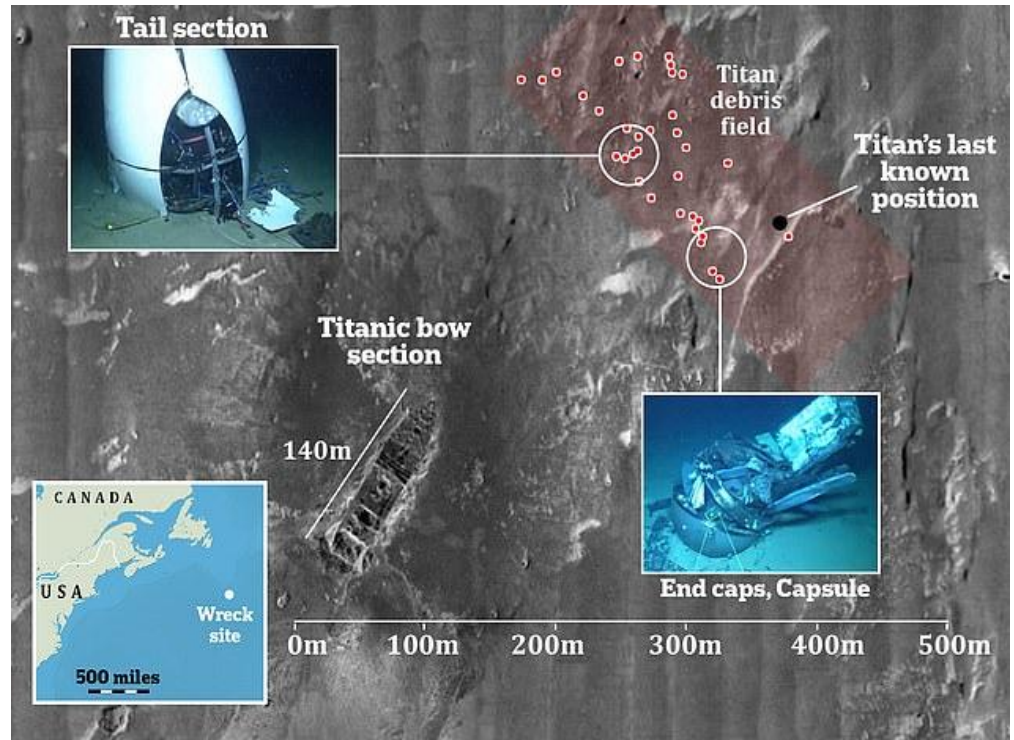


Figure 1. Above is a map of the Titan Submersible debris field post-implosion. In the bottom left graphic, the Newfoundland coast can be spotted and is located on the upper portion of Canada's east coast, along with the labeling of *The Titanic* wreck site. It can be seen from the overall map that vessel was about 1,600 feet away from the bow of the wreck site before the fatal implosion took place. The 2 live-camera feed images, show findings of tail section and capsule debris [1].

3:48 PM: A ROV discovers a debris field near the *Titanic* shipwreck [11].

8:00 PM: US Coast Guard holds press conference after announcing the findings of the debris field. They claim a 'catastrophic implosion' was to blame [11].

What Happened?

The main failure of the Titan submersible was the design in itself. As mentioned before, Titan's hull was made of a filament wound carbon fiber, an insanely strong material. In certain aspects that is, carbon fiber is known to be a very strong material, but this is when it is acting in 'tension'. They are used often in aircrafts, where the cabin is pressurized pushing out on the carbon fiber hull thus putting it in tension [4]. The idea of fusing a carbon fiber hull between 2 titanium end caps may have stemmed from Stockton and his background in the aeronautical field, however many would then expect him to understand the vice versa effects on carbon fiber when not in tension. Carbon fiber is not very well known for its strength when placed in a compressive environment. In terms of forces on a submarine, it is the opposite of the above-described aircraft scenario where the cabin is pressurized to put the fibers in tension. The deeper a submarine dives the greater the existential pressure on the hull becomes, putting the carbon fiber in compression [4].

The idea to use a carbon fiber hull came from its natural buoyancy. Submersibles like Titan are designed in a way that they want to achieve natural buoyancy, making it easier to dive and resurface. A design utilizing natural buoyancy has an easy safety function, as in the wake of an emergency the sub simply drops weight off causing it to be positively buoyant allowing it to float to the surface on its own. Normally, submarine hulls are made from steel or titanium and are covered with an outer foam layer that helps it achieve its natural buoyancy [4]. OceanGate CEO, Stockton Rush decided to skip out on this layer because it added to cost, which would not have been a terrible thing if the carbon fiber composite hull was capable of dealing with the forces it would experience.

The implosion was due to snap buckling in this carbon fiber hull, [Figure 2](#), shows an example of just what exactly a snap buckling failure process of events may look like. Normally for a thin-walled pressure vessel, an implosion failure would simply cave in the entire wall, however for these subs, the walls are so thick, that the weakening of the internal layer of the vessel is suddenly peeled away causing catastrophic failure for the rest of the hull. Another quality of carbon fiber is its weak ability to recover from gradual stresses. If titanium is placed under certain stresses, normally it will retain its shape or return to its former shape based off of its modulus of elasticity. Carbon fiber on the other hand becomes exponentially weaker, with an almost cliff like graph structure when being tested beyond its capable limits, which can be seen in [Figure 3](#). This inability to take on stresses like this compared with the idea of snap buckling failures, leads to the conclusion that the inner layer of the hull was succumbed to that level of compression one too many times and on that unfateful morning in June, 2023 that inner layer of the carbon fiber on board the Titan submersible fully gave way.

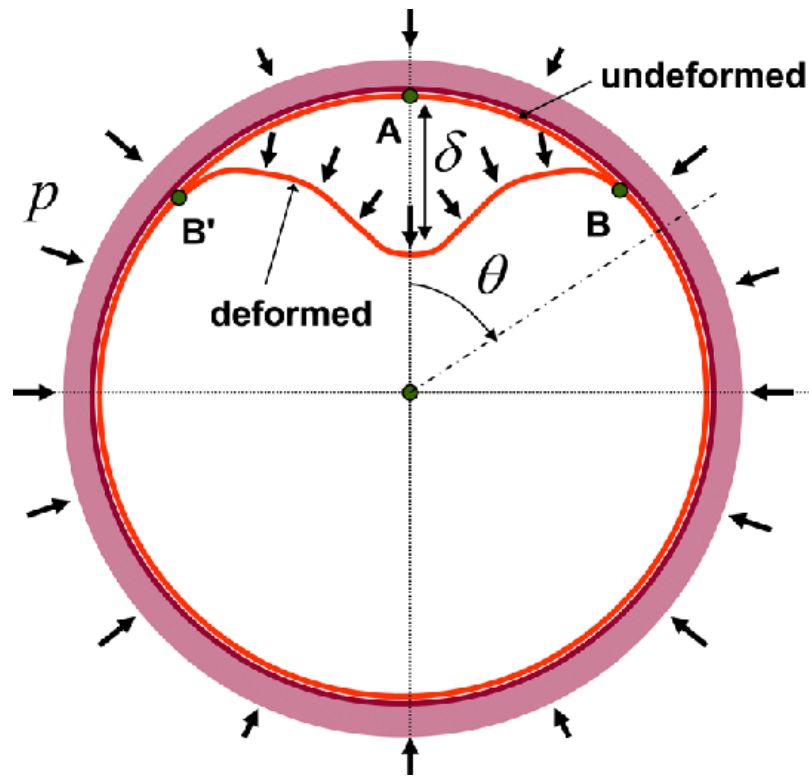


Figure 2. Snap Buckling

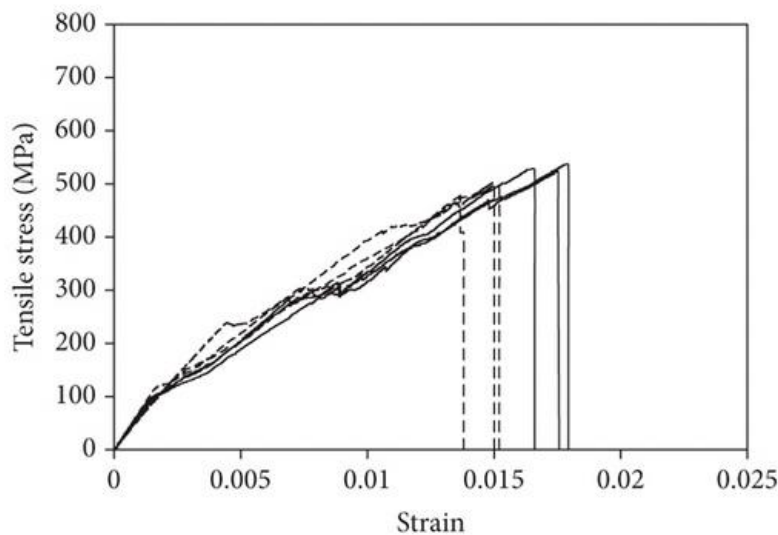


Figure 3. Stress / Strain Test for Carbon Fiber Composites

Above you can see the graph of a sample stress/strain test on carbon fiber composites. As you can see once this material reaches a certain point, it has no ability to return anywhere near its former shape or strength [12].

Failure of Testing & Quality of Equipment & Materials

The tragedy that occurred that morning would most likely never have taken place if OceanGate followed the proper regulations and required testing of equipment. The large driving factor behind

OceanGate negligence of proper testing stemmed directly from the top. The CEO, Stockton Rush had a mentality that pushed proper testing to the side and was focused more on simply getting to the end result as quickly as possible. His mindset seems to be an explanation for how all of this was allowed to happen. Rush once told an interviewer, "I think it was General MacArthur who said: 'You're remembered for the rules you break.' [9]". This sadly is not the only statement Rush has made, a multitude of questionable statements were made by the CEO such as, "I have broken some rules to make this... The Carbon fiber and titanium, there is a rule that you don't do that. Well, I did [9].", "At some point safety is just pure waste... I think I can do this just as safely by breaking the rules [9].", "We have heard the baseless cries of 'you are going to kill someone' way too often. I take this as a serious person insult [9]." Rush's mindset of pure negligence of regulations is the path of innovation received many deliberate warnings as well. Precisely in 2018, OceanGate's own director of marine operations had prepared a lengthy and detailed document which screamed of red flags throughout the Titan submersible design. Leading to Rush receiving an influx of letters explaining that the experimental approach he plans on taking has an untimely fate. He simply chose to ignore these warnings.

OceanGate, along with design flaws also seemed to have flaws within the construction of the equipment used in the submersible. Stated before in the, '*What Happened?*' section, majority of submarine hulls are made of titanium with a foam layer to achieve natural buoyancy, however OceanGate bypassed this to avoid costs. This would not have been a terrible action if the design was then capable for the job, yet Titan needed to be capable of handling a pressure of 366 of Earth's Atmospheres [4]. Which they in fact were unaware if the vessels capability could withstand the task, describing their reasons for bypassing testing in a now deleted blog post. The post read, "Most marine operators required chartered vessels are classed by an independent group... Classing assures ship owners, insurers, and regulators that vessels are designed, constructed, and inspected to accepted to standards. Classing may be effective at filtering out unsatisfactory designers and builders, but the established standards do little to weed out subpar vessel operators... The vast majority of marine and aviation accidents are a result of operator error, not mechanical failure. As a result simply focusing on classing the vessel does not address the operational risks [4]." The blog post made should have been another reason for an arousal of concern. The thought of bypassing testing simply because the tests do not test the standards/driving ability of the captain, is simply wrong. Majority of submersible accidents happening mainly from operator error stems from the fact that these classed submersibles have undergone rigorous testing to meet and surpass modern regulations and safety standards. OceanGate did complete their own testing on Titan. They created their own test to classify Titan. It consisted of one single test on Titan itself. A same statement from the blog post mentioned above reads that the test would consist of, "a licensed marine surveyor will witness a successful dive to 4,000 meters, inspect the vehicle before and after the dive and provide a Statement of Fact attesting to the completion of the dive test plan [4]." Once again, OceanGate proving to be negligent within their design of equipment by knowingly disregarding any type of regulations and safety standards. This one-time test simply would not be enough to ensure the repeatability of quality assurance for the submersible, hence why the requirements to have a submersible (that will be diving to this depth) classified are so rigorous. A vessel being succumbed to these types of stresses must be fatigue tested constantly, especially when the material undergoing those stresses is not meant for its capabilities within that environment.

Titan was designed almost entirely based off computer modeling and simulations. Which are helpful for basic developmental and prototyping stages, however when it comes to Titan, a vessel diving to extreme depths, it must be real world tested as to adhere with modern NSPE code of engineering, which will be discussed in a later section. These simulations simply are not reliable enough to ensure the quality of the vessel over time and over the endurance of repeated stress loads. This becomes even more of an issue because computer simulations cannot properly or adequately represent composite materials, compared to the proficiency with materials such as steel and titanium, where the material is

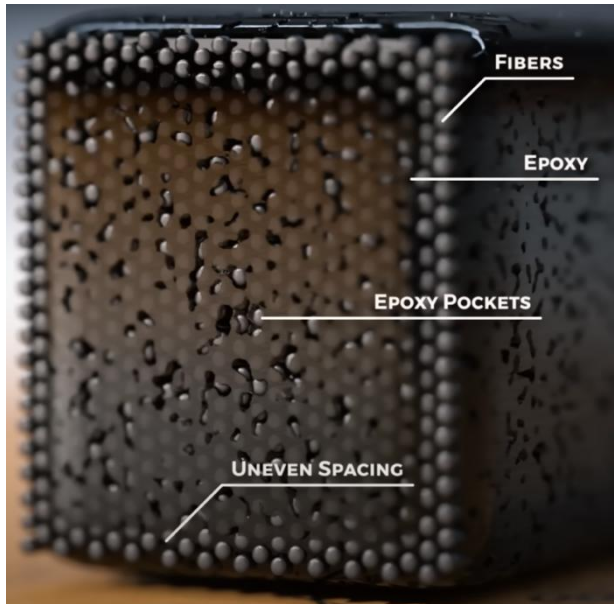


Figure 4. Above is a screenshot taken from the YouTube video [The Questionable Engineering of OceanGate](#). The image shows a cross section cut of carbon fiber composite material [4].

consistent throughout [4]. Composite materials are “composed of fibers bound together by a matrix material like epoxy [4].” When looking at a cross section of carbon fiber such as in [figure 4](#), you see some fibers all bundled together mostly touching together bound by epoxy. Yet there are many areas within the bundle where you can see uneven spacing or spots where there is an uneven gap between the fibers. Epoxy Pockets also can be spotted, this is areas where the bonding matrix did not completely fill in the gaps, increasing the structural weakness of the material in that specific spot. There are ways to prevent these epoxy pockets and occurrences of uneven spacing, yet the overall cheapness and failure to uphold modern safety standards within OceanGate can be seen in their construction of the carbon fiber used in the hull. A vessel like this that will be subject to such immense stresses should have been cured in an autoclave, a pressurized oven which helps to cure the composite material [4]. OceanGate did

not use this procedure though as it would add to costs and decided to simply bag and cure the hull. They outsourced to a company Spencer Composites in order to have the hull constructed. When the CEO was interviewed on the matter, he claimed that, “the porosity level of the cured pressure vessel was assessed to be less than 1% [4].”. This exact defect in a composite material would be a massive increase to a catastrophic failure such as snap buckling. The now deleted blog post by OceanGate previously mentioned, continued on to say, “Bringing an entity up to speed on every innovation before it is put into real world testing is anathema to rapid innovation [4].” Furthering the point of Stockton Rush’s overly inflated self-confidence and will to push rules to the side if it meant getting to his result faster.

Another design flaw seen in the Titan submersible is that of their steering system. As mentioned previously in the report, the control device used for steering the vessel was a Logitech F7 10 remote controller, whereas a submarine classified to dive to these depths, such as ‘The Alvin’(one of the first created deep depth submersibles), use a computer oriented steering control system [10]. Many of these design flaws should have and did raise concern for many. However, the one man who thought he was above everybody and thought he was the one who could do it all and break through, succumbed to the consequences of his own shortcuts.

NSPE Ethical Analysis

The *National Society of Professional Engineers*, or the NSPE, is an organization created in 1934 with one crucial goal. The overall goal of the NSPE taken directly from their website is to, “create an inclusive, nontechnical organization dedicated to the interests of licensed professional engineers, regardless of practice area, that would protect engineers (and the public) from unqualified practitioners, build public recognition for the profession, and stand against unethical practices and inadequate compensation [8].” With that being said, the NSPE has come together to set up a list of rules/guidelines to uphold the morals and ethics within the engineering world. OceanGate failed to meet the requirements of many of these standards and served to pay the ultimate price, while taking four innocent lives down as well.

OceanGate has multiple blatant infractions of the NSPE code of ethics. In section 'I. Fundamental Canons' of the NSPE code of ethics, they fail to prove satisfactory in almost every category. Rule 1 was broken by Rush when he allowed customers on board the vessel. There was no testing done to deem that submersible safe for use at that level. He immediately put all lives on board that day at risk, whilst he was no expert in the realm of submersible. Rush's background entailed aerospace engineering for the most part and him deeming himself properly fit to be able to say whether or not the submersible was up for the task was not his position. This was in no one his area of expertise, although if he went through proper testing, he would have been required to gain specific clearances from people who are deemed fit in this jurisdiction of engineering. OceanGate also did not adhere to rule 3 as they claimed their submersible to be safe for the voyage, whilst they had done no real testing to prove that it was deemed safe to attempt this dive. Yet above can be seen multiple public statements made by OceanGate as a whole with no real evidence to back themselves up. Without the use of public statements, it is hard to believe they would have been able to attract customers the way that they did. Rule 4, also broken, when in 2018 OceanGate had a court case brought against them when they had fired an employee for bringing up concerns involving the carbon fiber hull [4]. Rule 5 was broken when OceanGate charged money from customers in order for a voyage in a vessel that was not deemed safe by any sense of authority, yet they claimed it was. They had fully lied to their clients about the qualifications of their submersible, therefore deceiving their clients. In no way did OceanGate conduct themselves properly throughout the entirety of their operations, breaking the final rule in section I, which reads, "Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession. [8]"

Conclusion

OceanGate and their CEO had the theory behind innovation and progression completely backwards. The real opportunity for innovation and scientific breakthrough, would have been the creation and testing till classified of the submersible. They should have gone through and figured out what exactly causes snap buckling and advanced the materials science for all of mankind as it is not well understood as a whole yet. Concluding whether or not a catastrophic event was avoidable or not, sometimes is quite difficult. For the case of OceanGate's Titan submersible, there is no question that this tragic implosion was avoidable. This is justified based off many factors discussed entirely throughout the case study above. As an outsider looking in, I believe there were many actions that should or should not have taken place and simply a lot of short cuts taken in places you simply cannot take shortcuts in. Such as when curing their carbon fiber hull, cutting the cost, and not having the most important structural component of your vessel constructed in the highest quality manner simply cannot be done. Along with having a submersible device that is taking on the task of diving almost 4000 meters steering system be controlled by a video game remote. However, I believe the biggest issue originated from the CEO himself. His mindset surrounding science and innovation as a whole is solely to blame for the outcome they received. OceanGate Inc. as a company has ceased all operations since the accident and have yet to reopen their operations, while they are currently undergoing investigations.

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