Responsible Innovation of Deep Sea Vehicles

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

The ocean is the final frontier that mankind has yet to truly explore with roughly 90% of the deep sea remaining unexplored (Helmenstine, 2019). Some argue that underwater exploration is more challenging and dangerous than space exploration but leaving the atmosphere and entering outer space may sound more exciting but reaching the deepest depths of our oceans could be even more intriguing (Etzioni, 2022). Underwater robotics will be crucial in this mission to explore the ocean and unlock its secrets. Thus, studying underwater creatures, like fish and how they survive in the ocean, will provide key insights into how they are able to do so every day (Berlinger, 2021).

Underwater exploration may be more than intriguing to tourists, it could provide solutions to our world's energy, food, or environmental problems that are rapidly approaching a point where they direly need solutions. Finding solutions in our oceans is far more likely than in our solar system which is why underwater vehicles are experiencing a "surge" in popularity (Etzioni, 2022).

With the advancement of underwater exploration and robotics, more consideration needs to be given to the rules and regulations that govern safety (Asady, 2023). What rules and regulations currently exist for deep sea vehicles? Who created and enforces the rules and regulations to ensure compliance? These research questions will be analyzed through a case study of Ocean Gate's Titan Submarine tragedy in coordination with a complete explanation of what could have been done to prevent this.

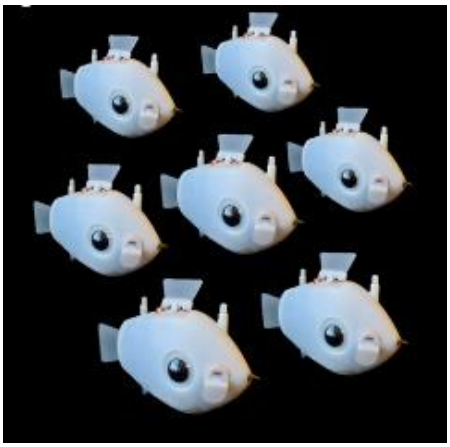

Figure 1: Seven Bluebots with streamlined, fish-inspired bodies are used in Blueswarm experiments (Berlinger, 2021)

Deep sea human exploration has been active since the 1500's when Ferdinand Magellan unsuccessfully attempted to measure the depth of the Pacific Ocean. In the 1870's, the HMS Challenger conducted the first deep sea exploration expedition which discovered new oceanic species previously unknown due to dee they were in the ocean. When in 2012, James Cameron completed the first solo dive to the bottom of the Challenger Deep, it had been previously considered an impossible feat. More modern deep-sea exploration utilizes Remotely Operated Vehicles (ROVs) or Autonomous Underwater Vehicles (AUVs) (Helmenstine, 2019).

With so many international companies, governments, and civilians at play, it is challenging to create and maintain an acceptable level of safety and regulation across the board. However, we must start somewhere to now so that future tragedies can be prevented as rules and regulations especially uniform ones, take time to create and enforce correctly. The responsible innovation of deep-sea vehicles is crucial as we enter into a new era of underwater exploration accessibility. Ensuring that all parties are protected and as safe as possible will be the key with maturation of the underwater vehicles and robotics. Without advancement and maintenance of these rules and regulations, more tragedies like the Titan submarine will happen thus deterring further underwater tourism and more importantly, exploration.

Background And Significance/Motivation

There is a severe lack of rules and regulations regarding deep sea exploration, there is even a well-known loophole under the United Nations Convention on the Law of the Sea (UNCLOS). Under UNCLOS, a submersible is considered to be a ship, vessel, equipment, or device. By exploiting this ambiguity, stakeholders have been deploying underwater vehicles (UVs) without any regulatory constraints for a long time. The International Maritime Organization (IMO) has developed regulatory framework for maritime autonomous surface ships, but neglects UVs. Even the United States Government does not require inspections for submersibles with six or fewer passengers. Also, different countries rules for UVs can be avoided as well by launching in different nationalities (one where the rules and regulations are quite lacking compared to the home country) waters, a different nationalities ship, or by considering the UV as cargo until deployed (Venancio, 2023).

Professional opinions of the safety standards subcommittee membership detail that more safety standards need to be established for human occupied underwater vehicles. There are numerous safety standards for Human Occupied Vehicles (HOVs) that include the vehicle, ship, handling system, training, operations, and the ship personal/scientific crew. This includes an operations manual, support ship (equipped with two way communication, tracking, transducers, properly trained personnel, depth sounding equipment, self-rescue capability, and self-sustaining capability), chain of command protocol, international safety management, and support assessments (weather, operating area, surface traffic, communication, surface support, planning, dive conditions, abort dive procedure, and unique situations) (Safety standards for human occupied vehicles, 2009). As well as testimony from Stephen Lord (director of homeland security) at the hearing before the subcommittee on investigations and oversight committee on

science, space, and technology for the house of representatives stating that oceanic exploration is critical for the United States and how to best oversee this program similar in way that the space industry as well as the airplane industry are overseen (GovInfo, 2019).

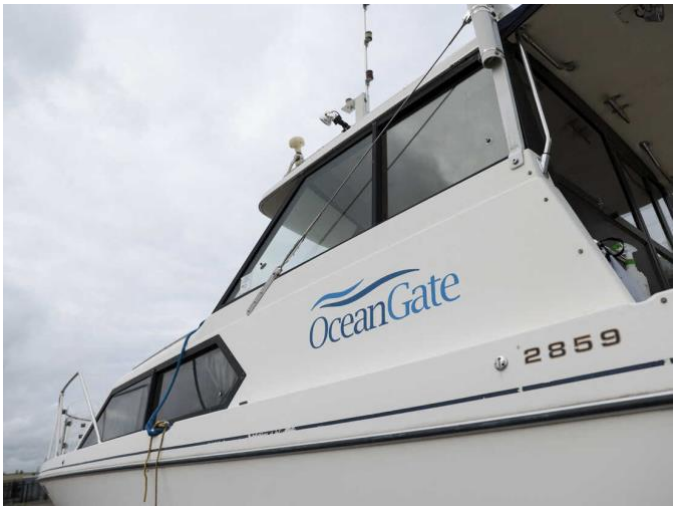

Figure 2: Ocean Gate support ship (Treisman, 2023)

A case study of the Titan submarine details the lack of safety regulations and common rules that were not followed when the submersible launched in June, 2023. Since 2021, Ocean Gate had been taking tourists to see the Titanic wreck for $250,000 and a signed waiver stating that Ocean Gate is not liable for "physical injury, disability, emotional trauma, or death". Former passengers, including Brian Weed and Mike Reiss, of the Titan have spoken about safety concerns including loss of communication with the host ship, general safety concerns with the companies new and innovative designs, and how the CEO, Stockton Rush, felt that "… At some point safety just is pure waste …" (Shah, 2023). Industry experts, including Will Kohen (Chair of the Marine technology Society's Submarine Committee) were also concerned for the design choices made, as early as 2018, when the submarine was in development but nothing was changed. A former Ocean Gate director of marine operations and experienced submarine pilot, David Lochridge, was also fired for raising safety concerns such as the improperly tested carbon fiber hull, which were ignored, to executive management. After he published a problem report,

he was invited to an engineering meeting in which he found out that the submersible was built to withstand only pressures of 1300 meters even though the Titanic shipwreck is roughly 4000 meters below the shore, shortly after he was fired. Afterwards, on the Titan's maiden voyage (2021) it encountered not only a battery issue but external damage. Then in 2022, the submersible lost contact with the surface crew for approximately five hours and on its second attempt, the trip was aborted after making it 37 feet down due to a mechanical issue (Treisman, 2023).

Responsible innovation of deep-sea vehicles is crucial going forward as the industry turns away from militarization and toward commercialization. With all of the legal loopholes that are well known, it is no wonder how the Titan Submarine was able to be deployed numerous times. Luckily, there was only one fatal accident when there was opportunity for numerous with even internal sources at the company doubting the safety and trustworthiness of the submarine. Understanding who creates and enforces the rules and regulations that companies like Ocean Gate are bound to is crucial going forward in the safety of not only future companies but their customers as well. To keep this industry alive and safe, regulations and enforcement agencies need to be created to ensure that deep sea travel for consumers and scientists is not only allowed but safe for everyone involved.

Methodology

I approached my research questions by considering all facets of this complex issue of responsible innovation of deep-sea vehicles. This includes studying all current standing rules and regulations, loopholes to extort these rules and regulations, and lastly a case study of a recent failure of these rules and regulations, the Titan submarine accident of June 2023. I approached these questions carefully to ensure that all of these issues were considered separately for each

nationality when, in the future, they need to be considered uniform internationally. With all of these vastly interconnected issues, I wanted to make sure that all issues were being considered individually and their correlation was also considered to ensure that there was no bias, in just considering one or the other.

This approach is the correct approach to answer my research questions because it is methodical and involves a vast amount of research into all of the subjects defined above. By utilizing, such a slow and methodical research method, I was able to get a through a concise look at all perspectives of the actors in this network. Studying a case study also gave me the perfect opportunity to illustrate how all of the minor safety issues and lack of rules and regulations can stack upon each other and cause a major accident. Similarly, to every major engineering accident that has been caused and studied throughout the years and that we are taught how to avoid. Somehow these accidents keep happening, in almost the same way. Thus, studying the Titan submarine accident provided me a great opportunity to apply what I have learned in school but to also sum up my research questions with a practical example or answer.

By utilizing actor- network theory, I was able to see this complex issue of responsible innovation of deep-sea vehicles as its own system with its own unique actors that all involve each other. Actors include: companies that provide deep sea tourism opportunities, customers that buy these excursions, every government in the world, government collaborations, and scientists. They are all related in this network of deep-sea exploration in underwater vehicles (Dolwick, 2009). This allowed me to further break down the actor connections that connect them in their network and explain where there are gaps in the rules and regulations that these actors are bound to. I also utilized responsible innovation because it states that engineers and innovators should be creating their products responsibly and with safety in mind. Thus, a company should

not knowingly create an unsafe product, like the Titan submarine, and knowingly put people and customers at risk by selling them their product, or an excursion on their submersible (Owen, 2020). This allowed me to shed light on where the fault lies in this accident as the company should have known better and should have brought their product to market when it was not thoroughly safety tested.

This approach is the right approach to answer my research questions because the combination of actor network theory and responsible innovation allowed me to show that some of the actors need to step up and take responsibility to prevent further accidents from happening. This also directly allows me to show how some of the actors in the network, like the consumers and general public, had no reason to not trust the companies because one would assume that the government or some regulatory body was doing safety checks and that this company would be compliant or they would not be allowed launch their submersible. However, that is not always the case in this industry. I believe these two theories provide me the right approach for my research questions as they allow me a complete picture of this complex issue that involves a lot of moving parts. It also allows me to hold all negligent parties responsible for their mistakes and show the vast amounts of improvement that could and should be made in this industry going forward to prevent more tragedies form occurring. Thus combining these two strategies yields a perfect way to analyze all of my research questions along with partaking in slow and methodical research of all topics mentioned above.

Literature Review

The ocean is one of the biggest untapped resources left on our planet and no one seems particularly interested in exploring it. With the final frontier being denoted as outer space, that is

where all the action is but in reality, space is distant, hostile, and barren. This is why not a lot of resource has come from out outer space exploration but if we turn our attention to what's under us, we could find solutions for climate change, food crisis, energy sources, and more (Etzoni, 2014). In this new age of oceanic exploration, there will need to be a new age of guidelines and safety research to ensure that all of these new resources and discoveries are found correctly.

While the target has not always been resource collection or survival, there is a deep history of oceanic exploration within our earth. This started in 1521, when Ferdinand Magellan attempted to measure the depth of the Pacific Ocean but was unsuccessful. This continued in the 1800's when Charles Thomson led the HMS Challenger to the deep-sea floor. Even as recently as 2012, when James Cameron completed the first solo dive to the challenger deep (Helmenstein, 2019). More notably, the most recent attempt at oceanic exploration was Stockton Rush and his Titan Submarine which fatally exploded, killing all on board in June 2023. This fatal accident was the result of an overeager entrepreneur not having any rules or safety guidelines to follow in his new company, Ocean Gate, which allowed the average consumer to explore the Titanic shipwreck in their submarine, the Titan (Asady, 2023).

Ocean Gate began taking tourists on its tours of the Titanic in 2021, while not the first company to join underwater tourism, it is the most notable while other companies simply take you around the coral reefs our on a tour of the Maldives. Ocean Gate has gotten even more extreme with their experiences they offer, including three-day tour of the hydrothermal vents in Portugal or a Bahamas dive. While this industry is similar to the space tourism industry, space travel has been accomplished before many times thus these new space companies are just changing some variables, not creating a whole new equation. Since, before 2023, there had been

no major accidents, there was no need to regulate this industry when they were seemingly self-regulating successfully. However, former passengers have come forward stating their own safety concerns during their excursion, citing lost communication with the host ship and the company's new and innovative designs that simply do not meet the established submarine standards. Passengers most sign a liability waiver stating that anything up to their own death is a possibility but that is just the fine print to these adventurous travelers. The CEO, Stockton Rush evens said "At some point safety is just pure waste" (Shah, 2023).

This came to a head on June 18, 2023 when five people, including Stockton Rush, boarded the Titan submarine for a regular Titanic exploration when the hip lost communication with the host ship for hours, until it was discovered, days later, that the ship had imploded and all lives were presumed lost at sea. This was a great tragedy that should have been prevented. In fact, experts in this community, such as Will Kohen, chair of the Marine Technology Society's Submarine Committee, were not surprised when the submarine imploded. They were concerned about Ocean Gate's experimental approach, lack of oversight, and not adhering to industry accepted safety guidelines (Treisman, 2023).

Figure 3: Titan Submarine (Asady, 2023)

Third party agencies such as the American Bureau of Shipping are responsible for overseeing ships, oil platforms, and submarines. But this agency only assesses the physical vehicles and not operating procedures and decision-making processes, which are the point of failure more likely than not. Within the company, employees had been fired for raising safety concerns. David Lochridge, the former director of marine operations and experienced submarine pilot, was fired after raising concerns that the company was not properly testing the vessel's carbon fiber hull. After being ignored by his supervisors, he wrote up his concerns in a report detailing that the submersible was only built to withstand 1300 meters of pressure when it was diving to as deep as 4000 meters below sea level. He was soon fired and sued the company for wrongful termination (Treisman, 2023).

With it seems only one agency looking over these submersibles, it is possible that safety measures and materials are slipping through the cracks. This is even more probable when companies like Ocean Gate, refuse to acknowledge that they are being wreck less and not having everything tested and safe for the depths they are going to dive. Are there any other rules/regulations in the books that these companies are not being held to and are the other agencies that should be held accountable?

Discussion/Results

The United Nations Convention on the Law of the Sea (UNCLOS) provides a few categories that submersibles can be classified as: ships or vessels, equipment, and devices. These underwater submersibles or vehicles (UVs) are not classified as any of the above mentioned, thus it is ambiguous as to what protocols these UVs should be following as there are no regulations for UVs. According to UNCLOS, the only real restriction for UVs applied if they are launched

within the exclusive economic zone of a country. This zone restricts activities related to marine science research, protection of the environment, and exploration and exploitation of natural resources. However, deploying a UV for recreational exploration is not covered. After this zone lies the high seas, which are open to everyone and thus the jurisdiction is related to the nationality of the ship. However, UVs are not defined as ships by UNCLOS thus if a country does not specifically define UVs in their laws, there are no rules restrictions for them in the high seas either (Venancio, 2023).

The lack of effort to regulate these UVS is due to their lack of presence in most countries and because the ones that do exist are mostly for the military of the respected countries (USA, China, France, Japan, and the UK). With deep-sea tourism on the rise, there have been attempts to regulate UVs with the scope of marine scientific research by the Draft Convention on the Legal Status of Ocean Data Acquisition Systems, Aids, and Devices, where a UV was defined as "structure, platform, installation, buoy or other device, not being a ship, together with its appurtenant equipment deployed at sea for non-military purposes essentially for the purpose of collecting, storing or transmitting samples and data relating to the marine environment or the atmosphere or the uses thereof". In addition, International Maritime Organization (IMO) is also trying to develop a regulatory framework for maritime autonomous surface ships, however they are focused only in the scope of the shipping industry. While these agencies do not seem to be focusing on all aspects of UVs, some countries have been proactive. For example, the EU and UK have laws for crewed UVs while China requires a voice communication system for their UVs, which the Titan did not have (they only had a text messaging system with their host ship) (Venancio, 2023).

Within the United States, where Ocean Gate is headquartered, there are less regulations and agencies looking over these expeditions. The most notable is a subcommittee on investigations and oversight committee on science, space, and technology before the House of Representatives in 2011. This not only covers oceanic exploration but space as well as general technology in these spaces. Thus, not much came of this (GovInfo, 2019). There has also been research done to create a set of guidelines for human occupied vehicles (HOVs) by the University-National Oceanographic Laboratory System (UNLOS) Safety Standards for Human Operated Vehicles, 2009).

They start these guidelines by defining all of the roles for the crew and an HOV in general terms. The HOVs Operator's written operations plan must include organization and position descriptions, general operational considerations, vehicle information and performance data, requirements for surface support vessel launch and recovery system, normal operating procedures, special considerations, procedures and limitations applicable to the intended cruise, emergency operating procedures, casualty procedures and information for scientists/observers, documentation of system certification, documentation of pilot qualifications, and requirements for maintenance and change documentation. The support ship is defined to have two-way communication, tracking, transducers, personal training, depth-sounding equipment, self-rescue capability, self-sustaining capacity, HOV servicing space, seafloor mapping system, science laboratories, acoustic doppler current measuring system, dynamic positioning system, and a chain of command during HOV operations. They also suggest that before the HOV is launched a weather assessment, operating area assessment, surface traffic assessment, establishment of communication protocol, conduct planning meetings, surface support assignments, evaluate dive conditions, establishment of abort dive procedure, and address unique operations needs to be

completed. They also discuss international support guidelines, handling systems, and training of submersible support ship personal (Safety Standards for Human Operated Vehicles, 2009).

The lack of rules and regulations for this industry is alarming, considering how many actors are involved in this oceanic exploration network. The actor network theory, shows how these relationships are constantly shifting based on the interaction between all the actors within. Actors include, consumers, companies offering oceanic exploration, international governments and their interactions, and third-party agencies that are responsible for overseeing these operations. This network should be everchanging especially with the recent accident, it should be updating however this network has remained stagnant for what seems like 10 years (Dolwick, 2009).

Conclusion

The responsible innovation of deep-sea vehicles is crucial as we enter into a new era of underwater exploration accessibility for the average consumer. Ensuring that all parties, including the consumer, companies, and wildlife, are protected and as safe as possible will be the key with maturation of the underwater vehicle's robotics and deep-sea travel. Without advancement and maintenance of these rules and regulations, more tragedies like the Titan Submarine accident will happen thus deterring further underwater tourism and more importantly, exploration.

The results of my technical research paper show that vertical fin interaction in relation to fish schooling yields hydrodynamic benefits and that their varying vertical separation plays a factor in thrust, lift, power, and efficiency of the fins. This ethical research paper will also show that responsible innovation of deep-sea vehicles is critical going forward on this new frontier not only

for tourism but for scientific exploration of the deepest depths of our oceans. Together this research will provide a way forward for ethical and safe underwater robotics maturation.

Future works should consider the progress made from the aftermath of the Titian Submarines accident to where the safety rules and regulations are in their point of time. Future researchers should be able to see significant growth in this industry and ideally no further accidents if the right actions are taken in our time. Next steps should also involve considering how enforceable and applicable these rules and regulations are throughout various countries to ensure that no travel loopholes form. Lastly, the implications of being found of breaking them should be studied to ensure that the consequences are sever enough that the action is not repeated but not too severe that it hurts the industry and causes a lack of growth due to the repercussions or the cost of getting everything updated.

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