October 2, 2025 MIR-25-36

Hull Failure and Implosion of Submersible *Titan*

North Atlantic Ocean
370 nautical miles southeast of St. John's, Newfoundland and Labrador, Canada
June 18, 2023

Abstract: This report discusses the June 18, 2023, hull failure and implosion of the submersible *Titan*, manufactured and operated by OceanGate, while diving to the *Titanic* wreck in the North Atlantic Ocean, about 370 nautical miles southeast of St. John's, Newfoundland and Labrador, Canada. There were five fatalities, and the vessel was a total loss; according to a 2023 customs declaration, the submersible's value, combined with its launch and recovery system, was estimated to be about $4.2 million USD. Safety issues identified in this report include OceanGate's inadequate engineering process for the *Titan*; OceanGate's flawed analysis of *Titan* strain gage and acoustic emission (real-time monitoring system) data as a measure of pressure hull integrity; OceanGate's failure to notify search and rescue assets about its planned expedition; and insufficient voluntary guidance and US regulations for pressure vessels for human occupancy. As a result of this investigation, the National Transportation Safety Board makes four new safety recommendations to the US Coast Guard.

Contents

Figures

Tables

Acronyms and Abbreviations

Abbreviation	Name
ASME	American Society of Mechanical Engineers
CEO	chief executive officer
CFR	*Code of Federal Regulations*
IMO	International Maritime Organization
ISMERLO	International Submarine Escape and Rescue Liaison Office
LARS	launch and recovery system
NTSB	National Transportation Safety Board
NVIC	Navigation and Vessel Inspection Circular
OSHA	Occupational Safety and Health Administration
PVHO	pressure vessel for human occupancy
RCC	Response Coordination Center
RTM	real-time monitoring system
ROV	remotely operated vehicle

Executive Summary

What Happened

On June 18, 2023, about 1047 local time, while diving to the wreck of the ocean liner *Titanic* in the North Atlantic Ocean, about 372 miles southeast of St. John's, Newfoundland and Labrador, Canada, the submersible *Titan*'s pressure hull failed, and the vessel imploded. All five persons on board the vessel died. The *Titan* was a total loss; according to a 2023 customs declaration, the submersible's value, combined with its launch and recovery system, was estimated at $5.6 million CAD (about $ 4.2 million USD).

What We Found

We found that the *Titan* pressure vessel likely sustained damage after it surfaced at the end of dive 80 in the form of one or more delaminations, which weakened the pressure vessel. We found that after dive 82, the *Titan* sustained additional damage (of unknown origin) that further deteriorated and weakened the pressure vessel. The existing delaminations and additional damage that deteriorated the condition of the pressure vessel between dive 82 and the casualty dive (dive 88) resulted in a local buckling failure that led to the implosion of the *Titan*.

We found that OceanGate's engineering process for the *Titan* was inadequate and resulted in the construction of a carbon fiber composite pressure vessel that contained multiple anomalies and failed to meet necessary strength and durability requirements. Because OceanGate did not adequately test the *Titan*, the company was unaware of the pressure vessel's actual strength and durability, which was likely much lower than their target, as well as the implications of how certain operational changes, including storage condition and towing, could impact the integrity of the pressure vessel and overall safety of the vessel. Additionally, OceanGate's analysis of *Titan* pressure vessel real-time monitoring data was flawed, so the company was unaware that the *Titan* was damaged and needed to be immediately removed from service after dive 80.

We found that, had OceanGate followed Navigation and Vessel Inspection Circular (NVIC) 05-93 guidance for emergency response plans, they likely would have had emergency response assets standing by, and the *Titan* likely would have been found sooner, saving time and resources even though a rescue was not possible in this case. Despite OceanGate's failure to notify search and rescue assets about its planned expedition, as well as the limited resources able to operate at the depth of the *Titanic*, the US Coast Guard's search and rescue coordination efforts were effective and resulted in the timely discovery of the *Titan* wreckage.

We found that voluntary guidance and current US small passenger vessel regulations are not sufficiently tailored to current pressure vessel for human occupancy (PVHO) operations to ensure the safety of PVHOs in accordance with established technical and classification society standards. Additionally, we found that international standards for PVHOs would ensure consistency in design, construction, and operation requirements for PVHOs that operate around the world.

We determined that the probable cause of the hull failure and implosion of the submersible *Titan* was OceanGate's inadequate engineering process, which failed to establish the actual strength and durability of the *Titan* pressure vessel and resulted in the company operating a carbon fiber composite vessel that sustained delamination damage that was subsequently exacerbated by additional damage of unknown origin, resulting in a damaged internal structure that subsequently led to a local buckling failure of the pressure vessel. Contributing were US and international voluntary guidance and US small passenger vessel regulations that were insufficient to ensure OceanGate adhered to established industry standards. Also contributing was OceanGate's flawed analysis of their pressure vessel monitoring system data, which led to their continued operation of a damaged pressure vessel.

What We Recommended

As a result of this investigation, we recommended that the US Coast Guard commission a panel of experts to study current PVHO operations and disseminate findings of the study to industry. Additionally, we recommended that the US Coast Guard implement US regulations for PVHOs informed by the findings of the recommended study and consistent with international PVHO requirements and guidance. We also recommended that the US Coast Guard update NVIC 05-93 to include the revised definition of small passenger vessel as reflected in the Passenger Vessel Safety Act of 1993 and to reflect the findings of the recommended study. Finally, we recommended that the US Coast Guard propose that the International Maritime Organization make *MSC.1/Circ. 981* mandatory to promote consistent application of pressure vessel for human occupancy rules amongst member states.

1 Factual Information

1.1 Event Sequence

1.1.1 Synopsis

On June 18, 2023, about 1047 local time, while diving near the wreck of the ocean liner *Titanic* in the North Atlantic Ocean, about 372 miles southeast of St. John's, Newfoundland and Labrador, Canada, the submersible *Titan*'s pressure hull failed, and the vessel imploded (see figure 1).[1] All five persons on board the vessel died. The *Titan* was a total loss; according to a 2023 customs declaration, the submersible's value, combined with its launch and recovery system, was estimated at $5.6 million CAD (about $4.2 million USD).[2]

Figure 1. Submersible *Titan* descending on unknown date. (Source: OceanGate)

[1] In this report, all miles are nautical miles (1.15 statute miles).

[2] Visit ntsb.gov to find additional information in the public docket for this NTSB investigation (case no. DCA23FM036). Use the CAROL Query to search investigations.

1.1.2 *Titan* Submersible

The 22-foot-long submersible *Titan* was designed, built, and operated by OceanGate Inc., through its affiliate companies, to provide expeditions to the wreckage site of the ocean liner RMS *Titanic*, which was located in the North Atlantic Ocean, about 370 miles southeast of St. John's, at a depth of 3,880 meters (12,730 feet) (section 1.3 further describes the *Titan*, and section 1.5 describes OceanGate's operations).[3] The cylindrical-shaped 8.1-foot-long pressure hull (pressure vessel) portion of the submersible maintained atmospheric air pressure for the *Titan*'s human occupants during dives.[4]

The pressure vessel was constructed in 2020 and consisted of a thick-walled, carbon fiber-based composite cylinder fitted at each end with a titanium ring (segment) that was capped with a titanium dome (hemisphere) (see section 1.3.3 for more details about the vessel's construction) (see figure 2).[5] The titanium segments were glued to the cylinder, and the titanium domes were bolted to the segments.

[3] (a) In this report, *submersible* describes any self-propelled vessel that carries people and is designed to operate on the surface, submerge, operate submerged, surface, and remain afloat at the surface. It does not include submersibles that do not carry people, such as remotely operated vehicles. (b) In this report, depths are listed in meters because OceanGate dive requirements and measurements were given in meters. Metric measurements are converted to US standard measurements.

[4] At sea level, atmospheric pressure is 14.7 pounds per square inch. At the depth of the *Titanic* wreckage site, water pressure is 5,554.5 pounds per square inch. A submersible's pressure vessel is designed to withstand the pressure at the submersible's rated depth and maintain atmospheric pressure for human occupancy.

[5] In this report, the *Titan* pressure vessel includes the carbon fiber-based composite cylinder, titanium rings, and titanium domes. Everything external to the pressure vessel comprises the "outer hull."

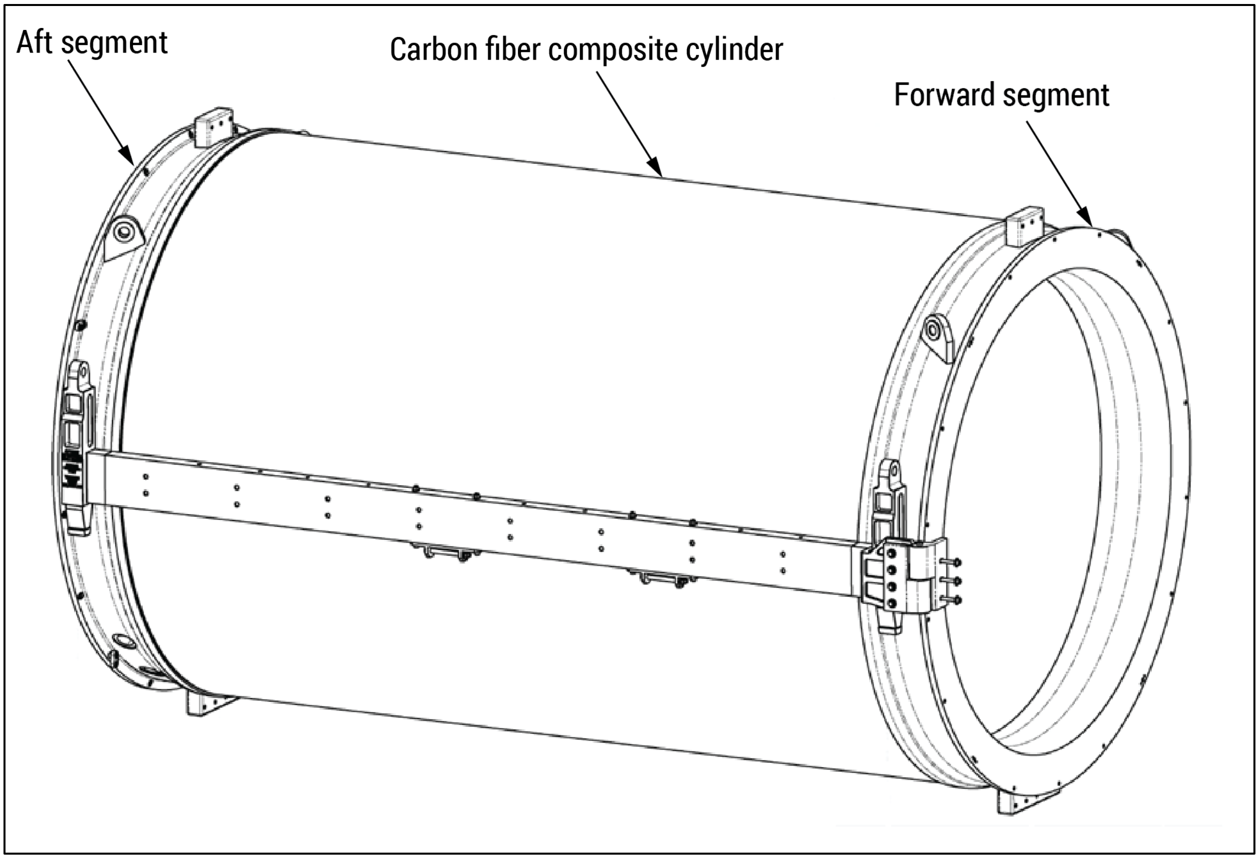


Figure 2. Pressure vessel composite cylinder and titanium end segments. Titanium spherical domes (not shown) were bolted to the segments at either end. (Background source: OceanGate)

Inside the pressure vessel was an occupant compartment, which could hold up to five people. The compartment contained the vessel's operational control: a wireless, battery-operated controller that communicated with control software—displayed on a monitor—to allow the operator to control the thrusters and drop weights. Oxygen tanks, a spare controller, and extra controller batteries were also stored in the compartment. The forward dome included a viewing port so occupants could look outside the submersible. A bulkhead separated the aft dome from the occupant compartment; the dome contained vessel control systems, servers, and processors.

Outside the pressure hull, an outer hull of fiberglass fairings was supported by a metal exoskeleton. Contained within the tail cone fairing were the submersible's hydraulic pumps, batteries for the thrusters, and other equipment. Four reversible, oil-filled thrusters (two horizontal and two vertical) with speed control provided the submersible with propulsion and were attached to the exterior of the fairings. A landing frame was used to secure the submersible while being transported (see figure 3).

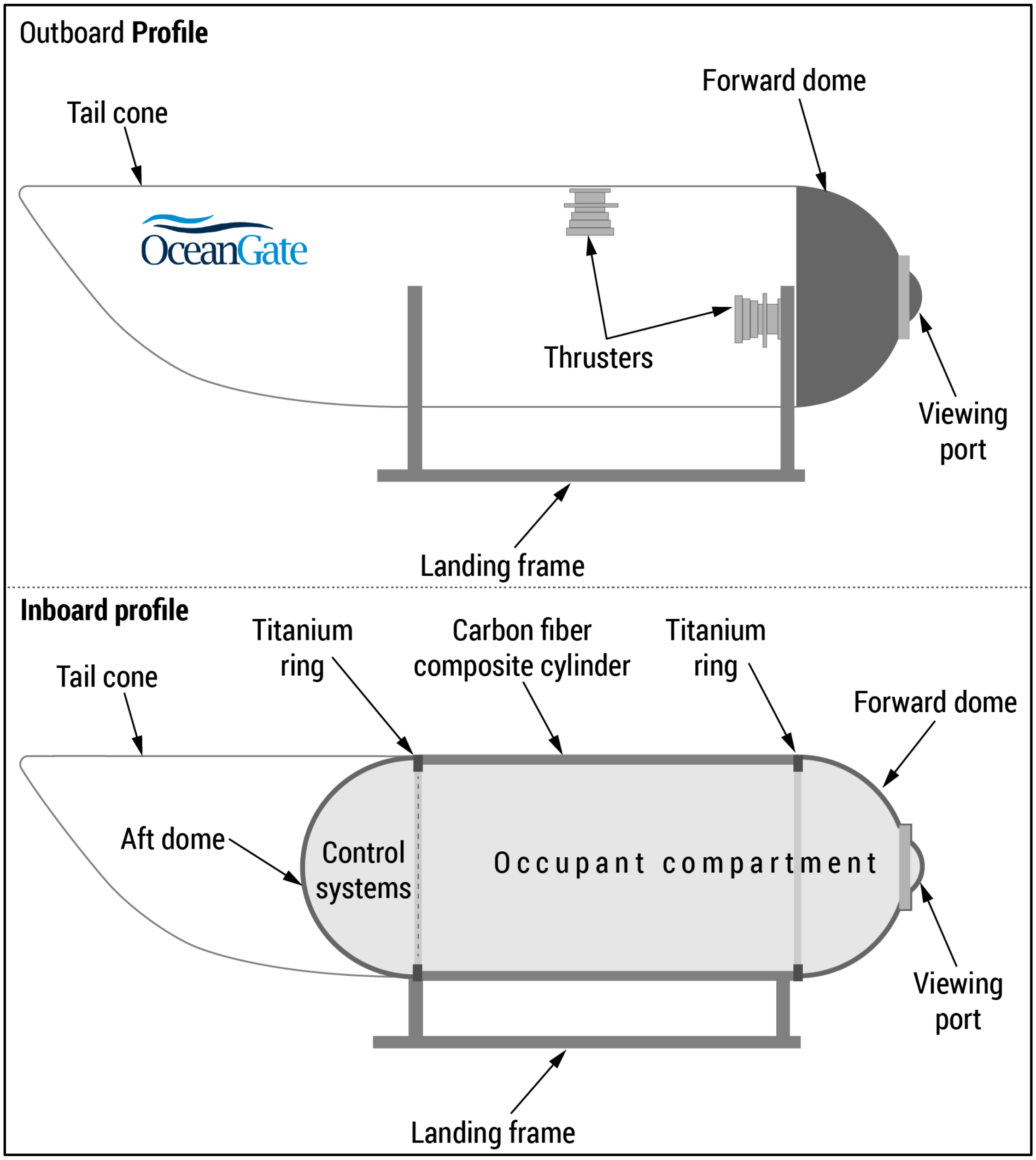


Figure 3. *From top*: Simplified profile view and inboard profile view of the *Titan* (scale approximate). Area highlighted in grey (bottom image) is the pressure hull.

For each mission, OceanGate loaded the *Titan* onto its launch and recovery system (LARS)—a purpose-built, floodable barge also owned by OceanGate that served as a launching platform for the vessel (see figure 4). To launch the *Titan*, divers opened valves to flood the barge, sinking it to 9.1 meters (30 feet), and then released the submersible, allowing it to thrust away.

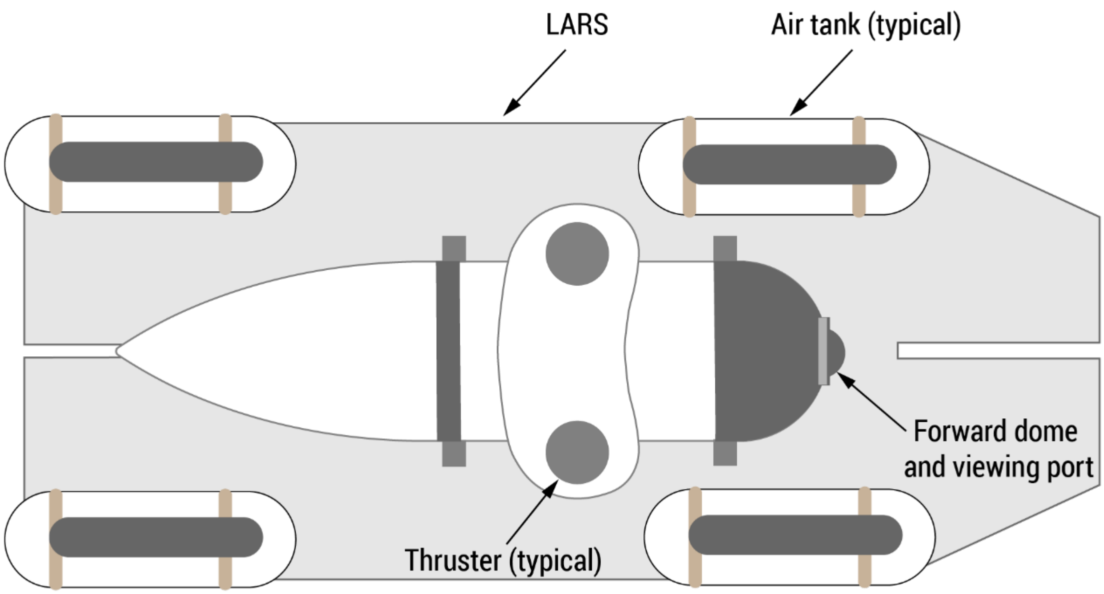


Figure 4. *From top*: Top-down view of *Titan* on LARS (scale approximate), and *Titan* secured on LARS in 2022. (Source [bottom]: Garry Comber)

The *Titan* had 4–6 cylindrical drop weights (operated by electric motors) per side with 25–30 pounds of steel shard in each weight. The weights were used to begin the submersible's descent by providing negative buoyancy. To slow the *Titan*'s descent, the pilot would drop weights to achieve neutral buoyancy. To ascend to the surface after a dive, the pilot would drop additional weights to achieve positive buoyancy. The submersible could also ascend to the surface using air bags supplied by high-pressure air tanks in the tail (variable ballast tanks) or the landing frame (which could be jettisoned). The drop weights were configured to automatically release after being submerged 24 hours, forcing the submersible to the surface.

To recover the *Titan* at the end of a dive, the *Titan* pilot would land the submersible on the submerged LARS, and divers (from the surface tender) would lock it down. Air stored in tanks on the LARS deck would displace the ballast water, and the LARS would surface with the submersible.

1.1.3 Precasualty Events

The *Titan* had completed two expeditions to the *Titanic* wreck—in 2021 and 2022. An expedition included 4–5 missions, and each mission typically included one or more planned dives (see section 1.3.7 and Appendix C). During the 2021 and 2022 expeditions, the *Titan* attempted numerous dives to the *Titanic* wreck but only successfully completed 13 dives to the wreck. These dives took an average of 8.3 hours to reach the *Titanic* and about 2.5 hours to ascend afterward.[6]

For each expedition, OceanGate chartered a vessel to act as a surface tender, either transporting or towing the *Titan* to the *Titanic* wreckage site and providing support for the submersible during expeditions and dives. In 2023, OceanGate chartered the 220-foot-long, Canadian-flagged vessel *Polar Prince* for use as a surface tender for the *Titan*'s 2023 expedition season.[7]

On May 12, OceanGate's first of six planned missions for the *Titan*'s 2023 expedition began. Over the next month, the *Titan* completed four missions: The first mission did not include any dives (OceanGate personnel worked to integrate with the *Polar Prince* crew and to collectively test dive procedures), the second mission included one uncrewed dive, the third mission included two crewed dives, and the fourth mission included one crewed dive. None of the dives exceeded 33 feet (10 meters) depth. For each mission, the *Polar Prince* towed the LARS from St. John's, Newfoundland and Labrador, Canada, to the designated dive area. At the end of each mission, the *Polar Prince* towed the LARS/*Titan* back to port in St. John's.

[6] Average dive and ascent times are based on dive data from 2022, the year for which dive data was available for all dives. Complete dive data was not available for 2021 or 2023.

[7] In this report, *surface tender* refers to a surface vessel that provides support to the submersible.

1.1.4 Event Narrative

On June 16, the fifth mission of the 2023 expedition began when the *Polar Prince* departed St. John's with the *Titan* and LARS in tow en route to the *Titanic* dive site. There were 42 persons on board the *Polar Prince*:

- 17 *Polar Prince* crewmembers.
- 3 individuals called "mission specialists" who had paid to participate in the mission.[8]
- 21 OceanGate personnel, including the OceanGate chief executive officer (CEO), who also served as the *Titan* pilot; the mission director, an OceanGate employee on the *Polar Prince* responsible for managing the dive); and other OceanGate employees, contractors, volunteers, and mission specialists' family members.
- 1 *Titanic* expedition guide who would dive with the pilot and mission specialists on the *Titan*.

On June 18, about 0400, the *Polar Prince* arrived at its destination (see figure 5). At the time, the winds were southwest at 13–19 knots. The *Polar Prince* crew and OceanGate personnel aboard the vessel began preparing for the dive. About 0530, the mission director and the CEO—who was also the pilot for the dive—held a pre-dive brief to review the dive plan and *Polar Prince* crewmember and mission specialist responsibilities during the dive.[9]

[8] OceanGate referred to its clients as "mission specialists." According to the "Project Execution Plan" for the *Titan* 2023 expedition, mission specialists were "guests who help fund OceanGate expeditions … [and] have the option to join the OceanGate crew" (see section 1.5.3). The crew of the tender (*Polar Prince*) assigned tasks based on their determination of each mission specialist's capability. This report refers to the three paying OceanGate clients as "mission specialists" based on OceanGate's labeling of them as such.

[9] OceanGate personnel briefed the mission specialists on dive plans during morning and evening meetings. These briefings did not involve the surface tender's crew.

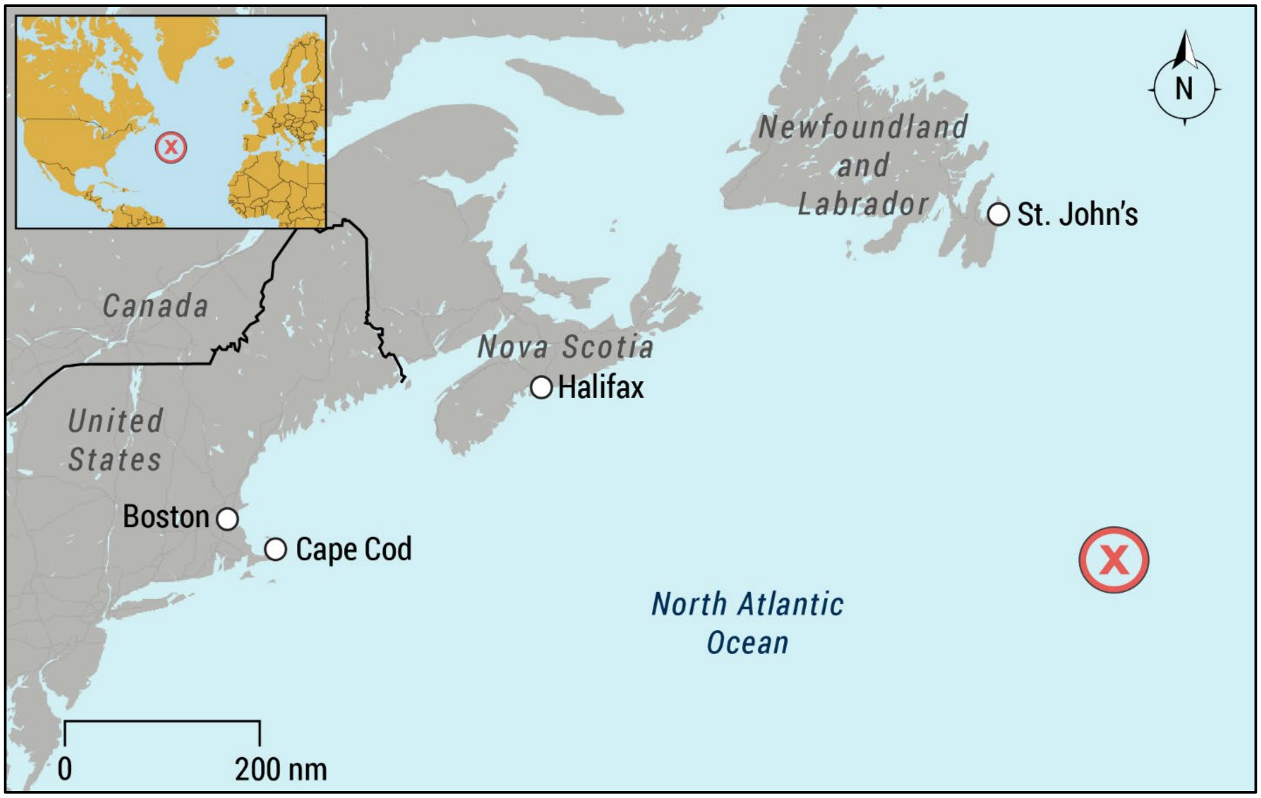


Figure 5. Area where the *Titan* dove to the *Titanic* wreckage, as indicated by a circled *X*. (Background source: Google Maps)

To allow the mission specialists to board the *Titan*, three OceanGate personnel opened the forward dome by using a pneumatic lifting device to support the weight of the dome while they loosened the 18 bolts that secured the dome to the forward segment and the hull. About 0800, the OceanGate CEO, the *Titanic* expedition guide, and the three mission specialists boarded the *Titan* and began preparing the vessel to dive. Once aboard, all individuals involved—both on the *Titan* and the *Polar Prince*—conducted a 5-minute planned hold, known as a "stopski." During a "stopski," individuals typically reviewed their checklists for missed items and reflected on their responsibilities for the dive; there was no talking.

About 0830, OceanGate personnel closed the forward dome by bolting it to the titanium segment. Divers opened the LARS valves and began sinking the platform (with the *Titan* on it) until the LARS was suspended by buoys; meanwhile, the OceanGate mission director conducted final checks on the *Polar Prince*.

About 0900, the *Titan* was released from the LARS and began its descent to the *Titanic* wreckage at a rate of 98 feet per minute (30 meters per minute). It was the first dive of the 2023 expedition to descend below 33 feet (10 meters). The dive was expected to take about 8 hours (2.5 hours to descend, 3 hours to explore the wreck, and 2.5 hours to ascend). The *Titan* had an estimated 96 hours—or about 4 days—of emergency oxygen and carbon dioxide-scrubbing capability when it dove.

While diving, the pilot on the *Titan* maintained communications with the *Polar Prince* via an acoustics system (see section 1.3). Transponders were attached to the submersible and transducers were suspended from the surface tender. The transponders used telemetry to transmit to the tender the submersible's position and depth. Additionally, the system allowed the submersible occupants to exchange text messages with the tender.

About 0919, the *Polar Prince* initiated the first communications check. Communications checks occurred every 10 to 15 minutes thereafter.

At 1047, while the *Titan* was at a depth of 11,032 feet (3,363 meters), OceanGate received a message that the submersible was dropping two weights (which was a standard procedure at this depth to slow its descent). At 1048, the *Polar Prince* sent a message back to acknowledge the *Titan*'s message, but they received no response.

At 1049, the *Polar Prince* sent the *Titan* a "lost tracking" message but received no response. OceanGate crew aboard the *Polar Prince* first assumed there was an issue with the acoustic communications equipment and sent two to three messages every minute in an attempt to restore communication with the submersible.[10] According to the *Polar Prince* captain, "this was not perceived to be an emergency by OceanGate."[11]

OceanGate's "Project Execution Plan"—which detailed requirements and operational procedures for the *Titan* 2023 expedition—required the submersible to begin ascending to the surface 60 minutes after communications were lost with the surface (see section 1.5.3). The mission director calculated that, given the *Titan*'s anticipated ascent rate and last known depth (11,032 feet), the *Titan* should have surfaced about 1500 had the pilot followed OceanGate's procedures. However, there

[10] The US Coast Guard was the lead federal agency in this investigation. In September 2024, the Coast Guard held a Marine Board of Investigation hearing, conducted over 2 weeks, as part of its accident investigation. During the hearing, the Coast Guard and NTSB investigators questioned 25 individuals, including former OceanGate staff, former mission specialists, industry leaders, regulatory authorities, and search and rescue specialists. Some of the factual information in this report, including quotes and statements, is derived from this testimony.

[11] During the accident dive, the *Titan* was equipped with a different communications system than had been used in previous expeditions (see section 1.3.5). According to an OceanGate software engineer, the *Titan* had lost communications during previous missions when using the submersible's thrusters, so it would not have been unusual for the vessel to lose communications.

was no indication that the vessel had surfaced. The *Polar Prince* crew continued their attempts to send messages to the *Titan* but received no response.

1.2 Response

After receiving no response from the *Titan*, about 1500, OceanGate personnel directed the *Polar Prince crew* to search the surface for the submersible. According to the *Polar Prince* captain, he was instructed to call for help after 3 hours if the *Titan* had not been found.

After 3 hours of searching, they still had not located the vessel, so, about 1855, the *Polar Prince* crew contacted Joint Rescue Coordination Center Halifax and, at 1910, US Coast Guard Rescue Coordination Center (RCC) Boston. Additionally, OceanGate personnel aboard the *Polar Prince* contacted Pelagic Research Services (Pelagic), one of the deep water remotely operated vehicle (ROV) operating companies listed in OceanGate's "Project Execution Plan," to coordinate use of their ROV, *Odysseus*, in searching for the *Titan*. Pelagic immediately started preparing the *Odysseus* ROV, which was capable of reaching 19,685 feet (6,000 meters). (The *Odysseus* was in Buffalo, New York, at the time.)

Because the area where the *Titan* dove was within US Coast Guard RCC Boston's Search and Rescue Region, the US Coast Guard coordinated search and rescue efforts (see figure 6).[12] The US Coast Guard did not monitor activity—including dives or expeditions—at the *Titanic*, nor were they aware of OceanGate's "Project Execution Plan." RCC Boston established a multi-agency, multinational Incident Management Team to coordinate resources, prioritize objectives, interpret data, and plan ROV operations. A US Coast Guard officer from the team testified, "… no one agency, and not even a single country had all the assets that we needed, and frankly, it took a collaboration between the public sector and private sector …."

[12] The RCC's role was to find and assign resources, plan searches, maintain communications with the on-scene coordinator, and provide search patterns. These procedures are prescribed in the *International Aeronautical and Maritime Search and Rescue Manual*, the *United States National Search and Rescue Supplement to the International Aeronautical and Maritime Search and Rescue Manual*, and the *U.S. Coast Guard Addendum to the US National Search and Rescue Supplement (NSS) to the International Aeronautical and Maritime Search and Rescue Manual (IAMSAR)*.

The US Coast Guard issued a SafetyNET HYDROLANT message at 2124, seeking assistance from nearby vessels to look out for a "21 foot submarine, white hull, overdue."[13]

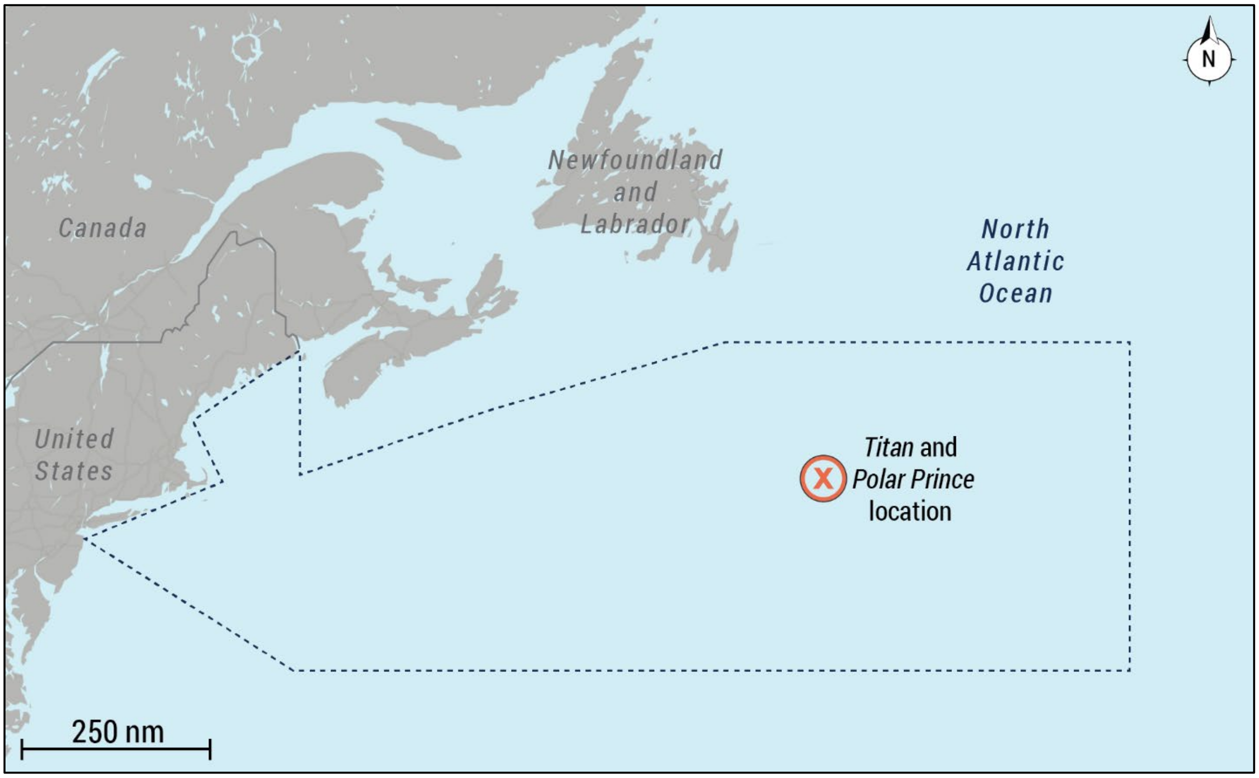


Figure 6. RCC Boston Search and Rescue Region. (Background source: Google Maps)

At 2200, a US Coast Guard C-130 Hercules, based in Elizabeth City, North Carolina, and assigned to the International Ice Patrol, launched from Newfoundland and Labrador. At 2203, the Coast Guard provided the *Polar Prince* with a search pattern to follow; however, the *Polar Prince* crew made the decision to remain where they were to focus on listening for possible communications from, or subsea indications of, the *Titan*. At 2325, the C-130 arrived on scene and began conducting an overflight air search.

On June 19, a second Elizabeth City-based C-130 conducted the first daylight search. Over the next 4 days, Canadian and US aircraft and ships arrived on scene and searched the surface for the *Titan* and the persons on board (Appendix C lists

[13] (a) SafetyNET enables international broadcasts of maritime safety information and search and rescue-related information. HYDROLANT marine navigational warnings are issued to provide urgent information about persons in distress or objects/events that pose an immediate hazard to navigation and safety of life at sea in the Atlantic Ocean. (b) The *Titan* was actually 22 feet (6.7 meters) long.

search and rescue assets that participated in the response). Additionally, Canadian naval aircraft deployed sonar buoys.[14]

The International Submarine Escape and Rescue Liaison Office (ISMERLO); the US Navy, as well as its Undersea Rescue unit in San Diego, California; and the Canadian Coast Guard coordinated to locate available ROVs capable of reaching the depth of the *Titanic*. US Coast Guard search and rescue personnel testified it would normally take 2 weeks to get an ROV to the location (transporting it via air to an offshore supply vessel, outfitting the offshore supply vessel, and assembling a crew).

On June 19, OceanGate contacted the US Air Force's RCC for help transporting Pelagic's *Odysseus* ROV from Buffalo (contacting the US Air Force for assistance with transport was not included in OceanGate's Project Execution Plan).

The commercial cable ship *Deep Energy* was the first to arrive on scene with ROVs. Responding to an ISMERLO request, the vessel arrived on scene about 1500 on June 20 (about 34 hours after the request) with two ROVs capable of reaching 9,843 feet (3,000 meters). OceanGate personnel moved from the *Polar Prince* to the *Deep Energy*, and the *Deep Energy* crew deployed one ROV to its maximum cable length but found nothing. Next, in an effort to reach the seabed, they dove the ROV beyond its rated depth, almost another 3,281 feet (1,000 meters); the ROV was destroyed in the process. They then used the second ROV for sonar scanning.

Over the next 2 days, two ROVs capable of reaching 6,000 meters (19,685 feet) arrived on scene. The US Air Force Reserve's Ohio-based 910th Air Wing flew the ROV *Odysseus* on a C-130 to Newfoundland and Labrador, where it was loaded aboard the *Horizon Arctic* about 0500 on June 21. The French research vessel *Atalante* responded from midocean, carrying the ROV *Victor 6000*.

On June 22, both the *Atalante* (with the *Victor 6000*) and the *Horizon Arctic* (with the *Odysseus*) were in position over the site. Both ROVs were deployed; the *Odysseus* conducted search patterns while the *Victor 6000* was positioned to serve as backup in case the *Odysseus* had to be recovered.

At 0940, the *Odysseus* discovered a debris field consistent with the *Titan*, including the tail cone and both titanium domes, near the submersible's last known position, about 500 meters (1,148 feet) northeast of the bow of the *Titanic*. There were no survivors.

[14] Typically used for underwater acoustic research or anti-submarine warfare, *sonar buoys* (or sonobuoys) are used to detect, locate, and track submarines.

1.3 Vessel Information

1.3.1 General

Built in 2020 by OceanGate, the submersible *Titan* was owned by Cyclops II Inc. and operated by OceanGate Expeditions, both affiliate companies of OceanGate Inc. OceanGate leased the *Titan* to OceanGate Expeditions, which was based in The Bahamas and created to operate the *Titan* on expeditions to the site of the *Titanic* wreckage. According to OceanGate, the *Titan* could dive to 4,000 meters (13,123 feet) and could carry up to five persons, including one pilot.

The *Titan* was not registered in any US state, documented by the US National Vessel Documentation Center, nor inspected by any flag state.[15]

Table 1 shows the vessel particulars for the *Titan*.

Table 1. Vessel Particulars.[a]

Vessel	***Titan***
NTSB Vessel Group	Specialty/Other (Submersible)
Owner/Operator	Cylcops II Inc/OceanGate Expeditions (Commercial)
Flag	N/A
Port of registry	N/A
Year built	2020
Official number (US)	N/A
IMO number	N/A
Classification society	N/A
Length (overall)	22.0 ft (6.7 m)
Breadth (max.)	9.2 ft (2.8 m)
Draft (casualty)	N/A
Tonnage	4 GRT est.

[15] A flag state is a country where a commercial vessel is registered. The flag state routinely conducts inspections of vessels flagged in its country to ensure safety of the vessel and its crew and compliance with flag state regulations. Owners of vessels choose which country in which to register ("flag") the vessel; the country may or may not be the country in which the owner resides.

Vessel	*Titan*
Engine power; manufacturer	4 x 12 hp; Innerspace 1002HL Hexscreen Electric Thrusters
Persons on board	5

[a] Most of the information in this table is sourced from OceanGate marketing materials and its operating manual for the *Titan*. The tonnage was calculated by the US Coast Guard.

1.3.2 Classification

Classification societies are nongovernmental organizations that establish and maintain standards for shipbuilding and operations. They may also be delegated by a flag state to perform certain flag state vessel inspection and certification functions. A vessel owner or operator may choose to work with a classification society to "class" the vessel. The classification process involves reviewing plans and documentation before and during construction to ensure they meet applicable classification standards in place at the time, witnessing critical testing, and surveying the vessel. Upon completion of the process, the classification society issues a certificate of classification for the vessel. To maintain a valid certificate of classification, a vessel must undergo additional periodic surveys to ensure compliance with class rules.

According to former OceanGate personnel, the company originally intended for the *Titan* to be classed by a classification society. OceanGate's former director of marine operations stated that, when he was hired in 2016, the company planned to class the submersible through Lloyd's Register or DNV.[16] According to the first OceanGate director of engineering, OceanGate also considered calling the vessel

[16] Det Norske Veritas and Germanischer Lloyd merged in 2013 to form DNV GL. The company changed the name to DNV in 2021.

"experimental."[17] The first director of engineering also stated that the OceanGate CEO funded the classing process himself. However, the OceanGate CEO ultimately decided classing the *Titan* would take too long, and, according to the first director of engineering, the CEO "was extremely pressured for funding as time went on."

In 2018, OceanGate abandoned classing efforts. In February 2018, while OceanGate was designing and constructing the *Titan*, members of the Marine Technology Society's Submarine Committee met for a conference.[18] Since they were aware of OceanGate's efforts to develop the *Titan* as well as the dangers of diving near the *Titanic*, they decided to draft a letter to the CEO of OceanGate, expressing "unanimous concern regarding the development of 'TITAN' and the planned Titanic Expedition." The letter stated:

> … the current "experimental" approach adopted by OceanGate could result in negative outcomes (from minor to catastrophic) that would have serious consequences for everyone in the industry.[19]

[17] (a) Classification societies have a path for owners to prove seaworthiness of new technology. However, classification societies and the US Coast Guard have no "experimental" design endorsement for vessels carrying passengers or cargo. The US Coast Guard's current approach to passenger submersibles "is to require a level of safety equivalent to that required for a surface craft of similar size and service for owners pursuing a COI to operate as a small passenger vessel" (US Coast Guard 2025). Additionally, to assist submersible owners in the process of certifying vessels with a "novel design," the US Coast Guard issued CG-ENG Policy Letter 01-23 to provide guidance on submitting design standard equivalencies for consideration. (b) Between 2016 and 2023, OceanGate had three directors of engineering. The first director of engineering, who had a background in diving and engineering, worked for the company between 2016 and 2019 during the design, development, and testing of the first pressure vessel (see section 1.3.3.1). The second director of engineering had a background in engineering management and worked for the company between 2019 and 2021, during the design and development of the second pressure vessel (see section 1.3.3.2). The third was a software engineer who had worked extensively with the acoustic emission system; he was promoted in 2021 (after the construction of a second pressure vessel) and left the company in 2023. After the third director left OceanGate, a software engineer was the most senior staff member in the engineering department.

[18] The Marine Technology Society is an international society that "promotes awareness, understanding, and advancement and application of marine technology." See https://www.mtsociety.org/about-us. The Marine Technology Society Submarine Committee, also known as the Manned Underwater Vehicles Committee, is comprised of organizations and individuals that participate in the "'manned' quest, evolution and exploration of the underwater world through the use of submersible vehicles." The Submarine Committee provides resources on active submersibles, operators, and manufacturers and organizes an annual symposium for members. See https://www.mtsmuv.org/committee.

[19] The Marine Technology Society's letter was one exhibit presented during the Coast Guard's 2024 Marine Board of Investigation (see Exhibit CG-068).

Additionally, the letter advised OceanGate's CEO of the importance of following class rules when designing and developing a submersible. The letter was signed by dozens of other industry representatives.

The Marine Technology Society never formally sent the letter. However, according to one signatory, the CEO received the letter; afterward, in a conversation with the CEO, the signatory expressed concern that OceanGate was "highly inferring that the vehicle [*Titan*] is classed" and was using the name of a classification society on their website.[20] According to the signatory, the CEO stated that classification was "too expensive" and "not doable."

OceanGate's website was later updated to reflect that the *Titan* was an "experimental submersible." In a 2019 blog post on its website, OceanGate stated,

> … by itself, classing is not sufficient to ensure safety. In part this is because classing does not properly assess the operational factors [that] are vital for ensuring a safe dive, and because classing assessments are done annual (at best) and do not ensure that the operator follows procedures or processes that are key to conducting safe dive operations. (OceanGate 2023).

1.3.3 Construction

Between 2016 and 2021, OceanGate developed and tested two pressure vessels (v1 and v2) for the *Titan*. OceanGate used their submersible *Cyclops I* as a prototype to build the *Titan* (see section 1.5.5). The company's original optimal design goal was for the submersible to be rated to dive up to 6,000 meters (19,680 feet) with a 2.25 safety factor and a 10,000-cycle life limit.[21]

1.3.3.1 First Pressure Vessel

1.3.3.1.1 Design and Development

Before constructing a full-scale pressure vessel for the *Titan*, OceanGate hired Spencer Composites in 2015 to complete a stress analysis for a carbon fiber cylinder

[20] The signatory referenced in this report also provided testimony that OceanGate's CEO was aware of the contents of the letter during the US Coast Guard's 2024 Marine Board of Investigation.

[21] *Safety factor* in submersible design is the ratio between the failure depth and the maximum allowable operational depth. A 3,000-meter (9,843-foot) depth limit and 1.5 safety factor would correspond to a 4,500-meter (14,764-foot) failure depth. *Cycle life limit* is the number of dives (from the surface, diving, and back to the surface).

design; the analysis indicated an implosion depth about 13,200 meters (43,307 feet). After the analysis was completed, OceanGate worked with Spencer Composites to construct a one-third scale model of the pressure vessel to visualize their prototype and test its design features. Spencer Composites constructed the model sometime before March 2016. The sub-scale model pressure vessel comprised two carbon fiber domes and a carbon fiber composite cylinder. The composite cylinder for the subscale model was constructed using a method called wet winding—wherein carbon fiber strands were run through a bath of liquid resin, and the resin-laden strands were then used to construct the cylinder. According to a former OceanGate director of marine operations, the CEO chose carbon fiber because he believed it was "better in compression than tension." Additionally, since carbon fiber is lighter than other materials, such as steel or titanium, the CEO believed it would require less buoyancy and could be launched from a bigger variety of surface tenders—as opposed to necessitating a purpose-built ship—and it would also be easier to transport and could carry more people.

During two successive tests of sub-scale models, the carbon fiber domes prematurely failed, so OceanGate replaced the carbon fiber domes with titanium end domes constructed by TiFab. During testing in June 2016, the updated sub-scale model pressure vessel imploded at a depth of about 4,200 meters (13,780 feet). According to the CEO, that model had a delamination in the carbon fiber cylinder.[22]

In 2018, Spencer Composites constructed the first (v1) full-scale *Titan* pressure vessel with the outer hull—including the fairing, landing frame, and external equipment—again using wet winding to construct the carbon fiber cylinder and titanium domes.

1.3.3.1.2 Test Dives

Between February 2018 and June 2019, OceanGate completed 49 dives of the *Titan* v1 pressure vessel with outer hull to varying depths in Everett, Washington, and The Bahamas (see Table 2).[23]

[22] A *delamination* is a failure mode in layered materials where a separation forms between layers. The *Titan* carbon fiber cylinder was built from many layers (laminae). The delamination in the model cylinder was a separation that formed between two of these layers.

[23] OceanGate assigned a sequential dive number to each outing of the *Titan* (both the v1 and v2 pressure vessels), no matter the purpose of the outing or the maximum dive depth. Thus, dive numbers do not correlate with attempts to reach the *Titanic*. See Appendix C: for a list of expedition dives. See US Coast Guard MBI Exhibit CG-052 for a complete list of dives.

Table 2. Dives conducted using the first full-scale *Titan* pressure vessel. (Data source: OceanGate)

Dive	Date	Location	Depth reached (range)	No. dives beyond 100 m	No. crewed dives (at least a pilot)
1-18	2/6/18–4/9/18	Everett	3 to 37 meters	0	15
19-48	5/8/18-4/18/19	The Bahamas	2 to 4,000 meters	13	20
49	8/17/2019	Everett	1 meter	0	1

During dives 42 through 44 and 45.1 through 47, conducted in The Bahamas in 2019, persons aboard the *Titan* reported hearing cracking sounds.[24] In June 2019, after dive 48, while making preparations for a dive, an OceanGate employee noticed a hairline fracture in the pressure vessel cylinder and reported it to OceanGate leadership. An examination of the crack indicated that it had originated from a sub-surface delamination (an internal separation within the carbon fiber cylinder). OceanGate subsequently halted field testing of the *Titan*. OceanGate shipped the *Titan* back to Washington and attempted one dive (dive 49) in Everett Marina, but the dive was aborted due to an issue with the improperly secured blanks (a type of plug) on the LARS.

OceanGate had planned for the *Titan* to begin diving to the *Titanic* wreck site in summer 2019 and had booked clients ("mission specialists") for an expedition during that time. However, the first director of engineering stated that he told the CEO that because there was a crack, the pressure vessel hull was "done," he was "not going to take this [the *Titan*] anywhere." The director of engineering stated that he would not sign off on the planned 2019 expedition. He was terminated shortly thereafter. The planned 2019 expedition to the *Titanic* wreck site was cancelled.

The v1 pressure vessel was shipped to the Deep Ocean Test Facility, then operated by Northrup Grumman, in Annapolis, Maryland, for additional testing. OceanGate condemned the v1 pressure vessel following this testing and postponed its planned 2020 expedition.

[24] Dive 45 occurred on March 20, 2019, and was an uncrewed surface/buoyancy test. OceanGate designated the following dive on April 12, 2019, as "dive 45.1."

1.3.3.2 Second Pressure Vessel

1.3.3.2.1 Design and Development

Under a new (second) director of engineering, in 2020, OceanGate embarked on a second stress analysis and testing program for a second (v2) *Titan* pressure vessel design. The second stress analysis predicted an implosion depth for the carbon fiber cylinder of about 7,500 meters (24,606 feet). It also indicated that the depth of the *Titan* was limited to 4,200 meters (13,790 feet) due to the potential for deformation of the titanium forward dome around the viewport.

OceanGate constructed a one-third scale model to test the v2 pressure vessel design. The carbon fiber cylinder was constructed using unidirectional filament-wound carbon fiber pre-impregnated with an epoxy resin (pre-preg) purchased in rolls instead of using the wet winding method to create resin-laden carbon fiber strands—as had been done for the v1 cylinder. (The pre-preg carbon fiber came from the fiber manufacturer with the resin already applied to the fiber.) OceanGate staff slit the rolls into 0.5-inch-wide reels (tows) and built the cylinder by winding the tows onto a cylindrical carbon steel mandrel by automatic fiber placement at an Electoimpact, Inc. facility, in Mukilteo, Washington.[25]

OceanGate began testing the sub-scale model on July 26, 2020, at the University of Washington's Oceanography Laboratory. The model pressure vessel developed wrinkles in the carbon fiber composite cylinder and imploded at 2,800 meters (9,186 feet). OceanGate identified wrinkles in the cylinder as a likely cause of failure.

OceanGate constructed a second sub-scale model using the pre-preg carbon fiber. On August 20, the second sub-scale model was tested at the same laboratory; OceanGate stopped the test at 2,500 meters (8,202 feet), when pressure vessel integrity monitoring data made it clear that the model pressure vessel was going to fail. The second sub-scale model had wrinkles in the cylinder like the first sub-scale model.

Afterward, based on the company's experience with the sub-scale models and the experience of its manufacturing partners, OceanGate decided to use a co-bonding process to construct the cylinder to mitigate the development of wrinkles.

[25] *Automatic fiber placement* is a robotic means of building carbon fiber composite structures. It allows the continuous application and compaction of pre-preg carbon fiber during article construction.

OceanGate constructed a second (final) full-scale pressure vessel (v2) using the co-bonding process between November 2020 and January 2021.

The v2 full-scale pressure vessel cylinder was manufactured from rolls of pre-preg carbon fiber—again by winding 0.5-inch-wide tows onto a cylindrical carbon steel mandrel by automatic fiber placement—and constructed as a series of five co-bonded, nominally 1-inch-thick composite layers. Each layer consisted of 133 pre-preg plies applied to the mandrel following a predetermined build ply sequence. The sequence consisted of two cylindrical plies followed by one longitudinal ply. The sequence was repeated until all 133 plies had been applied. According to data published by the fiber manufacturer, this would have resulted in a nominal 0.9975-inch-thick layer. A removable layer (peel ply) was applied on top of the pre-preg, and the assembly was cured in an autoclave (autoclave curing was performed at Janicki Industries, Inc. in Hamilton, Washington).[26] After autoclave curing, the peel ply was removed and an adhesive film was applied to the cylinder surface. The build ply sequence was then repeated and the assembly was autoclaved until the cylinder was (nominally) 5 inches thick (see figure 7).

[26] An *autoclave* is an oven where the air inside the chamber can be pressurized above ambient air pressure. The positive pressure and high temperatures were used to compress and consolidate the pre-preg composite material during a curing cycle.

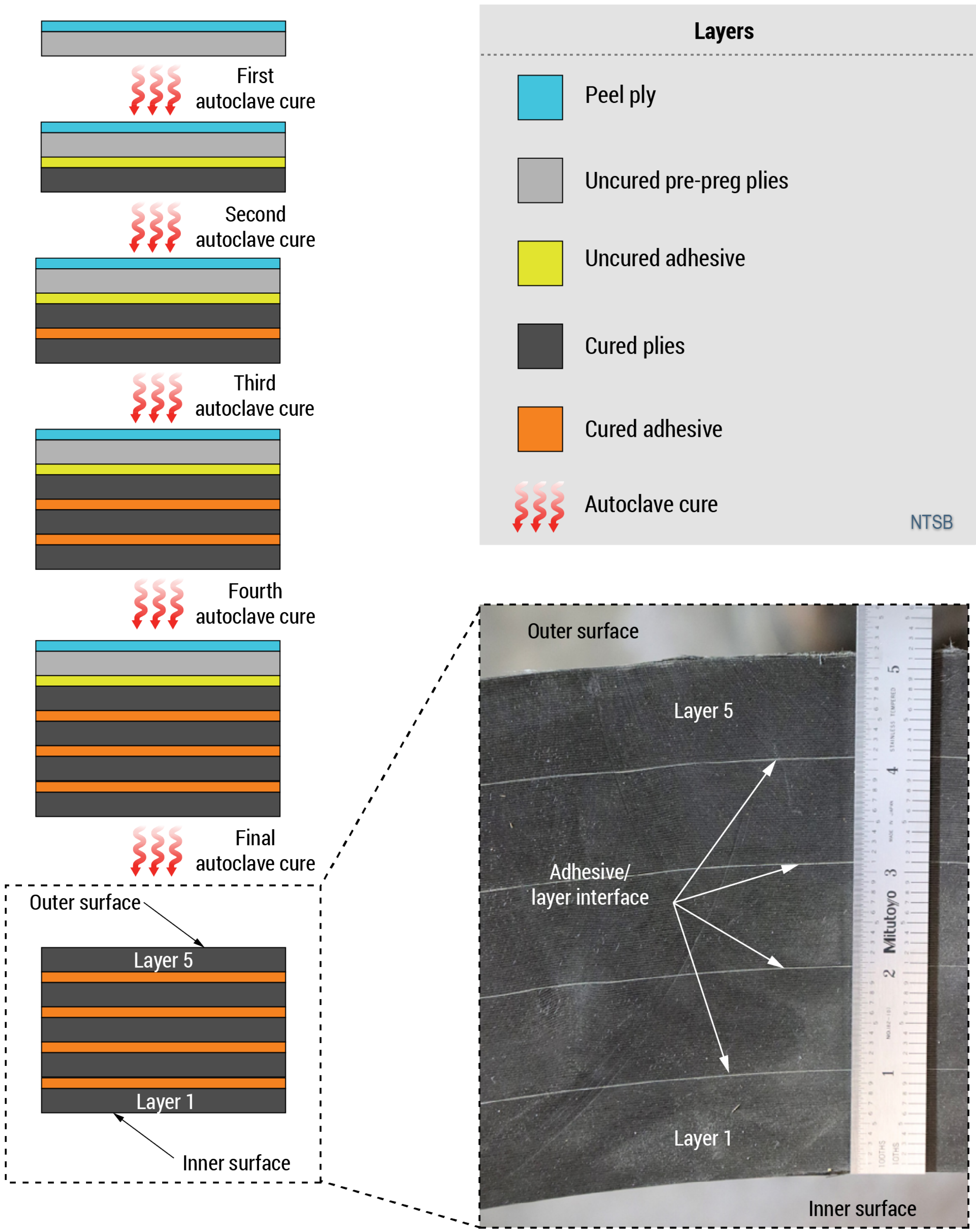


Figure 7. Representation of co-bonding process used to manufacture the *Titan*'s hull. Inset is a cross-section of the actual *Titan* cylinder wall showing the co-bonded layered structure.

The cylinder was manufactured with excess material at both ends, which was subsequently trimmed off. The trimmed cylinder was then glued to commercially pure grade 3 titanium segments.[27] The cylinder-facing side of both segments contained an annular C-shaped channel; the cylinder was inserted into this channel and joined using an epoxy paste adhesive. The titanium domes were attached to the segments using 18 bolts to cap the pressure vessel at either end. The forward dome included a viewing port constructed of an acrylic window certified to 1,000 meters (3,281 feet).[28] The segments, domes, and viewing port had been built for the v1 pressure vessel and were reused with the replacement v2 composite cylinder.

1.3.3.2.2 Testing

The v2 full-scale pressure vessel was pressure tested at the Deep Ocean Test Facility in Annapolis between February 25 and March 4, 2021, to a simulated maximum depth of 4,200 meters (13,780 feet). According to analysis performed under contract for OceanGate, the test depth was limited by the yield strength of the forward titanium dome at a location around the viewport.

From April 29 to May 25, 2021, OceanGate conducted 11 test dives (dives 50 to 60) of the v2 pressure vessel in Washington to a maximum depth of 170 meters (558 feet) (dive 56) (see Table 3). Afterward, OceanGate began using the pressure vessel for expeditions up to a maximum depth of 3,840 meters (12,598 feet) (see section 1.3.7).

Table 3. Dives conducted using the second full-scale *Titan* pressure vessel. (Data source: OceanGate)

Dive	Date	Location	Depth reached	Including at least a pilot
50	4/29/21	Everett	3 meters	Yes
51	5/2/21	Everett	7 meters	Yes
52	5/6/21	AO	79 meters	Yes
53	5/8/21	Possession Sound	8 meters	Yes
54	5/12/21	Everett	3 meters	Yes

[27] Unalloyed (pure) titanium is graded 1 to 4 based on the level of trace elements allowed in the metal. The grades provide a tradeoff between formability and mechanical strength. Grade 3 titanium is high-strength, formable, and corrosion-resistant.

[28] The viewing port was a non-standard design—it was thick in the middle and thinner toward the edge, rather than maintaining a constant thickness. Because the design had not been studied thoroughly, the manufacturer (Hydrospace) would only certify it to 1,000 meters.

Dive	Date	Location	Depth reached	Including at least a pilot
55	5/14/21	Everett	3 meters	Yes
56	5/17/21	*Al-Ind-Esk-A-Sea*	79 meters	Yes
57	5/19/21	Everett	3 meters	Yes
58	5/20/21	Hat Island, Washington	170 meters	Yes
59	5/24/21	Everett	3 meters	Yes
60	5/25/21	Hat Island, Washington	162 meters	Yes

1.3.4 Real-time Monitoring System

The *Titan* was equipped with a system for monitoring the structural health of the pressure vessel; OceanGate called it the "real-time monitoring (RTM) system." The system was comprised of eight acoustic emission sensors, eight circumferential (hoop) strain gages, and eight longitudinal (axial) strain gages. Hoop and longitudinal strain gages were co-located. Some acoustic sensors were co-located with strain gages, and some were not. Acoustic sensors and strain gages were assigned channel numbers 1 through 8, but sensors and gages with the same channel number were not always placed in the same location. The RTM system was only operational during dives and recorded to a series of computers on board the *Titan*.

During a dive, acoustic events were continuously monitored via the acoustic emission sensors. After amplification of the acoustic emission signal and analog-to-digital conversion, if an acoustic event exceeded a predetermined threshold, the event was counted as a "hit," indicating that micro-cracking was occurring in the pressure vessel. Pre-programmed levels would trigger a green, yellow, or red indicator to the pilot based on the number of hits. The warning levels were based on the acoustic activity of the v1 pressure vessel when it was tested at the Deep Ocean Test Facility after OceanGate discovered the crack and of the sub-scale pre-preg pressure vessels that were built afterward. According to the third OceanGate director of engineering, if the system detected 30 hits during a dive, the system issued a yellow display warning. If 50 hits were detected, a red warning was issued, and the dive was to be aborted. Hit counts did not accumulate between successive dives, and hits while at the surface were not counted.

OceanGate processed acoustic emission and strain gage data collected by the RTM system after dives, in accordance with their typical procedure. According to the third and final director of engineering, pressure vessel monitoring data were collected for the v1 *Titan* pressure vessel (during testing in Washington and The Bahamas in 2018 and 2019), but no time or depth information was included. During the development of the v2 pressure vessel, the data acquisition software was rewritten to include these parameters and to reduce the data to a manageable size. OceanGate staff plotted, for each v2 pressure vessel dive, pressure vessel strain side-by-side with dive depth as a function of time (see section 1.6). OceanGate assumed that, as the pressure vessel's condition deteriorated, it would gradually transition from a sound pressure vessel to one that produced acoustic events of a similar amplitude and frequency as the previous *Titan* pressure vessels (v1 sub-scale models, v1 full-scale model, and v2 sub-scale models). OceanGate believed that these data would give them indication that they should safely retire the pressure vessel from service.

1.3.5 Cameras

On the *Titan*, four cameras provided visibility for the pilot and occupants and aided in navigation during dives:

- a forward-facing camera mounted near the viewing port, which provided a clear view of the area forward of the *Titan*;
- a camera mounted to the outer hull on the bottom of the vessel, which helped the pilot monitor the *Titan*'s proximity to the seafloor, dropping weights, and takeoff and landing from the LARS;
- an aft-facing camera, which provided a view of obstacles aft of the *Titan* when the pilot reversed the submersible; and
- an internal camera, which provided additional visibility forward through the viewing port.

1.3.6 Communications

During the 2023 expedition, the *Titan* was equipped with an EvoLogics communications system that allowed for communication—via textual messaging—between the submersible and the *Polar Prince* (surface tender).

The *Titan* was also equipped with a VHF radio to communicate with personnel on the surface tender and an Iridium beacon used by the surface tender to locate the submersible after it surfaced.

1.3.7 Expeditions

OceanGate conducted two complete expeditions to the *Titanic* with the final (v2) *Titan* pressure vessel hull—one in 2021 and one in 2022. In 2023, OceanGate completed a partial expedition with the *Titan* (including the casualty dive). OceanGate took mission specialists on each expedition.

1.3.7.1 2021 Expedition

The 2021 *Titanic* expedition began on June 24, 2021, and ended on August 6, 2021 (five missions, including dives 61 to 70). For each expedition mission, the Canadian-flagged offshore supply vessel *Horizon Arctic* carried the *Titan* and its LARS aboard/on deck (see Appendix E for vessel particulars for the surface tenders used to transport the *Titan*). Each mission began with 2.5 days to transit to the *Titanic* wreck site from St. John's, followed by 3–4 days on scene, and ending with another 2.5 days to return to St. John's. According to the OceanGate dive log, the *Titan* reached 3,840 meters (12,598 feet, the depth of the *Titanic*) six times and 3,500 meters (11,483 feet) one time during the 2021 expedition (see Table 4).

Table 4. Dives conducted during the 2021 expedition.

Mission	Dive	Date	Depth reached (meters)	Type of dive
1	61	6/30/2021	7	System test
	62	7/3/2021	1,700	System test
2	63	7/9/2021	3,840	System test
	64	7/13/2021	89	System test
3	65	7/19/2021	3,500	Exploration
4	66	7/24/2021	3,840	Exploration
	67	7/27/2021	3,840	Exploration
	68	7/28/2021	3,840	Exploration
5	69	8/4/2021	3,840	Exploration
	70	8/5/2021	3,840	Exploration

The *Titan* and its LARS experienced numerous issues during the 2021 expedition. On June 30 (dive 61), during mission 1 of the 2021 expedition, OceanGate personnel and *Horizon Arctic* crewmembers were preparing to launch the LARS and *Titan* from the *Horizon Arctic*, which was outfitted with a ramp with rollers off the stern (figure 8 shows the ramp). After mission specialists had boarded the *Titan*, the LARS came down on the deck with enough force that the bolts holding the forward dome sheared (during this dive and previous dives OceanGate had only secured the dome using four bolts to speed recovery time). The dome slid down the ramp and became stuck on a fitting, with the occupants still in the now-open submersible. There were no injuries. Following this incident, OceanGate decided to secure the *Titan*'s domes with all 18 bolts, even though it would take longer to get the occupants out of the submersible during recovery. After the event, OceanGate executed a dive (no. 62) to 1,700 meters (5,577 feet), completing mission 1.

Figure 8. The *Titan* and LARS being launched via stern ramp from the *Arctic Horizon* in 2022. (Source: Garry Comber)

On July 9, 2021 (mission 2, dive 63), the *Titan*'s drop weights were jettisoned due to a failed electric motor, the aft port fairing was ripped off, the sonar died, and the lights flickered. Additionally, the CEO heard a sound he described like "a slap of the ruler on the table." After the dive, OceanGate replaced the drop weight system, including the motors, and tested the replacements.

On dives 67 and 68 (mission 4), the LARS was damaged while the pilot attempted to land the *Titan* on it. OceanGate did not document any maintenance performed on the LARS after these dives.

After the 2021 expedition concluded on August 6, 2021, OceanGate shipped the *Titan* and LARS to Everett, where they were stowed indoors at an OceanGate facility during the winter season.

1.3.7.2 2022 Expedition

The 2022 expedition began on June 12, 2022, and ended on July 25, 2022 (four missions, including dives 71 to 83). OceanGate again used the *Horizon Arctic* as a surface tender during this expedition. According to the OceanGate dive log, the *Titan* reached 3,840 meters (12,598 feet) seven times (see Table 5).

Table 5. Dives conducted during the 2022 expedition.

Mission	Dive	Date	Depth reached (meters)	Type of dive
1	71	6/16/2022	7	System test
	72	6/18/2022	1,380	Exploration
	73	6/20/2022	3,840	Exploration
2	74	7/1/2022	25	System test
	75	7/3/2022	3,840	Exploration
	76	7/6/2022	3,840	Exploration
	77	7/8/2022	30	System test
3	78	7/11/2022	10	Exploration
	79	7/14/2022	3,840	Exploration
	80	7/15/2022	3,840	Exploration
4	81	7/19/2022	3,840	Exploration
	82	7/22/2022	3,840	Exploration
	83	7/23/2022	2,954	Exploration

The *Titan* once again experienced numerous issues during the 2022 expedition. On June 19, 2022 (mission 1, dive 73), the *Titan*'s batteries died before the submersible could land on the LARS. The pilot was unable to use thrust, and divers were unable to secure the submersible on the LARS due to rough seas, so the *Titan* remained on the surface with occupants aboard overnight.

On July 15, 2022 (mission 3, dive 80), mission specialists inside the *Titan* and the crew of a small boat on the surface heard a "loud bang" as the *Titan* ascended after successfully reaching the *Titanic* wreckage (3,840 meters). According to a former mission specialist and crew on the *Horizon Arctic*, staff and mission specialists were told the hull had shifted in its metal cradle. The CEO wanted to continue operations and, after inspecting the strain and acoustic emission data, told the director of engineering, "Let's dive again and see what happens" (see section 1.6 for acoustic emission data from this dive). The *Titan* completed three additional dives following dive 80 (mission 4, dives 81-83); the submersible reached 3,840 meters (12,598 feet) on dives 81 and 82 and 2,954 meters (9,692 feet) on the final dive of the expedition.

After the 2022 expedition, the *Titan* was initially stowed at an outdoor location in St. John's. It was left in a parking lot, outside, uncovered (see figure 9). In early 2023, the submersible was moved to storage at an indoor bay dedicated for ROVs at Memorial University's Marine Institute in St. John's. In April 2023, the vessel was moved to the Institute's Holyrood Facility for installation on the LARS for the 2023 expedition.

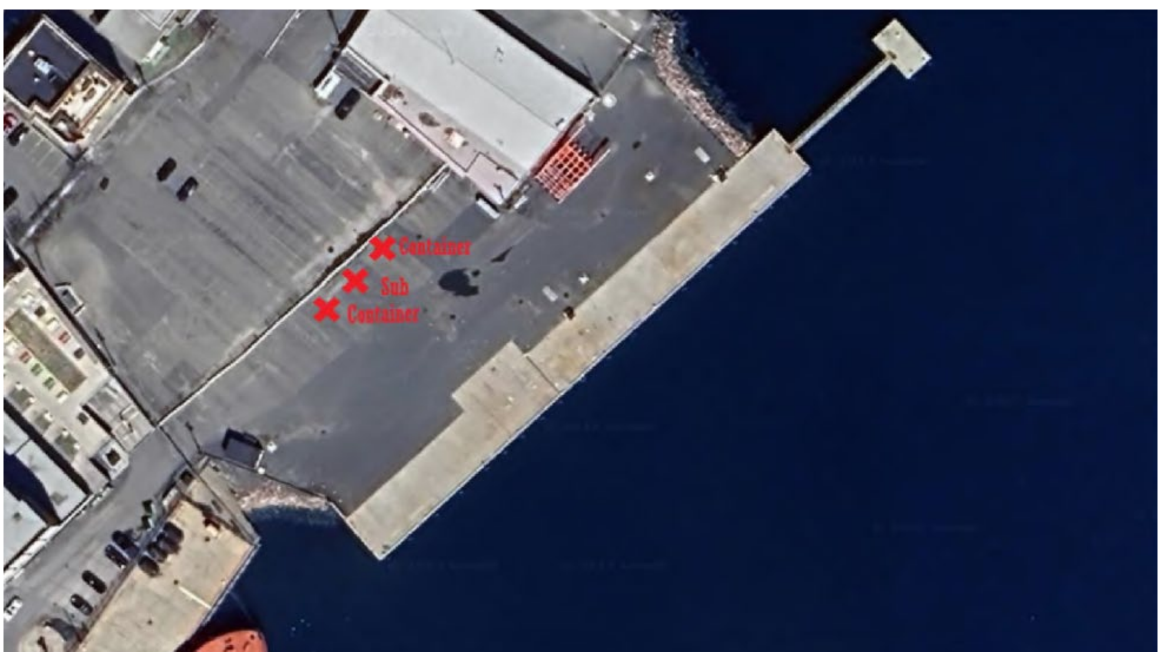


Figure 9. Overhead of parking lot in St. John's where the *Titan* was stored, uncovered, after the 2022 expedition. The locations of the *Titan* and two containers storing its equipment are marked with an *X*. (Source: A. Harvey)

1.3.7.3 2023 Expedition

For the 2023 expedition, OceanGate chartered the *Polar Prince* for use as a surface tender instead of the *Horizon Arctic*. The 2023 expedition began on May 12, 2023; five of six planned missions were completed (see Table 6).

Table 6. Dives conducted during the 2023 expedition.

Mission	Dive	Date	Depth reached (meters)	Type of dive
1	N/A	N/A	N/A	No dives
2	84	5/22/2023	8	Disabled sub drill
3	85	5/31/2023	10	Test
	86	6/5/2023	10	Test
4	87	6/12/2023	10	Aborted dive
5	88	6/18/2023	3,363 (last known depth)	Casualty dive

During the 2023 expedition, the *Titan* and LARS were towed behind the *Polar Prince* instead of being transported on deck (as they had been on the *Horizon Arctic*). Typically, the LARS was trimmed by the stern while being towed. The *Polar Prince* captain stated that on the first three missions of the 2023 expedition, the LARS began listing to starboard after 12 hours of being towed. Each time, OceanGate personnel visited the LARS by small boat and corrected the list. There were also technical difficulties with the external cameras on the *Titan*.

During mission 1, OceanGate did not have mission specialists aboard so that OceanGate personnel could integrate with the *Polar Prince* crew and collectively test procedures. Mission 1 did not include any dives.

Mission 2 included one uncrewed dive for a systems check on May 22, 2023 (dive 84). The first scheduled dive to the *Titanic* wreckage was to be dive 85 (mission 3); however, this dive, along with dive 86 (mission 3) was unsuccessful. Although OceanGate attempted to complete dive 87 (mission 4), the dive was aborted due to ballast issues and a malfunction with the LARS. Dive 88 was the casualty dive.

On missions 2-4, the Titan was not able to launch due to either weather or technical difficulties with the LARS (see figure 10). According to a former scientific director at OceanGate, on May 23, the day after dive 84 (mission 2), while the

Polar Prince was towing the LARS with the *Titan* on board about 30 miles southwest of the *Titanic* site, the tow trimmed forward (instead of by the stern, as was typical), which OceanGate attributed to a "ghost fishing net." According to OceanGate's director of administration, the *Titan* lost a fairing in high seas, and the blanks on the bottom of the hull (where penetrations let water in to sink the vessel) came loose. The crew found the LARS listing, and divers had to make repairs.

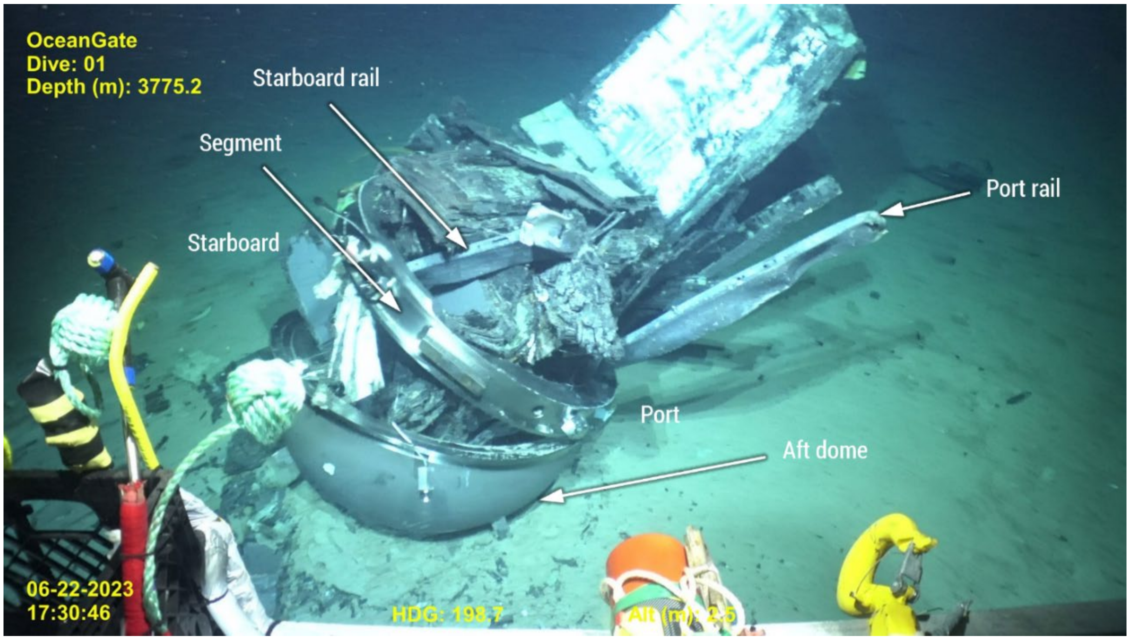
Figure 10. *Left to right*: Operational mishaps during the 2023 expedition showing the aft starboard corner of the LARS tipped downward on May 20 while leaving St. John's, and the aft end of the LARS tipped downward on May 27 in Witless Bay, Newfoundland and Labrador. (Source: Steven Taragel)

1.4 Damage

1.4.1 Remotely Operated Vehicle Surveys

ROVs completed two surveys (examinations) of the *Titan* wreckage: one during the initial search and rescue mission from June 22 to June 26, 2023, and one during the salvage mission from September 27 to September 29, 2023.

ROVs discovered the wreckage about 330 meters (1,083 feet) east-northeast of the *Titanic*'s bow. The aft dome, aft segment, aft portions of the cylinder, and rails were located together in a comingled mass that included compressed metal, plastic, electronic components, and other materials; the forward dome was located by itself (see figure 11). The forward segment and tail section were also located by themselves. Other pressure vessel fragments, likely from the middle or forward portion of the cylinder, were scattered about the ocean floor. The aft segment was still attached to the aft dome by two flange bolts on the port side.



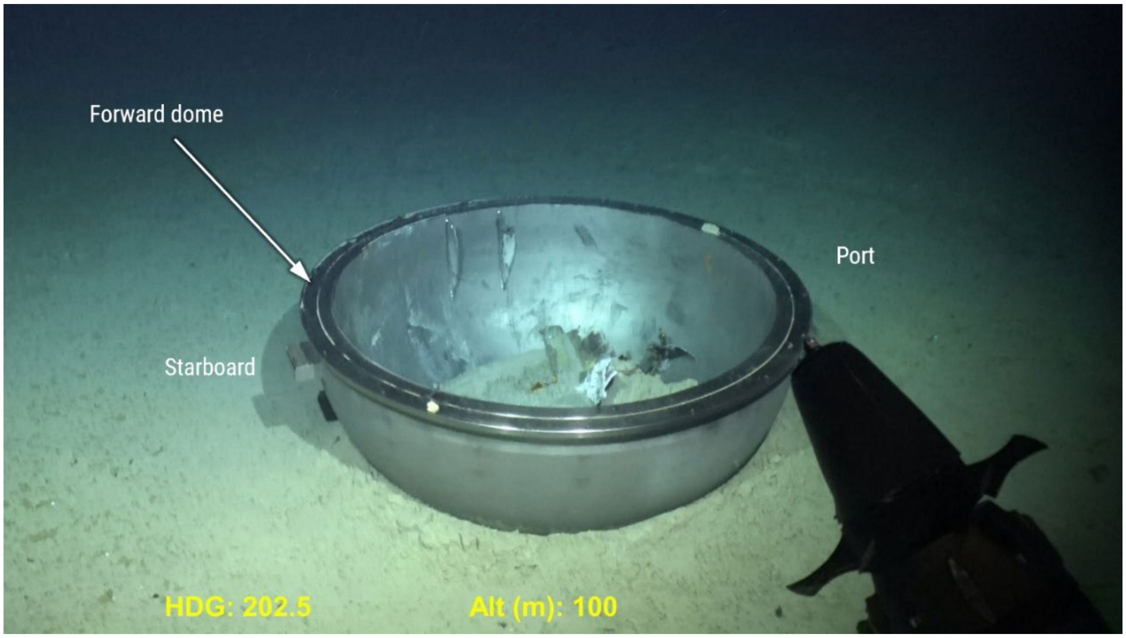


Figure 11. *From top*: *Titan* wreckage as discovered on the ocean floor, with aft dome, titanium ring (segment), and portion of cylinder separate from the forward dome. (Background source: Pelagic Research Services)

Examination of the wreckage from ROV video footage showed the pressure vessel had fragmented into multiple pieces. US Coast Guard and National Transportation Safety Board (NTSB) investigators identified several notable pressure vessel pieces and labeled them as Pieces A, B, C, and D (see figure 12). Investigators could see that the carbon fiber composite cylinder had delaminated into multiple layers nearly around the entire circumference and that the delaminations occurred between the co-bonded layers of the cylinder. One delamination was between layers 1 and 2 and the other was between layers 3 and 4. The delamination between layers 1 and 2 resided within the adhesive and showed signs of preexisting rubbing damage. The delamination between layers 3 and 4 appeared to have occurred within the adhesive on the port side and extended down toward the bottom side, while it resided within the carbon fiber composite elsewhere. On Piece D, which was found in the center of the wreckage but likely originated from the bottom of the pressure vessel, investigators identified a sigmoidal buckle (an inward bend combined with an adjacent outward bend). The *Titan* was a total loss.

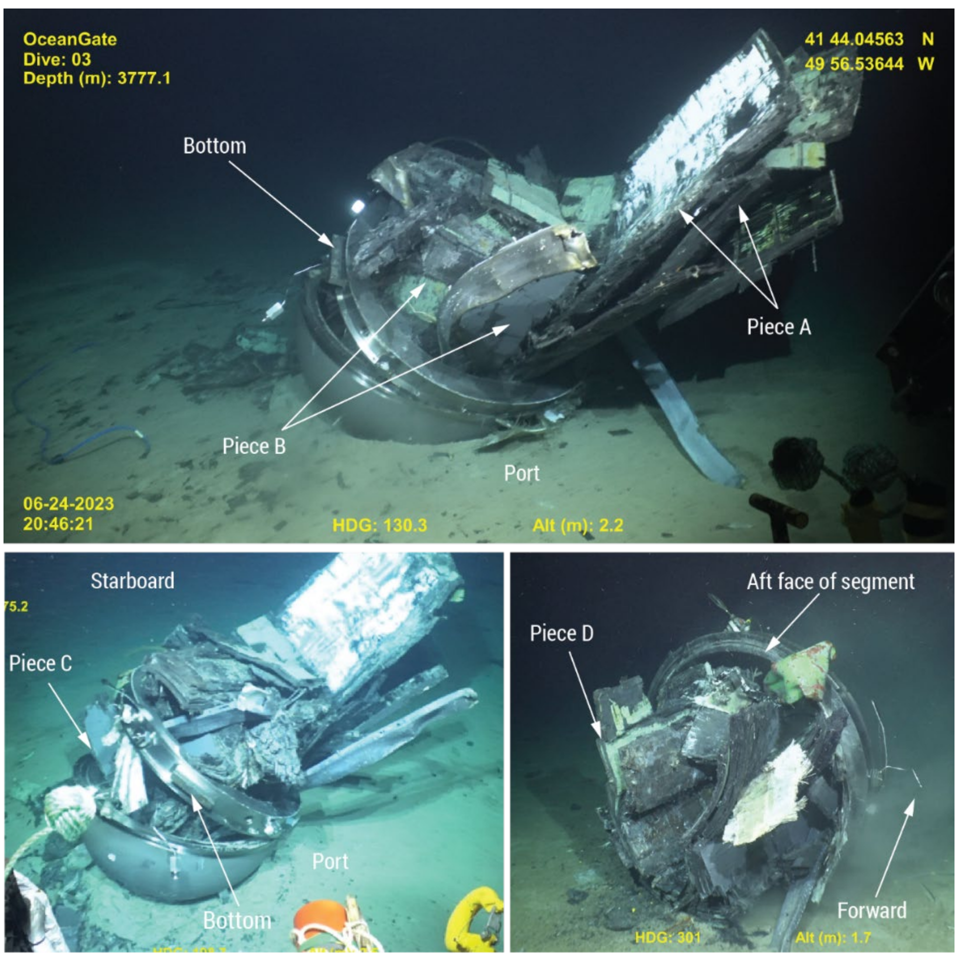


Figure 12. *Counterclockwise from top*: *Titan* wreckage on ocean floor, showing pressure vessel pieces A, B, C, and D. (Background source: Pelagic Research Services)

1.4.2 Wreckage Examination

The NTSB Materials Laboratory examined a piece of the v2 composite cylinder, which had been recovered about 350 feet (107 meters) from the main wreckage and measured about 61 inches long by 20 inches wide by 1 inch thick. The outer surface of the recovered piece of the cylinder was coated by green film adhesive, and the inner surface was coated with white paint (the interior of the pressure vessel was painted white), indicating that the piece originated from layer 1, the innermost co-bonded layer (see figure 13). We examined the piece to characterize the structure and properties of the composite hull material and the adhesive bonding, as well as to determine, where possible, the modes of separation.

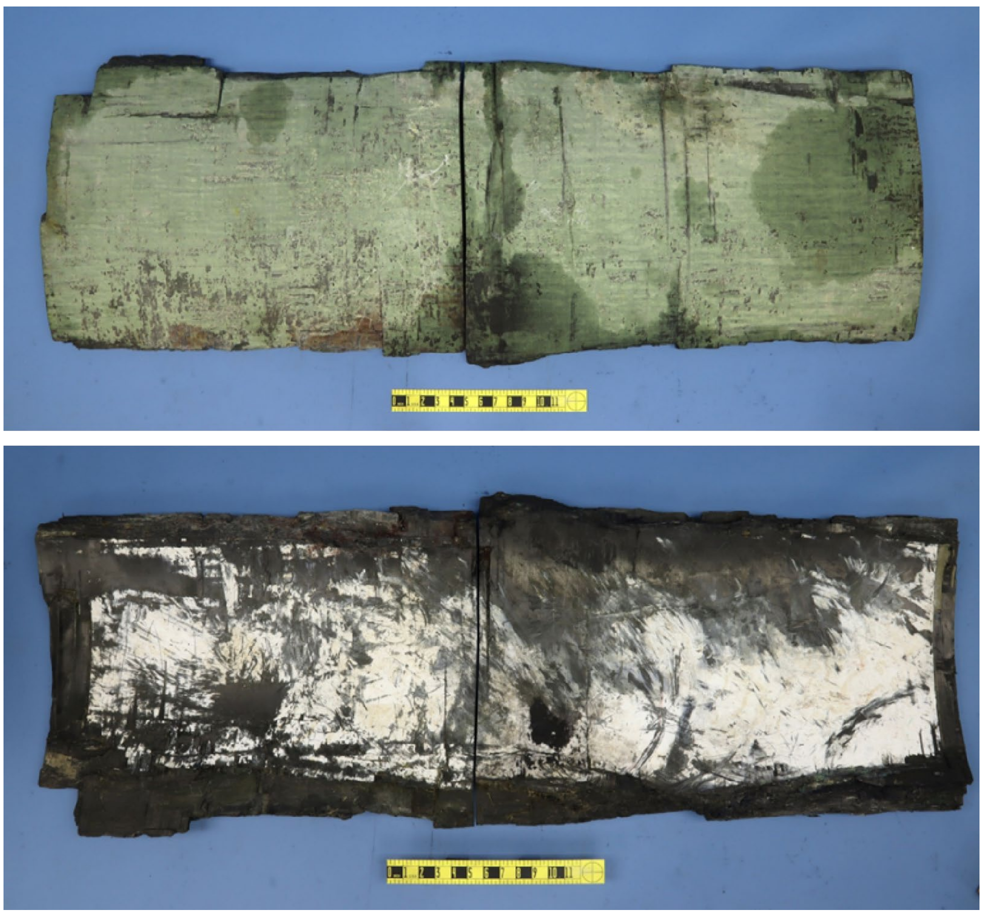


Figure 13. *From top*: Recovered carbon fiber composite pressure hull outer surface and inner surface.

One end of the piece was machined, and some bits of cured adhesive were still attached. The other ends/edges were fractured (see figure 14).

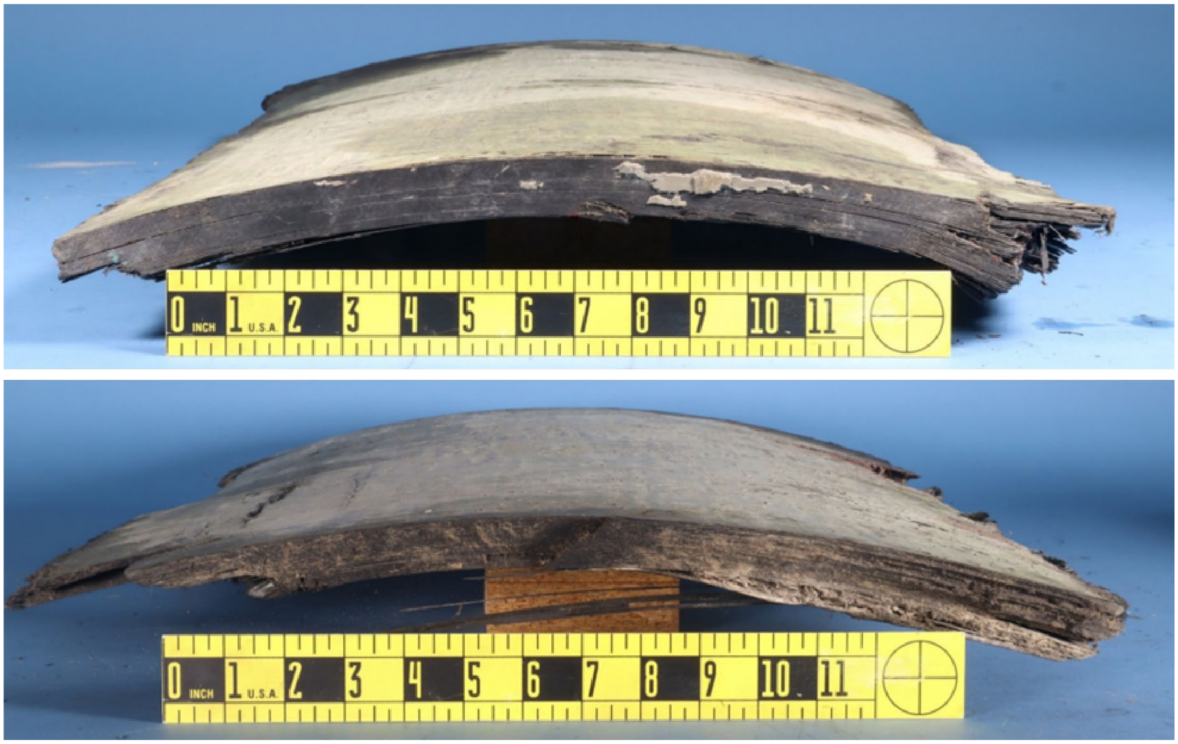
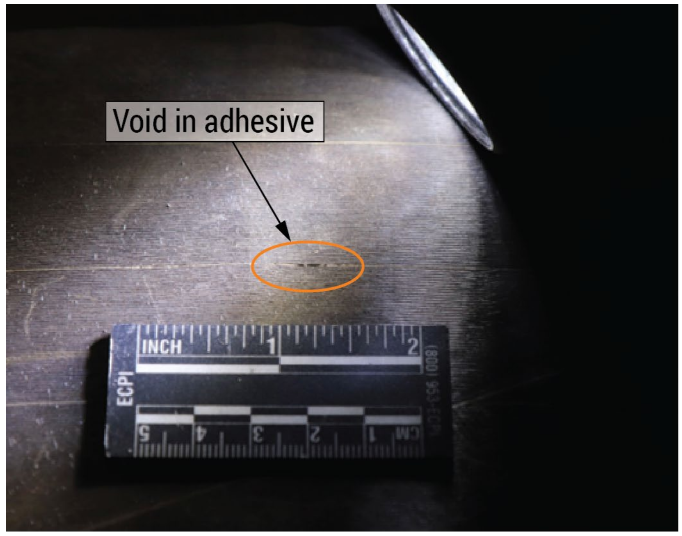


Figure 14. *From top*: Recovered carbon fiber composite cylinder machined end face, and mid-span fractured face.

We also examined end pieces that had been trimmed from the v2 full-scale cylinder during the construction/production process (see figure 15).

Figure 15. Side view of a trimmed end piece of the *Titan* cylinder.

Our examination determined that there was porosity between plies, voids in the adhesive used to join the co-bonded layers, and a preexisting disbondment between the first and second co-bonded layers. Wrinkles and waviness in the carbon fiber were observed on the trimmed end pieces, and multiple wrinkles in the carbon fiber had been leveled flush with the outer surface using a grinding tool during the manufacturing process (see figure 16).



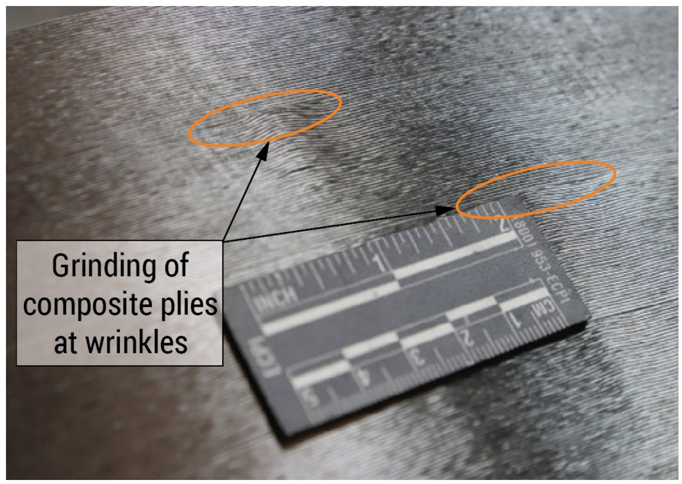


Figure 16. *From top*: Void in the adhesive layer tenting around a wrinkle, and grinding of outer carbon fiber plies at a wrinkle.

A volumetric void measurement determined that the average porosity content of the composite cylinder was about 2.7%. Microstructural analysis indicated that the porosity was localized in layers between the composite plies. The excess porosity resulted in an increase in layer thickness. Instead of 0.9975 inches thick (the expected thickness), the layers were between 1.019 inches and 1.033 inches thick. Combined with the thickness of the adhesive layers, the two trimmed cylinder ends were 5.166 inches and 5.175 inches thick. The excess thickness necessitated trimming the outer diameter of the cylinder in order for it to fit inside the annular C-channels on the titanium rings, which could only accommodate a 5-inch-thick cylinder. V-notch shear tests in the through-thickness direction showed significant variability, ranging from 6.92 to 12.05 kilopounds per square inch.[29]

Cross sections through the adhesive used to join co-cured layers showed voids at the layer interfaces (see figure 17). The voids were present in all layers but were significantly greater in size and number at the interface between the first and second layers and the third and fourth layers. For example, two voids, one from the layer 1/2

[29] *V-notch shear tests* measure the shear strength of a material. The test specimens are made with a V-shaped notch to control where the shear failure occurs.

interface and one from the layer 3/4 interface, measured 0.6 inches and 0.4 inches in length, respectively. The voids resulted in a gap between the adhesive and the underlying layer.

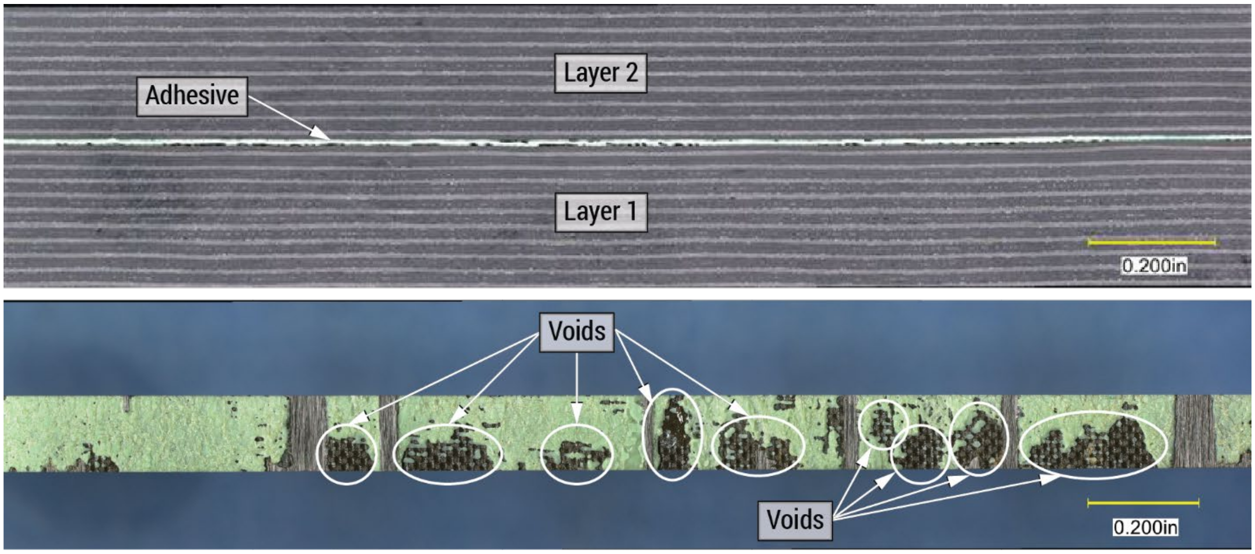


Figure 17. *From top*: Cross section of layers 1 and 2, showing adhesive between layers, and voids in the adhesive between layers 1 and 2.

The examination determined that the adhesive on the top of the recovered layer 1 piece had likely failed before the casualty, resulting in an internal delamination between the first and second layers. The surface was characterized by adhesive regions, voids, and carbon fiber regions. The adhesive regions were rubbed flat and adhesive wear debris was found collecting in the voids. The rub marks in the adhesive were oriented in the lengthwise direction. Cracks in the adhesive and carbon fiber were consistent with shear sliding between the already-separated first and second layers during the implosion.

The NTSB also examined trimmed end pieces from the v1 full-scale pressure vessel (which had been condemned) and the two one-third scale models manufactured after the v1 full-scale pressure vessel and before the v2 pressure vessel. The v1 pressure vessel cylinder's trimmed end contained multiple delaminations and voids. Both scale models' trimmed end pieces had notable wrinkles and delaminations (see figure 18).

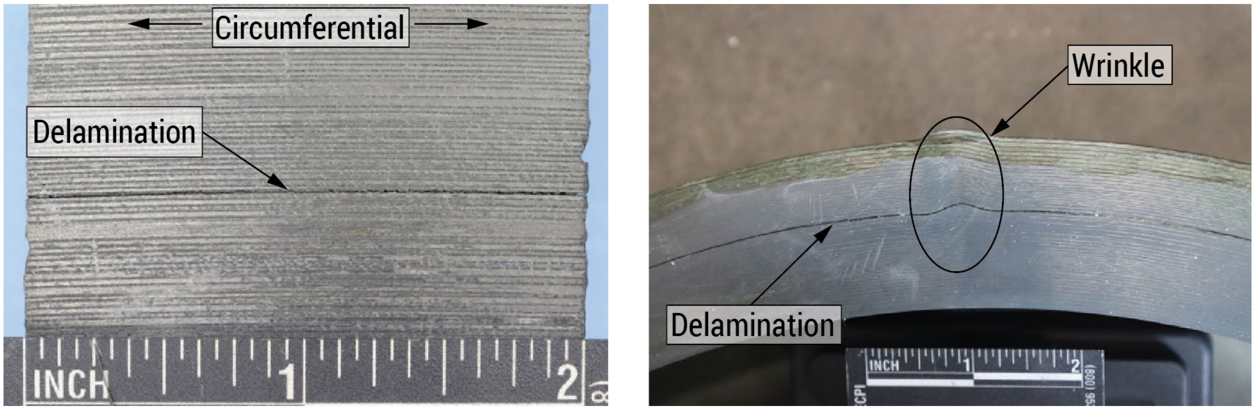


Figure 18. *From left to right*: Centerline delamination in trimmed end piece of first full-scale *Titan* pressure vessel, and wrinkle and delamination in trimmed end piece of one-third scale model.

Investigators also examined electronic components found in a compressed mass. Investigators suspected the mass contained a mission computer that would have included data related to the *Titan*'s performance history, operation, and other diagnostic information; however, investigators were not able to recover any data from the components.

1.4.3 External Camera Examination

Investigators recovered from the wreckage one of the external cameras on the *Titan*. The camera was designed to record video and still images underwater up to a rated depth of 6,000 meters (19,685 feet). Camera data could be stored to onboard memory or an attached computer, depending on the configuration.

The camera's outer casing was intact, but the lens had shattered. Investigators disassembled the casing and discovered an undamaged memory card on one of the camera's circuit boards. Twelve still images and nine videos were recovered from the device. However, none of the images were from dive 88 (the casualty dive).

1.5 Operations

1.5.1 General

OceanGate Inc. was founded in 2009. According to one of the two founders, the company's vision was to "create a fleet of four or five deep-diving submersibles … capable of carrying five people, available for charter anywhere in the world and with no dedicated mother ship [surface tender]." OceanGate was initially based at Paine Field, Washington, but moved to Florida about 2012 and Everett, Washington, in 2013. Also in 2013, the original CEO (one of the founders) left the company, and the remaining co-founder became CEO.

According to the 2023 expedition "Project Execution Plan" (see section 1.5.3), there were four branches within the organization:

- Operations, which included a lead submersible pilot and an operations tech;
- Engineering, which included three engineering techs;
- Business Development/Client Reps/Media, which included an Expedition Manager, a Media Manager, an Expedition Guide, and two additional personnel; and
- OceanGate Foundation, an independent organization that "advances understanding of the ocean by providing grants in support of scientific and archaeological marine research" (OceanGate n.d.).

The plan also listed the company's management at the beginning of the 2023 expedition, which included the CEO, a chief operating officer, a director of logistics and quality assurance, a director of engineering (the third such director, who departed the company in 2023), and an operations manager.

1.5.2 Organizational Culture

OceanGate employees interviewed after the casualty provided multiple, at times conflicting, perspectives on the safety culture of the company leading up to, and at the time of, the casualty. For example, employees on the casualty expedition stated occupational safety was a priority and identified small boat operations shuttling personnel to and from the towed LARS as the biggest hazard. The operations manager stated that safety "was one of the things [the CEO] preached a lot." According to the operations manager, the company held frequent safety meetings and briefs to communicate how to prevent injuries, and according to an OceanGate electrical engineer, employees were encouraged to speak up if something was unsafe.

However, multiple OceanGate employees, including a former director of marine operations, a boat operator, and a contractor, testified to a working environment where safety issues, particularly design issues, were ignored. The former director of marine operations told investigators he brought design issues to the engineering department's attention numerous times and was ignored. He stated, "the atmosphere there … was toxic." According to the first director of engineering, the CEO "wouldn't hire anybody that disagreed with him." The chief operating officer, who joined the company in 2019, about the time the v1 *Titan* pressure vessel was condemned, stated there were "bickerings" between departments, which was "very hard on a small company."

According to OceanGate's former director of marine operations, the *Titan* was not constructed or tested in accordance with standards created by the American Society of Mechanical Engineers (ASME) Pressure Vessels for Human Occupancy (PVHO) Standards Committee (there are no known recognized national or international standards specifically for carbon fiber pressure hulls for submersibles).[30] In a recorded discussion with the former director of marine operations, OceanGate's CEO stated of the PVHO Standards Committee, "It is a volunteer group. It is not like a DOT [Department of Transportation] standard."

OceanGate's former director of marine operations stated that the CEO was aware that the US Coast Guard would need to be involved if the *Titan* operated in US waters. A former operations technician (hired in 2017), who had previous experience as an engineer/machinery technician in the US Coast Guard, stated that he expressed concern to the director of quality and logistics about OceanGate's business model—specifically, the company accepting paying clients as "mission specialists." The technician stated to the CEO, "… you can't just change the title of a person when you're receiving compensation." The technician also stated that, in a later conversation with the CEO about the same subject, the CEO stated that "if the [US] Coast Guard became a problem … he would buy himself a congressman and make it go away." The technician resigned following this conversation, citing concerns for "the legality of how it [OceanGate] was operating."

The first director of engineering stated that he would not dive in the v1 submersible, which he had designed, because he "knew firsthand that the operations group was not the right group for that role" and he "wouldn't trust his operations crew."

In January 2018, OceanGate's director of marine operations submitted a "quality control inspection report" (specific to the v1 pressure vessel) to the CEO and other OceanGate directors. The report stated that there were "very visible signs of delamination and porosity" in the machined-off ends of the v1 carbon fiber cylinder.

---

[30] (a) According to their operating guide, ASME's PVHO Standards Committee develops "safety standards for the design, fabrication, inspection, testing, operation, maintenance, and marking of [PVHOs]." The Committee first published standards for PVHOs in 1977. See Operating Guide for ASME Committee on Pressure Vessels for Human Occupancy. (b) A *PVHO* is "a pressure vessel that encloses a human being within its pressure boundary while it is under internal or external pressure that exceeds 2 pounds per square inch differential pressure." See 2023 Safety Standards for Pressure Vessels for Human Occupancy.

The report also included findings of pitting and scoring, excess glue, plunge holes, and lack of anodes, among other things, in various components of the v1 pressure vessel. During a subsequent conversation between the (now former) director of marine operations and the CEO on January 19, 2018, which the OceanGate CEO recorded, the CEO stated, "it's clear that there is not a lot of confidence on your part in the engineering that went into this vessel, and that your experience in other vessels gives you serious concerns about the safety of [the *Titan*] from the very fundamental level." On January 23, 2018, OceanGate terminated the director of marine operation's employment.

The former director of marine operations subsequently filed a complaint with the Occupational Safety and Health Administration (OSHA) under the Seaman's Protection Act.[31] He told an OSHA investigator that cut-off sections of the carbon fiber cylinder were "like Swiss cheese" and "you can see all the delaminations where the resin has not been glued properly." OceanGate subsequently filed a lawsuit, citing a breach of a non-disclosure agreement, among other things. The former director of marine operations then dropped the complaint.

An OSHA investigator stated that OSHA typically sent letters to the US Coast Guard when they opened and closed investigations, but he couldn't recall any contact with the US Coast Guard for this case. The US Coast Guard Officer in Charge, Marine Inspection could not recall any contact with OSHA regarding OceanGate. The OSHA investigator could not recall any other investigations of OceanGate. After the casualty, the US Coast Guard and OSHA worked together to establish interagency training and procedures regarding complaints filed under the Seaman's Protection Act.

1.5.3 Project Execution Plan

OceanGate developed a Project Execution Plan that contained "project specific requirements and operational procedures" for each *Titanic* expedition. The 2023 Project Execution Plan included procedures for preparing the *Titan* to transit to and dive to the *Titanic* wreck site, policies applicable to mission specialists, information about the *Titan*, and emergency management information.

According to the plan, mission specialists were "guests who help fund OceanGate expeditions … [who had] the option to join OceanGate crew and physically work with us on our equipment, perform maintenance tasks, write procedures, help with communications, etc." Tasks that mission specialists could help

[31] See *46 United States Code* 2114: Protection of seamen against discrimination.

with included serving as a communication liaison, tracking, cleaning the inside or outside of the submersible, charging submersible batteries, reviewing video, or completing documentation tasks.

Before diving or starting work, personnel, including mission specialists, were required to hold a "pre-job" or "pre-dive" meeting. During these meetings, personnel discussed risks and control measures and step-by-step task plans.

The plan listed contact information for medical evacuation and search and rescue services. These contacts included Joint Rescue Coordination Centre Halifax (Canadian Armed Forces/Canadian Coast Guard), RCC Boston (US Coast Guard), and a third-party helicopter service. The plan also included emergency contact information for OceanGate personnel and listed seven "potential rescue ROV operators."

In addition, the plan provided step-by-step emergency procedures for nine events, including power failure of internal or external batteries, de-ballasting, carbon dioxide scrubber failure, uncontrolled internal high pressure air release, excessive oxygen, loss of communications, smoke/fire, and entanglement.

1.5.4 Training

1.5.4.1 Pilots

OceanGate's pilot training consisted of a tiered system to demonstrate levels of competency. The training and task book covered systems, crew tasks, dive theory, and operational tasks and included a four-page list of assessments of various normal and emergency procedures a pilot was required to demonstrate competency in (for example, pre-dive checks, navigation, entanglement, or loss of communications).[32] At the time of the accident, the CEO and the director of logistics were the only trained pilots.

The CEO held a US Coast Guard-issued credential as a master limited to vessels of 25 tons. The director of logistics held a credential as an ordinary seaman.[33]

[32] A *task book* includes a list of tasks an individual is required to complete in order to earn a qualification.

[33] An *ordinary seaman* is an entry-level deckhand and usually has 1 year of experience or less.

1.5.4.2 Mission Specialists

According to the Project Execution Plan, mission specialists (OceanGate's paying clients) received training in "basic seamanship, submersible operations, emergency procedures, communications, navigation, and submersible systems."

Former mission specialists described the training they had received. One stated that he participated in "a series of … webinars or Zoom calls" and skimmed through "boiler plate and common-sense type of directives" before the expedition. He also stated that he received "onsite training and guidance" to complete "the menial tasks, cleaning inside outside the sub, helping with the oil-filled housings, and other tasks as deemed appropriate." According to another former mission specialist, OceanGate gave mission specialists "a walk-about," to learn "what were you going to do, what were you going to be exposed to … just get you familiar with … the procedures."

1.5.5 Other Submersibles

OceanGate also owned and operated two other submersibles, the *Antipodes* and *Cyclops I* (originally named *Lula 500*) (see Appendix E for vessel particulars for these submersibles). Both the *Antipodes* and *Cyclops I* were state-registered and designated as oceanographic research vessels by Coast Guard Sector Puget Sound.[34] Similar to the *Titan*, OceanGate leased the *Antipodes* and *Cyclops I* to OceanGate Expeditions to operate the submersibles on expeditions to dive sites.

OceanGate operated the *Antipodes* on dives in Puget Sound, Washington; Monterey Bay, California; and Santa Catalina Island, California. The *Antipodes* was classed by the American Bureau of Shipping when OceanGate acquired it; the American Bureau of Shipping continued to class the *Antipodes* throughout OceanGate's ownership of the submersible.

OceanGate operated the *Cyclops I* in various locations, including Hudson Canyon off New York; San Francisco Bay, California; and the wreckage of the passenger vessel *Andrea Doria* in the North Atlantic Ocean off Nantucket Island, Massachusetts. When OceanGate acquired the *Cyclops I*, then named *Lula 500*, the

[34] An *oceanographic research vessel* is "employed only in oceanography or limnology, or both, or only in oceanographic or limnological research, including studies about the sea such as seismic, gravity meter, and magnetic exploration and other marine geophysical or geological surveys, atmospheric research, and biological research." See 46 *CFR* Subchapter U. Such vessels are required to obtain a letter of designation from the Coast Guard (in lieu of a certificate of inspection) that says they meet the prerequisites to be an oceanographic research vessel.

submersible was classed by the American Bureau of Shipping. Before renaming the submersible *Cyclops I*, OceanGate stripped the *Lula 500* to its steel hull, keeping only the viewing port, steel hull, and conning tower (with hatch), which remained classed by the American Bureau of Shipping.

The operations manager told investigators that OceanGate typically informed local authorities and the US Coast Guard of dives near the Everett Naval Station, Washington, to avoid calls from good Samaritans about a barge sinking or to avoid security concerns. Personnel diving on the *Antipodes* typically notified Vessel Traffic Service Puget Sound when they were operating there. Likewise, OceanGate staff testified that they had notified US Coast Guard staff in Boston before the *Cyclops I* dove on the *Andrea Doria* wreck.

1.6 *Titan* Acoustic Emission and Strain Gage Data from Dives

OceanGate saved and processed acoustic emission and strain gage (RTM system) data for *Titan* expedition dives they considered to be notable. Dive data were stored onboard the vessel during a dive and downloaded and processed after the completion of the dive. Partial dive data were available for dives in 2021.[35] Complete dive data were available for 2022 expedition dives 75, 76, and 79–83. OceanGate plotted dive data from the 2022 expedition dives against time and correlated it with the vessel's ocean depth. Because the *Titan* did not execute any notable dives in 2023 leading up to the casualty dive, no data were available for the 2023 expedition, including the casualty dive (the implosion damaged the storage drive, and the data for the casualty dive were unrecoverable).

NTSB investigators reviewed the 2022 dive data and data plots prepared by OceanGate and derived from acoustic emission and strain gage data. The first of these dives (dive 75) took place on July 3, 2022. The last of these dives (dive 83) took place on July 23, 2022, but at a different dive location and to a depth of only 2,954 meters (9,691 feet). The other dives all descended to about 3,840 meters (12,598 feet). Three of the eight acoustic sensors (channels 1, 3, and 5) did not register acoustic events for any of the 2022 dives.[36]

OceanGate analyzed hull strain by plotting it side-by-side with dive depth as a function of time. OceanGate's data plots for dive 80 (July 15, 2022), when mission

[35]The data did not include the vessel's depth, and the portion of the dive while at the ocean floor was not included.

[36] For the dives in 2021, channel 5 recorded occasional high-amplitude events, not recorded by channels 1 or 3, that could have been acoustic events.

specialists heard a "loud bang," showed a burst of acoustic activity and a sudden jump in some of the strain gages between about 1515 and 1530 (see figure 19 and figure 20).

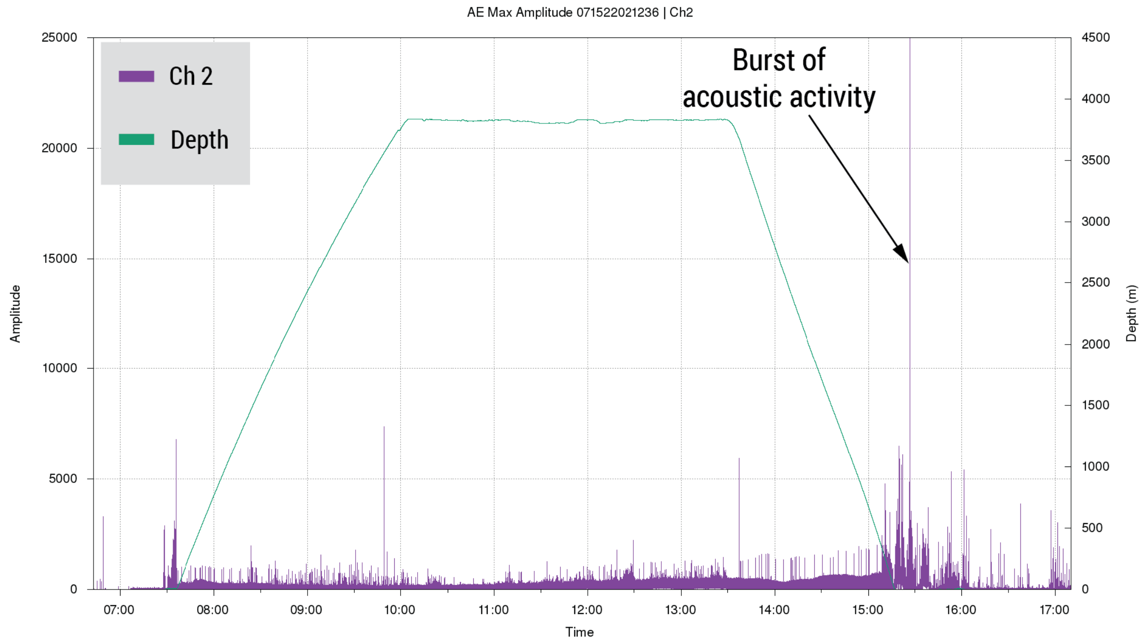


Figure 19. Time plot from dive 80 (time of day is Newfoundland and Labrador daylight time), showing acoustic activity (purple) and depth (green). (Background source: OceanGate)

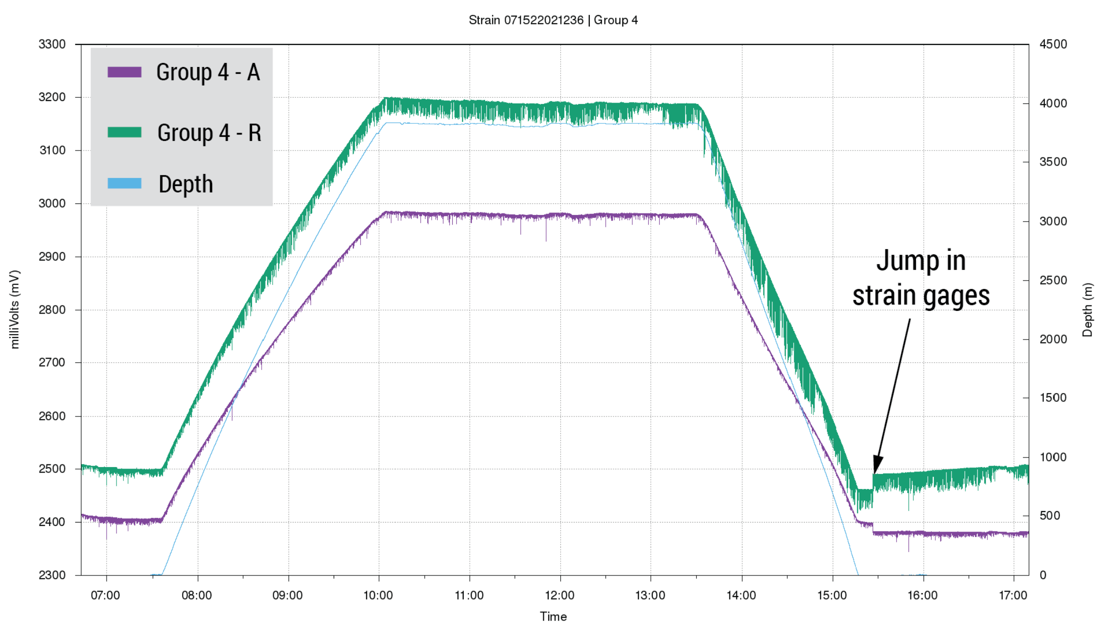


Figure 20. Strain gage output from dive 80, showing hoop strain (green) and longitudinal strain (purple) (time of day is Newfoundland and Labrador daylight time). (Background source: OceanGate)

Following a standard approach for evaluating the mechanical response of materials, the NTSB analyzed the OceanGate dive data by plotting strain data against dive depth.[37] Through dive 80, the strain response of the hull was linear at all depths (a typical mechanical behavior). Changes were observed in the initial strain response of the hull following dive 80. During dive 81, the first dive after the audible event, the strain response at low depth was non-linear. The same non-linear response was observed for dives 82 and 83 (see figure 21). Changes in strain response were observed for other strain gages as well.

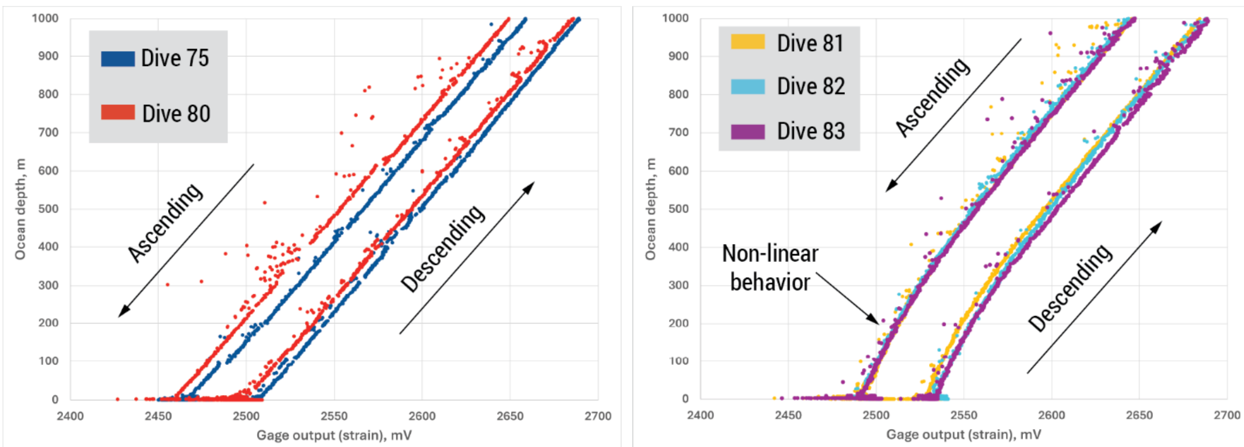


Figure 21. Strain gage output for the first and last 1,000 meters of dive depth for dives 75 and 80–83 (gage group 4 – hoop strain gage). The curves have been aligned using the linear portion of the descent phase of the trip. The strain for dives 81, 82, and 83 show non-linear behavior below 500 meters (1,640 feet) depth.

1.7 Waterway Information and Environmental Conditions

The casualty occurred in the Atlantic Ocean, about 370 miles southeast of St. John’s, Newfoundland and Labrador, Canada (see figure 5). The casualty occurred at a depth of 11,032 feet (3,363 meters). At the time of the casualty, seas were 2–3 feet, and the current was to the east-southeast at 1.6 knots. Winds were southwesterly at 20 knots. Skies were overcast, with visibility at 5 miles. The air temperature was 69°F, and the water temperature was 59°F.

[37] The external stress on the hull increases with dive depth. Plotting the data in this way produces a plot that is similar to a stress/strain curve, which is a standard approach for evaluating the mechanical response of materials (Hertzberg and others, 2020, p. 8).

1.8 Submersible Industry Overview

1.8.1 Population

According to the Marine Technology Society Manned Underwater Vehicle Submarine Committee, as of 2023, 326 crewed submersibles (PVHOs) had been built worldwide since 1960.[38] Of these, 161 were active and rated for various depths (see Table 7). Their purposes varied, including personal use, tourism, research, expedition, and submarine rescue and security.

Table 7. Active submersibles and their rated depths as of 2023. (Data source: Marine Techology Society)

Rated Depth	Number of Active Submersibles
Up to 300 meters	50
301–450 meters	49
451–984 meters	29
985–1,000 meters	21
Over 1,000 meters	12

According to the Marine Technology Society, nine known PVHOs, excluding the *Titan*, could dive to 4,000 meters (13,123 feet), exceeding the depth of the *Titanic* wreck (see Table 8). All these submersibles were designed and operated under review of a classification society or in accordance with a military standard; none were passenger-carrying submersibles.

[38] The data in this section were presented by a representative of Hydrospace Group and the Marine Technology Society during the September 2024 US Coast Guard Marine Board of Investigation. The data do not include government/military submersibles used for defense operations, personal/home-built submersibles, or historical submersibles that have been inactive for more than 25 years.

Table 8. Active crewed submersibles capable of diving greater than 4,000 meters. (Data source: Marine Technology Society)

Vessel Name	Class/Standard	Country	Rated Depth (meters)	Number of Occupants (max)
Fendouzhe	CCS	China	11,000	3
Limiting Factor	DNV	USA	11,000	2
Jiaolong	CCS	China	7,000	3
Alvin	US Navy	USA	6,500	3
Shinkai 6500	NK	Japan	6,500	3
Nautile	BV	France	6,000	3
Consul AS-37	Russian Navy	Russia	6,000	3
RUS AS-37	Russian Navy	Russia	6,000	3
Deep Sea Warrior	CCS	China	4,500	3

According to the Marine Technology Society, from 1960 to 1993, the production of PVHOs was comprised of 46% research submersibles, 37% tourist submersibles (carrying paying passengers), and 17% government submersibles; "other" submersibles (small submersibles) was "not significant" (see figure 22).[39] From 1994 to 2017, 68% of submersibles produced were "other," while 18% were tourist, 7% were government/military, and 7% were research.

[39] The Marine Technology Society category "government" refers to submersibles used for rescue/support operations.

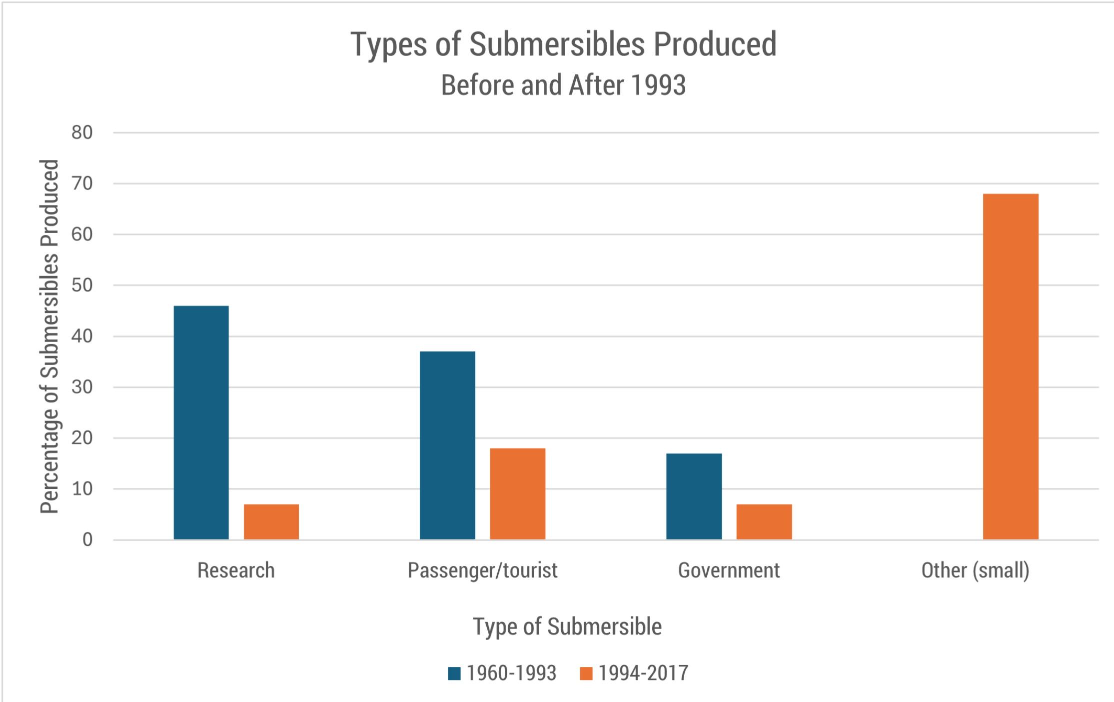


Figure 22. Production of submersibles (PVHOs) by type from 1960 to 1993 and 1994 to 2017. (Data source: Marine Technology Society)

According to a representative of the Marine Technology Society, this change in the population occurred because "all small submersible manufacturers defined their vehicles as not tourist subs." The representative further stated that "the ambiguity and variances in adjudication [of the definition of passenger for hire] from port to port … left even greater confusion," and "it didn't take too long for the industry to realize that the key was to just find an exception just like all other sectors [research, government, and private] had one."

1.8.2 US Coast Guard Guidance on Submersibles

In July 1993, the Coast Guard released Navigation and Vessel Inspection Circular (NVIC) 05-93, "Guidance for Certification of Passenger Carrying Submersibles."[40] The NVIC provides guidance for certification of passenger-carrying submersibles under Title 46 *Code of Federal Regulations* (*CFR*) Subchapter T (small passenger vessels under 100 gross tons). According to the Coast Guard, NVICs provide:

[40] See https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/5ps/NVIC/1993/n5-93.pdf. NVIC 05-93 does not address the "other" category of submersibles discussed by the Marine Technology Society.

> detailed guidance about the enforcement or compliance with a certain [*sic*] Federal marine safety regulations and Coast Guard marine safety programs. While NVIC's are non-directive, meaning that they do not have the force of law, they are important "tools" for complying with the law. (US Coast Guard n.d.)

At the time of NVIC 05-93's publication, submersibles carrying six or fewer passengers were considered "uninspected" vessels—not small passenger vessels—and thus were not required to comply with regulations in 46 *CFR* Subchapter T. After the Passenger Vessel Safety Act of 1993 was signed into law in December 1993, the definition of a small passenger vessel changed to include any submersible less than 100 gross tons carrying at least one passenger for hire.[41] A Marine Technology Society representative stated that the release of NVIC 05-93 and the signing of the Passenger Vessel Safety Act of 1993 into law coincided with "a very steep rise in the number of [other] vehicles" (see figure 23).

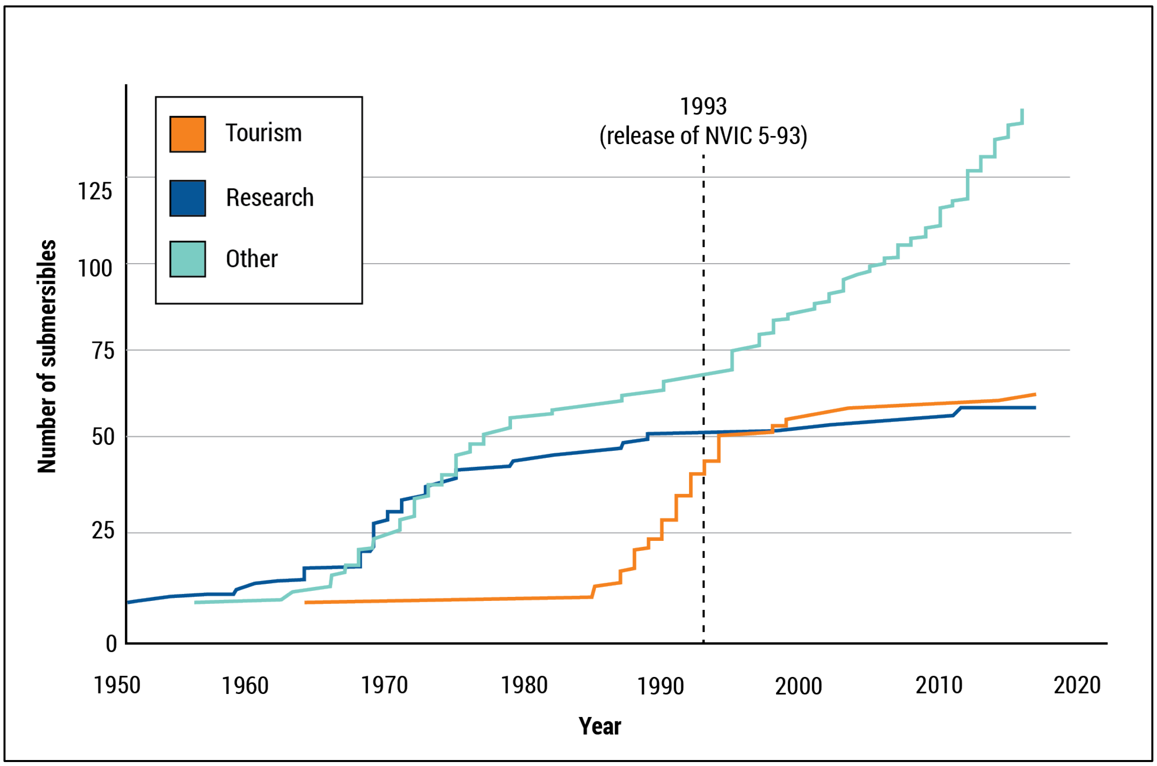


Figure 23. Crewed submersible population from 1950 to 2017. A dashed line marks the 1993 publication of Coast Guard NVIC 05-93. (Background source: Marine Technology Society)

[41] See Public Law 103-206, Title V (December 20, 1993), codified at Title 46 *United States Code* 2101. See also Public Law 103-206 Section 504. The terms "passenger(s)" and "passenger(s)-for-hire" are as defined in 46 *United States Code* 2101(21)(21a).

2 Analysis

2.1 Introduction

On June 18, 2023, about 1047 local time, while diving to the wreck of the ocean liner *Titanic* in the North Atlantic Ocean, 370 miles southeast of St. John's, Newfoundland and Labrador, Canada, at a depth about 11,032 feet (3,363 meters), the submersible *Titan*'s hull failed, and the vessel imploded. All five persons on board the vessel died.

This analysis evaluates the following safety issues:

- OceanGate's inadequate engineering process for the *Titan* (section 2.3)
- OceanGate's flawed analysis of *Titan* strain gage and acoustic emission (RTM system) data as a measure of pressure hull integrity (section 2.4)
- OceanGate's failure to notify search and rescue assets about its planned expedition (section 2.5)
- Insufficient voluntary guidance and US regulations for PVHOs (section 2.6)

2.2 Hull Failure and Implosion

OceanGate constructed the v2 full-scale *Titan* pressure vessel in 2021and successfully pressure-tested it, demonstrating that it was capable of reaching a depth of 4,200 meters (13,780 feet), marginally greater than the 3,840-meter (12,598-foot) dive depth required to reach the *Titanic*. During the 2021 and 2022 expeditions, the *Titan* successfully dove to the *Titanic* wreck site 13 times. However, during dive 88, the *Titan* imploded at a depth of 3,363 meters (10,032 feet). The loss of capability indicated that the condition of the *Titan* pressure vessel had deteriorated.

The first detectable indication of damage occurred at the end of dive 80 during the 2022 expedition, when mission specialists inside the *Titan* and crewmembers aboard a small boat on the surface heard a "loud bang" as the *Titan* ascended from a dive that reached *Titanic*. The NTSB reviewed the pressure vessel's RTM system acoustic activity and strain gage output; about the same time the "loud bang" was heard, the RTM system recorded a burst of acoustic activity and a sudden jump in some of the strain gage outputs. The NTSB also reanalyzed the RTM system strain gage data for subsequent dives (after the audible event) and observed differences in the initial strain response of the pressure hull. While the strain response on dives leading up to dive 80, when the loud bang occurred, were linear, the strain response on dives after that event were non-linear for some strain gages when the vessel was near the surface.[42]

The observed changes in strain response were consistent with one or more delaminations between co-bonded layers. If the strain response had changed at all depths, it could have indicated the pressure vessel had sustained significant compressive damage because any through-thickness damage to the carbon fiber composite cylinder would have diminished its capability to withstand external pressure. However, although the strain response at low depth (i.e., close to the surface with lower external pressure) changed for some strain sensors after the event on dive 80, the response at greater depths did not. This change in strain response is more consistent with a delamination between layers. The sensor that produced the data shown in section 1.6 was located at the forward end of the composite cylinder, indicating that the damage extended to the forward end of the cylinder. The intersection of a delamination with the end of the cylinder would have allowed the separated layers to initially respond differently to external pressure at shallow depths, but, at greater depths, the layers would have responded in a manner similar to the intact pressure vessel.

The NTSB's postcasualty examination of the *Titan* wreckage and review of ROV wreckage survey footage identified two delaminations between the five 1-inch-thick layers that comprised the vessel's carbon fiber composite cylinder (in the adhesive interfaces). One delamination occurred between the first and second layers, and the other delamination occurred between the third and fourth layers. Examination of the trimmed end pieces revealed that these adhesive interfaces contained long extended voids while the other two adhesive interfaces (between the second and third layers and the fourth and fifth layers) did not. The voids reduced the strength of the adhesive, causing the delaminations to form at those locations. The piece from the first layer examined by the NTSB showed evidence of rubbing and accumulated wear debris in the voids, indicating that the delamination existed before the implosion. The extent of the delamination at the second interface before the implosion could not be determined. Therefore, the NTSB concludes that the *Titan* pressure vessel likely sustained damage after it surfaced at the end of dive 80 in the form of one or more delaminations that formed from voids between the cylinder's five co-bonded layers, leading to the deterioration and weakening of the pressure vessel.

Following dive 80, the *Titan* completed two dives (81 and 82) to the depth of the *Titanic* wreckage, indicating the initial delamination(s) sustained at the end of dive

[42] The strain response at greater depths remained linear, similar to previous dives, indicating that the gages themselves had not changed, but rather the pressure hull itself had changed.

80 were not sufficient to cause implosion. Based on a review of the data, there was no apparent change in the strain response of the hull, beyond the new nonlinear responses at shallow depths, between dives 81 and 82. Therefore, the pressure vessel must have sustained additional damage after dive 82 and before the casualty dive 11 months later (dive 88).

During dive 83 (July 25, 2022), the final successful dive, the *Titan* descended to only 2,954 meters (9,692 feet), less than the depth at which the *Titan* later imploded. If the strain response of the pressure vessel changed during this dive—compared to dive 82—it would have been an indication of additional damage sustained. However, the strain response experienced no apparent additional change during this dive, indicating it is unlikely the *Titan* sustained additional damage during the dive. Because the submersible did not reach depth, however, investigators could not exclude this possibility.

OceanGate made multiple changes to their handling of the *Titan* that could have caused additional damage between the end of the 2022 expedition (dive 83) and the casualty dive. Dive data from the casualty dive were lost during the implosion, so the extent of additional damage to the pressure vessel at that time (or during the 2023 expedition) is unknown. The *Titan* was stored outside after the 2022 expedition until the early spring of 2023, subjecting it to freezing temperatures. If water had penetrated any part of the pressure vessel and frozen, the expansion that occurs due to the phase change to ice could have caused additional damage. Additionally, during the 2023 expedition, the *Titan* was towed on the LARS behind the support vessel instead of on the support vessel as had been done for previous expeditions—about 2,900 miles total in open ocean. In these conditions, the *Titan* would have been subjected to vibrations, impulse loads, and upset events, which could have caused bending/flexing, shear, and lateral impacts. It is possible that the *Titan* sustained damage during any of these events that could have further deteriorated the condition of the pressure vessel. However, because OceanGate did not study the effects of vibrations and impulse loads on the *Titan*, their actual effects are unknown. The NTSB concludes that after dive 82, the *Titan* sustained additional damage—of unknown origin—that further deteriorated and weakened the pressure vessel to a point where it could not survive a dive to the depth of the *Titanic*.

Three compressive failure modes are possible for laminated composite structures like the *Titan* pressure vessel: (1) material failure in compression, (2) global buckling, and (3) local buckling. Compressive failure occurs when the external loads exceed the compressive strength of the material. Buckling occurs when the original shape of the object becomes unstable under compressive loads. The object then is likely to bend and flex into a new shape. If the strength of the material is exceeded in this new shape, the object will fail. Global buckling occurs when the entire object changes its shape. Local buckling occurs when only a portion of the object changes its shape.

Delaminations are a known cause of local buckling failures. The delamination divides a single thicker composite layer into two thinner layers. The reduction in layer thickness causes a significant reduction in resistance to buckling (Bolotin 1996; Tafreshi 2006). When a delaminated region buckles, it produces a peeling separation at the edge of the delamination. The delamination expands, resulting in large delamination fractures.

The postcasualty condition of the *Titan* pressure vessel was consistent with a local buckling failure. The layers of the cylinder had peeled apart, producing extensive peel separation fractures of the hull, which is typical of a local buckling failure. The NTSB concludes that the existing delaminations and additional damage that deteriorated the condition of the pressure vessel between dive 82 and the casualty dive likely resulted in a local buckling failure that led to the implosion of the *Titan*.

2.3 Pressure Vessel Development and Cycle Life Evaluation

A quality engineering process incorporates a "Plan-Do-Check-Act" cycle to ensure processes are adequately managed and opportunities for improvement are identified and acted upon (ISO 2015). Additionally, an engineering process should include risk-based thinking to determine factors that could cause processes to deviate from planned results and mitigate negative effects (ISO 2015).

A quality design and development program is one aspect of an engineering process and can help ensure the quality and safety of complex vehicles and systems, and is typically used by submersible manufacturers.[43] A design and development program typically includes phases for design, testing, verification, and validation.[44] When OceanGate began developing the *Titan*, OceanGate defined requirements for the submersible. The *Titan* submersible was designed to carry up to five persons and dive to a depth of 4,000 meters, enabling it to reach deep wrecks like the *Titanic*. OceanGate eventually settled on a pressure vessel design consisting of a carbon fiber

[43] For example, ASME, 2023, *PVHO-1: Safety Standard for Pressure Vessels for Human Occupancy*, https://www.asme.org/codes-standards/find-codes-standards/safety-standard-for-pressure-vessels-for-human-occupancy/2023/pdf.

[44] *Verification* involves checking to see whether the as-manufactured item conforms to the design and manufacturing requirements. *Validation* involves checking to see if the captured requirements enable the intended use of the product. (ISO 2015)

composite cylinder with titanium rings and domes enclosing each end. However, OceanGate did not conduct adequate verification testing before deploying and operating the *Titan*. For example, after the failure of the v1 full-scale pressure vessel, OceanGate used different materials (pre-preg carbon fiber) and manufacturing methods to create two sub-scale models (test articles) of a v2 pressure vessel. The sub-scale models were manufactured using a new method and materials but failed to meet design requirements and either imploded or nearly imploded at depths less than 3,000 meters (9,843 feet), significantly less than the depth needed to reach the *Titanic* wreckage. These premature implosions indicated that there was an issue with the design or manufacturing of the carbon fiber composite cylinder of the pressure vessel. OceanGate determined that wrinkles in the cylinder had likely caused the sub-scale models' failure and identified the co-bonding process as a way to potentially mitigate wrinkle-related failures. However, OceanGate did not build or test any new sub-scale models using the co-bonding process; the only article produced using the co-bonding process was the v2 full-scale cylinder ultimately used in the casualty dive.

After the casualty, the NTSB examined trimmed end pieces of the v2 *Titan* cylinder from when the cylinder was constructed. Investigators found wrinkles and waviness in the carbon fiber layers, porosity within the carbon fiber composite, and voids in the adhesive between several of the co-bonded layers. Additionally, it appeared that multiple wrinkles in the carbon fiber had been ground flush during the manufacturing process. The observations indicated that the co-bonding process did not completely eliminate the wrinkles and, at the same time, introduced additional anomalies. All these anomalies would have impacted the strength and durability of the pressure hull by reducing its compressive strength and its shear strength, and by providing initiating sites for cracks and delaminations. However, because OceanGate did not follow standard engineering processes, including developing and testing a sub-scale model using the manufacturing process that would be used to create the full-scale pressure vessel, they did not understand the effect of these anomalies and their potential to induce failure in the v2 full-scale pressure vessel.

Understanding a submersible's cycle life (durability) through evaluation is another aspect of an engineering process critical to ensuring the safe operation of a submersible, as well as its continued seaworthiness.[45] However, OceanGate did not evaluate cycle life for the v2 *Titan* composite pressure vessel. OceanGate performed stress analysis on a carbon fiber composite pressure vessel, with all results (both v1

---

[45] *Cycle life* is the number of times a vehicle can perform an operational cycle before it reaches a life limit and it or one of its components must be retired from service. For the *Titan*, cycle life was the number of times *Titan* could dive below a defined depth and return to the surface before the vessel was retired.

and v2 designs) indicating that a carbon fiber composite pressure vessel would have significant safety margin at the depth of the *Titanic* wreckage. However, these analyses were based on theoretical models of composite structures that assumed perfect geometry and fiber orientation, rather than the actual carbon fiber composite pressure vessel built by OceanGate.[46] To rely on the models, OceanGate should have validated them through physical testing, but OceanGate never tested a co-bonded composite pressure hull to failure (full-scale or sub-scale) and, as a result, never established the strength or failure mode of that design. Given the presence of anomalies in the hull and OceanGate's previous sub-scale model testing, it is unlikely that the fabricated hull would have had the strength predicted by OceanGate's analysis.

Part of a cycle life evaluation includes establishing inspection and maintenance intervals. Manufacturers acquire data on adequate inspection and maintenance intervals through testing and modeling. Inspections and maintenance are designed to catch and prevent emergent defects before they become critical. Because OceanGate did not conduct cycle life evaluation or testing of the *Titan* v2 co-bonded pressure vessel, the company did not have strength or endurance data on the hull and thus had no knowledge of the number of safe dives that could be executed, signs that the hull was beginning to weaken, or the characteristics of the vessel leading to an implosion—and the ability of their RTM system to detect an impending implosion. Additionally, OceanGate's lack of cycle life evaluation meant that the company did not understand the role that the composite manufacturing process played in the durability of the hull. The lack of long-term performance data left OceanGate unaware of the possibility of delamination damage occurring at the co-bonded adhesive interfaces (the v2 *Titan* composite pressure vessel contained four adhesive interfaces).

An effective vessel design and development program also includes consideration of how operational factors, such as the vessel's transport, use, route, maneuvering, or storage, affect the safety and integrity of a vessel. For example, as part of a cycle life evaluation of the *Titan*, OceanGate could have considered the effects of towing the vessel (vibrations and impulse loads on the vessel) versus being transported aboard a surface tender. Additionally, OceanGate could have considered the effects of storage conditions—including environmental factors, such as weather

[46] When real structures fail by buckling, they always do so at pressures lower than those predicted by calculations due to the minute irregularities in all real structures. It is common to add a correction, called a knockdown factor, to account for this difference. The organizations that performed strength calculations for OceanGate applied these knockdown factors to their results.

and atmosphere/temperature—on the vessel. However, OceanGate did not consider these factors as part of its vessel design and development program for the *Titan*.

The NTSB concludes that OceanGate's engineering process for the *Titan* was inadequate and resulted in the construction of a carbon fiber composite pressure vessel that contained multiple anomalies and failed to meet necessary strength and durability requirements. The NTSB further concludes that because OceanGate did not perform adequate testing, including cycle life evaluation, of the *Titan* pressure vessel, the company was unaware of its actual strength and durability, which was likely much lower than their target, as well as the implications of how certain operational changes, including storage condition and towing, could impact the integrity of the pressure vessel and overall safety of the vessel.

2.4 Pressure Vessel Monitoring

OceanGate had limited means to monitor the pressure vessel's integrity to determine whether its condition had deteriorated. Interviews with multiple OceanGate staff indicated that using ultrasonic inspection or other non-destructive methods was impractical or impossible (the size of the *Titan* made it difficult to manipulate, and the submersible's thickness attenuated the signal). The fairing and rubberized coating on the pressure vessel's outer surface made a visual inspection impractical. Instead, OceanGate monitored the *Titan* pressure vessel's integrity using its RTM system.

OceanGate analyzed data from the strain gages against time. However, analyzing strain data in this way was flawed because it was difficult for OceanGate to compare data between dives. A more appropriate means of evaluating strain data would have been to evaluate it against depth, since the external pressure acting on the pressure vessel is a direct result of the vessel's depth. This method of analysis is akin to a stress/strain plot, which is a standard method used in evaluating the mechanical properties of materials (Hertzberg and others 2020, p. 8). For example, after the implosion, the NTSB evaluated the *Titan* strain data against the vessel's depth and identified the change in the low-depth strain response in the pressure vessel after dive 80.

OceanGate only analyzed acoustic emission data captured during a dive, so the data could not be used to capture and alert crew to damaging events that occurred at the surface or while the *Titan* was stowed. Additionally, OceanGate based their evaluation of acoustic emission data on the signals from previous *Titan* pressure vessels—the v1 full-scale hull and sub-scale models. However, this method of evaluation was flawed because the v1 full-scale pressure vessel and sub-scale models were manufactured using a different method and produced different acoustic activity due to anomalies in their structures—anomalies that were different from those investigators found in the v2 full-scale hull. OceanGate did not build and test composite sub-scale models made using the co-bonding process. Therefore, they had no data on how a co-bonded structure would deteriorate and fail or how the acoustic data from such a structure would evolve before the implosion. OceanGate assumed that, as the pressure vessel condition deteriorated, it would gradually transition from a sound pressure vessel to one that produced acoustic events of a similar amplitude and frequency as their previous test articles and that they would be able to safely retire the pressure vessel from service. However, this did not occur. The sensors produced activity on the dives that followed dive 80 but never produced the type of acoustic emission signal that would have triggered an alert and thus did not detect the initial damage. The NTSB concludes that because OceanGate's analysis of *Titan* pressure vessel strain gage and acoustic emission (RTM system) data was flawed, the company was unable to identify that the pressure vessel was damaged after dive 80 and that it needed to be immediately removed from service.

2.5 Emergency Procedures and Response

The Coast Guard's NVIC provides guidance for certification of passenger-carrying submersibles, including provisions for search and rescue in emergency situations. Specifically, US Coast Guard NVIC 05-93 recommends that "appropriate rescue facilities" must be ready in case a submersible is not able to surface on its own. The NVIC further states that the US Coast Guard does not have underwater search and rescue capability, and because underwater rescue resources may not be immediately available, "the submersible operator must anticipate all likely casualty situations and provide for the ready availability of specific resources" (see section 2.6). Additionally, according to OceanGate's former director of marine operations, it was industry practice to have a second asset (either an ROV or a second crewed submersible) on site or readily available elsewhere and to train for emergency recoveries. However, although OceanGate's Project Execution Plan for the *Titan* listed search and rescue assets to notify in case of an emergency, the plan did not require OceanGate personnel to notify search and rescue assets or have assets on-site before conducting diving operations. Thus on the day of the casualty, OceanGate did not have assets standing by when the *Polar Prince* lost communications with the *Titan*.

Because the implosion occurred in US Coast Guard RCC Boston's internationally agreed search and rescue region, the US Coast Guard coordinated search and rescue efforts. However, according to the US Coast Guard, no one agency or country had all the assets needed to perform the search, so additional coordination with other US agencies and organizations and other countries was needed (see figure 24). Additionally, Pelagic's ROV capable of reaching 6,000 meters, the *Odysseus*, was in Buffalo, New York, at the time of the casualty and had to be transported to the *Titanic* wreckage location via Newfoundland and Labrador. US Coast Guard SAR personnel testified it would normally take 2 weeks to get an ROV in the air, an offshore supply vessel outfitted, and a crew assembled. In the search for the *Titan*, responders transported the *Odysseus*, along with another ROV capable of reaching 6,000 meters (19,685 feet), to the scene within 4 days—just a few hours over the theoretical window of available oxygen (96 hours) in the *Titan* crew compartment. Although search and rescue efforts could not have saved lives due to the catastrophic nature of the casualty, adequately planning for emergency situations—such as the loss of a vessel at the surface or loss of communications or propulsion at depth—by preparing potential search and rescue assets is imperative for future emergency situations involving submersibles wherein search and rescue efforts could have a positive impact. The NTSB concludes that had OceanGate followed NVIC 05-93 guidance for emergency response plans, they likely would have had emergency response assets standing by and the *Titan* likely would have been found sooner, saving time and resources even though a rescue was not possible in this case. The NTSB further concludes that despite OceanGate's failure to notify search and rescue assets about its planned expedition, and the limited resources able to operate at the depth of the *Titanic* wreckage, the US Coast Guard's response coordination efforts were effective and resulted in the timely discovery of the *Titan* wreckage.

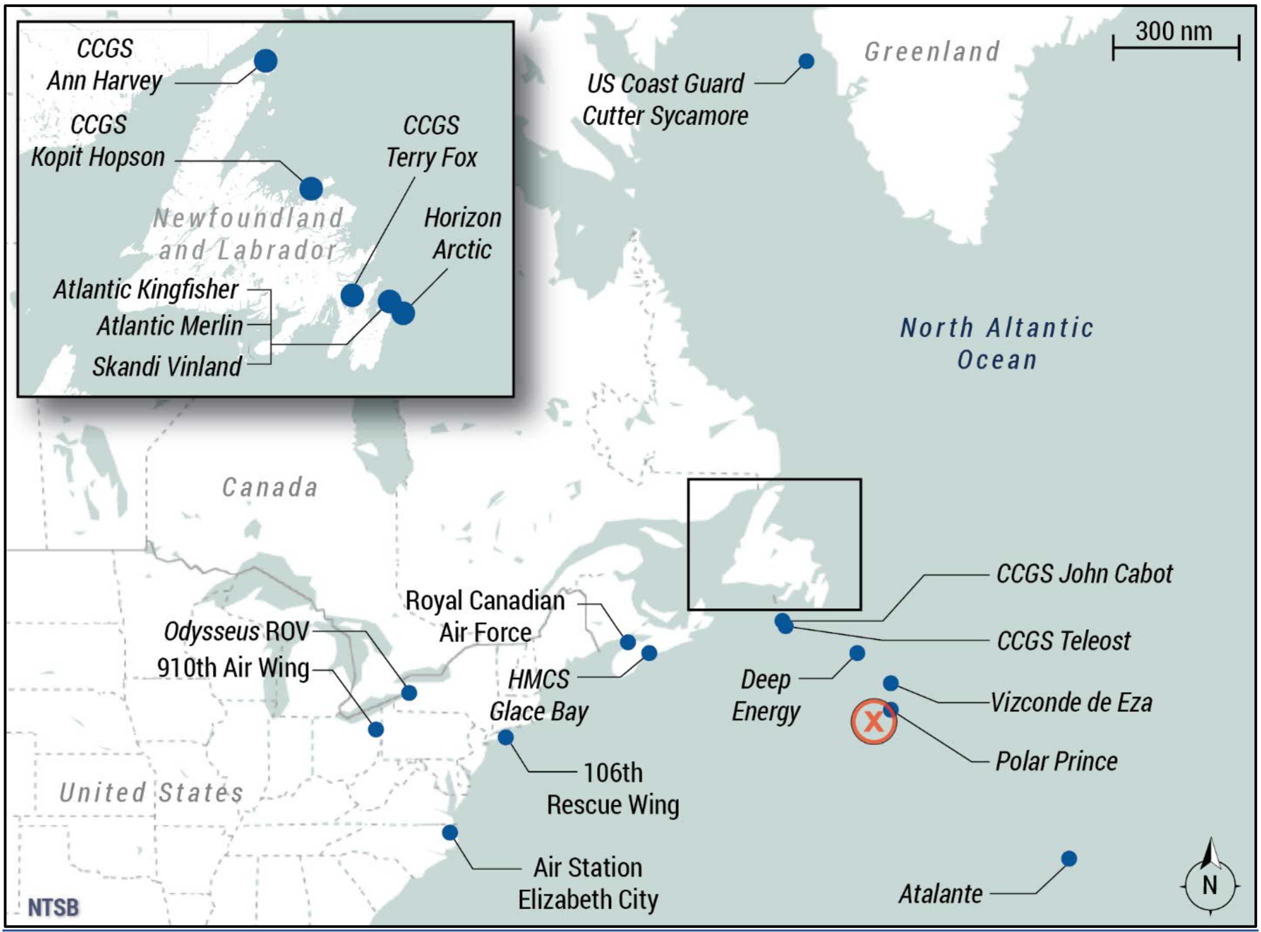


Figure 24. Assets that participated in the search for the *Titan*. A circled *X* marks the location of the *Titan*. Vessels are shown at their location about 2124 on June 18.

2.6 OceanGate Submersible Operations and Industry Regulations

According to the US Coast Guard, the *Titan* was a vessel of the United States (US Coast Guard 2025).[47] Additionally, because OceanGate operated the *Titan* with passengers for hire, it was required to be inspected by the US Coast Guard and to comply with regulations in 46 *CFR* Subchapter T, which define design, construction,

[47] A vessel of the United States means a vessel: (1) documented or required to be documented under the laws of the United States; (2) owned in the United States; or (3) owned by a citizen or resident of the United States and not registered under a foreign flag. See [46 *United States Code* Section 116]() and [46 *CFR* Subchapter A 4.40-5](). The *Titan* was owned by a US-based company (OceanGate). Vessels with US ownership may be, and often are, registered in other countries, making those countries the "flag state" of the vessel. However, the *Titan* was not registered under any flag state and therefore was a vessel of the United States.

and operations standards for small passenger vessels (US Coast Guard 2025).[48] However, OceanGate did not register or document the *Titan* in the United States, nor did they arrange to have it inspected by the US Coast Guard.

In July 1993, the US Coast Guard published NVIC 05-93, which recognized that the Coast Guard's inspection regulations were developed primarily with surface craft in mind and that, "many of the requirements cannot be applied to or may otherwise be inappropriate for submersibles." Accordingly, the NVIC provides voluntary guidance for the design, construction, and operation of "passenger carrying submersibles" subject to regulations in 46 *CFR* Subchapter T. NVIC 05-93 also provided guidance for submersibles that would be subject to regulation as "uninspected" vessels under 46 *CFR* Subchapter C. OceanGate's operation of the *Titan* did not meet many of the guidelines in the NVIC. For example, the NVIC recommended restricting submersible operations to waters less than a submersible's rated depth or the "depth to which its rescue assistance is effective (45 meters [150 feet] in the case of no-decompression diving)." Operations were not permitted deeper than the "demonstrated capability of the available rescue equipment," and "Lifting capability on the surface must be available within a reasonable time, considering the amount of reserve life support on board the submersible." The *Titan* regularly dove beyond 45 meters, and OceanGate regularly operated the *Titan* without rescue assistance on standby and capable of reaching the submersible while it dove to the *Titanic* wreckage, as was the case on the day of the casualty (see section 2.5).

At the time of the NVIC's publication in 1993, submersibles carrying six or fewer passengers (like the *Titan*) were considered uninspected vessels—not small passenger vessels—and thus were not required to comply with regulations in 46 *CFR* Subchapter T. This description was included in the NVIC. After the Passenger Vessel Safety Act of 1993 was signed into law, the definition of a small passenger vessel changed to include any submersible carrying at least one passenger for hire.

[48] (a) While the NTSB does not determine whether specific operator conduct violates statutory or regulatory requirements that may be the subject of enforcement by the US Coast Guard, we note OceanGate's intent to avoid safety oversight by assigning tasks to those paying to ride. (b) In the United States, any submersible that is less than 100 gross tons and carries at least one passenger for hire is considered a small passenger vessel and is subject to inspection. See [46 *CFR* Subchapter T 175.110] and [46 *United States Code* Section 3311]. Any passenger-carrying submersible that is 100 gross tons or more is subject to inspection under 46 *CFR* Subchapter H. According to 46 *U.S.C.* Section 2101(29), "passenger" means an individual carried on the vessel except–(i) the owner or an individual representative of the owner or, in the case of a vessel under charter, an individual charterer or individual representative of the charterer; (ii) the master; or (iii) a member of the crew engaged in the business of the vessel who has not contributed consideration for carriage and who is paid for on board services. (See [46 *U.S.C.* 2101] for the complete definition of "passenger" and "passenger for hire.")

The NVIC has not been updated since its release to reflect this change, and the US Coast Guard does not have specific inspection standards for the design or construction of submersibles but instead adapts regulatory inspection standards to attempt to meet a level of safety equivalent to surface vessels. The US Coast Guard also recognizes that the NVIC lacks comprehensive, submersible-specific inspection standards (US Coast Guard 2025).

Since 1993 and the publication of the NVIC, the submersible (PVHO) population—type, purpose, and size—in the United States has changed significantly. Before 1993, most submersibles were either research (46%) or passenger-carrying tourist (37%) submersibles. After 1993, the majority (68%) of submersibles produced were "other" (small submersibles), while 17% were tourist, 7% were government/military, and 7% were research (see figure 22 and figure 23). According to a representative of the Marine Technology Society, this change in the population occurred because "all small submersible manufacturers defined their vehicles as not tourist subs." The representative further stated that "the ambiguity and variances in adjudication [of the definition of passenger for hire] from port to port … left even greater confusion," and "it didn't take too long for the industry to realize that the key was to just find an exception just like all other sectors [research, government, and private] had one." This is the approach OceanGate took with the *Titan* and its other submersibles, the *Antipodes* and *Cyclops I*. In its report of investigation into the *Titan* implosion, the US Coast Guard outlined what it characterized as OceanGate's "Circumvention of U.S. Laws and International Standards" (US Coast Guard 2025). OceanGate called the *Titan* an "experimental" craft to avoid applicable design, construction, and testing rules and standards (there is no official US Coast Guard or classification society "experimental" vessel endorsement or designation, and therefore, there are not separate standards for "experimental" vessels). Additionally, interviews with OceanGate personnel indicated that OceanGate called its passengers "mission specialists" in an attempt to avoid the statutory and regulatory implications of, and, by extension, the NVIC guidance relating to, the designation of the *Titan* as a passenger-carrying submersible with at least one passenger for hire. Similarly, OceanGate categorized the *Antipodes* and *Cyclops I* as oceanographic research vessels and received letters of designation from the US Coast Guard for each, despite taking paying clients aboard these submersibles during expeditions. According to a former Coast Guard captain in Seattle, OceanGate discussed certification for one of their other submersibles, the *Antipodes*, but the restriction on diving depth—a maximum of 45 meters, as outlined in NVIC 05-93—and requirements for credentialed pilots and pre-designated routes made certification unfeasible.

The number of known PVHOs that can dive to the depth of the *Titanic* wreck site is small—only nine others, according to the Marine Technology Society. Class societies, such as the American Bureau of Shipping, Lloyd's Register, RINA, and DNV, have established rules for the design and construction of manned submersibles.[49] Additionally, since 1977, AMSE's PVHO Standards Committee has published recognized industry standards for submersibles, diving bells, and personnel transfer capsules.[50] However, the existing regulations and voluntary guidance, as currently written, enabled OceanGate's operation of the *Titan* in an unsafe manner. The NTSB concludes that voluntary guidance and current US small passenger vessel regulations are not sufficiently tailored to current PVHO operations to ensure the safety of PVHOs in accordance with established technical and classification society standards.

Organizations like the PHVO Standards Committee, the Marine Technology Society, and classification societies, among others, have at their disposal a wealth of expertise related to submersible operations. The US Coast Guard worked with some of these organizations when developing NVIC 05-93. The NVIC states:

> Submersible technology is not new, but its application in the passenger carrying industry is still very much under study. Although we have established a safe baseline, as this industry grows we will see many technological advances which will have to be carefully considered in view of safety.

The NTSB recommends that the US Coast Guard commission a panel of experts to study current PVHO operations, including, at a minimum, the availability of domestic and international design and construction standards; the competency and credentialing of persons on board; the distinction between crew and passengers and whether all PVHOs should be inspected regardless of operational category; maintenance and operation of submersibles; the effects of operational changes, such as storage conditions and towing; failure modes and best practices; and emergency response procedures, and disseminate findings of the study to industry. The NTSB also recommends that the US Coast Guard implement US regulations for PVHOs

---

[49] The deepest rated submersibles (see Table 8) are all classed or meet US Navy standards, including *Limiting Factor* by DNV and *Fendouzhe* by the CCS. Other classification societies also provide rules for classing submersibles. For example, see the American Bureau of Shipping's 2021 *Rules for Building and Classing Underwater Vehicles, Systems and Hyperbaric Facilities*, or DNV's 2021 *Rules for classification–Underwater Technology, Manned Submersibles*. (Det Norske Veritas and Germanischer Lloyd merged in 2013 to form DNV GL. The company changed the name to DNV in 2021.)

[50] See PVHO1-Safety Standard for Pressure Vessels for Human Occupancy, 2023. Other organizations that have published standards for pressure vessels include the US Navy (*Systems Certification Procedure and Criteria Manual for Deep Submergence Systems*, NAVMAT P-9020); the Society of Naval Architects and Marine Engineers; and the Marine Technology Society.

informed by the findings of the study recommended in Safety Recommendation M-25-012. If necessary, obtain legislative authority to act on this recommendation. The NTSB further recommends that the US Coast Guard revise NVIC 05-93 to include the revised definition of small passenger vessel as reflected in the Passenger Vessel Safety Act of 1993 and to reflect the findings of the study recommended in Safety Recommendation M-25-012.

Although the *Titan* was a vessel of the United States and should have been inspected in accordance with US regulations and guidance, OceanGate did not operate it as a US-flagged vessel. Any unflagged or stateless vessel operating in non-US waters becomes subject to the rules of whomever encounters it. Currently, rules and regulations applicable to PVHOs vary internationally; there is no mandatory standard. In 2001, the International Maritime Organization (IMO) released *MSC.1/Circ. 981*, "Guidelines for the Design, Construction and Operation of Passenger Submersible Craft," which provides guidance for passenger submersibles to provide "the highest practical standards of safety for passengers and crew on such craft."[51] The circular states that submersibles should meet the design, construction, and maintenance requirements of a recognized organization, typically a class society, or comply with applicable standards recognized by the flag state administration.[52] The circular further states that the management of passenger submersibles should comply with the International Safety Management Code.[53] However, these guidelines are voluntary unless made mandatory by the flag state, which has not been done by the United States. Therefore, there are no international rules/standards applicable to PVHOs operating internationally. As such, rules and standards applicable to PVHOs operating internationally vary, allowing operators to exploit any gaps that may exist in design, construction, and operation requirements. Given the changes in the PVHO population since the introduction of *MSC.1/Circ. 981*, the NTSB concludes that international standards for PVHOs would ensure consistency in design, construction, and operation requirements for PVHOs that operate around the world. US Coast

[51] The International Maritime Organization (IMO) is the global standard-setting authority for the safety, security, and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that is universally adopted and implemented. IMO measures cover all aspects of international shipping, including ship design, construction, equipment, manning, operation, and disposal.

[52] Flag administrations may issue a Safety Compliance Certificate for Passenger Submersible Craft for vessels meeting the requirements of the circular.

[53] The International Safety Management Code was developed to provide a standard for the safe management and operation of ships and for pollution prevention. Under the International Safety Management Code, companies that own or operate vessels subject to the *International Convention for the Safety of Life at Sea* must develop, implement, and maintain a safety management system.

Guard is the head of the delegation representing the United States at IMO. The NTSB believes IMO is the best way to reach other flag states throughout the world that currently have, and may have in the future, passenger-carrying submersibles operating that fall within their jurisdictions. Thus, the NTSB recommends that the US Coast Guard propose that IMO make *MSC.1/Circ. 981* mandatory to promote consistent application of PVHO rules amongst member states.

3 Conclusions

3.1 Findings

1. The *Titan* pressure vessel likely sustained damage after it surfaced at the end of dive 80 in the form of one or more delaminations that formed from voids between the cylinder's five co-bonded layers, leading to the deterioration and weakening of the pressure vessel.
2. After dive 82, the *Titan* sustained additional damage—of unknown origin—that further deteriorated and weakened the pressure vessel to a point where it could not survive a dive to the depth of the *Titanic*.
3. The existing delaminations and additional damage that deteriorated the condition of the pressure vessel between dive 82 and the casualty dive likely resulted in a local buckling failure that led to the implosion of the *Titan*.
4. OceanGate's engineering process for the *Titan* was inadequate and resulted in the construction of a carbon fiber composite pressure vessel that contained multiple anomalies and failed to meet necessary strength and durability requirements.
5. Because OceanGate did not perform adequate testing, including cycle life evaluation, of the *Titan* pressure vessel, the company was unaware of its actual strength and durability, which was likely much lower than their target, as well as the implications of how certain operational changes, including storage condition and towing, could impact the integrity of the pressure vessel and overall safety of the vessel.
6. Because OceanGate's analysis of *Titan* pressure vessel strain gage and acoustic emission (real-time monitoring system) data was flawed, the company was unable to identify that the pressure vessel was damaged after dive 80 and that it needed to be immediately removed from service.
7. Had OceanGate followed Navigation and Vessel Inspection Circular 05-93 guidance for emergency response plans, they likely would have had emergency response assets standing by and the *Titan* likely would have been found sooner, saving time and resources even though a rescue was not possible in this case.
8. Despite OceanGate's failure to notify search and rescue assets about its planned expedition, and the limited resources able to operate at the depth of the *Titanic* wreckage, the US Coast Guard's response coordination efforts were effective and resulted in the timely discovery of the *Titan* wreckage.
9. Voluntary guidance and current US small passenger vessel regulations are not sufficiently tailored to current pressure vessel for human occupancy operations to ensure the safety of pressure vessels for human occupancy in accordance with established technical and classification society standards.

10. International standards for pressure vessels for human occupancy would ensure consistency in design, construction, and operation requirements for pressure vessels for human occupancy that operate around the world.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the hull failure and implosion of the submersible *Titan* was OceanGate's inadequate engineering process, which failed to establish the actual strength and durability of the *Titan* pressure vessel and resulted in the company operating a carbon fiber composite vessel that sustained delamination damage that was subsequently exacerbated by additional damage of unknown origin, resulting in a damaged internal structure that subsequently led to a local buckling failure of the pressure vessel. Contributing were US and international voluntary guidance and US small passenger vessel regulations that were insufficient to ensure OceanGate adhered to established industry standards. Also contributing was OceanGate's flawed analysis of their pressure vessel monitoring system data, which led to their continued operation of a damaged pressure vessel.

4 Recommendations

4.1 New Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations.

To the US Coast Guard:

Commission a panel of experts to study current pressure vessel for human occupancy (PVHO) operations, including, at a minimum, the availability of domestic and international design and construction standards; the competency and credentialing of persons on board; the distinction between crew and passengers and whether all PVHOs should be inspected regardless of operational category; maintenance and operation of submersibles; the effects of operational changes, such as storage conditions and towing; failure modes and best practices; and emergency response procedures, and disseminate findings of the study to industry. (M-25-012)

Implement US regulations for pressure vessels for human occupancy informed by the findings of the study recommended in Safety Recommendation M-25-012. If necessary, obtain legislative authority to act on this recommendation. (M-25-013)

Revise Navigation and Vessel Inspection Circular 05-93 to include the revised definition of small passenger vessel as reflected in the Passenger Vessel Safety Act of 1993 and to reflect the findings of the study recommended in Safety Recommendation M-25-012. (M-25-014)

Propose that the International Maritime Organization make *MSC.1/Circ. 981* mandatory to promote consistent application of pressure vessel for human occupancy rules amongst member states. (M-25-015)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

JENNIFER L. HOMENDY
Chairwoman

MICHAEL GRAHAM
Member

THOMAS CHAPMAN
Member

J. TODD INMAN
Member

Report Date: October 2, 2025

Appendixes

Appendix A: Investigation

The US Coast Guard was the lead US federal agency in this investigation. The National Transportation Safety Board (NTSB) learned of this casualty from the Coast Guard on June 18, 2023. NTSB investigators traveled to Newfoundland and Labrador, Canada; Washington; North Carolina; and Rhode Island to inspect the wreckage of the *Titan* and exemplar equipment and to interview OceanGate staff.

Wreckage retrieved from the accident site by the *Odysseus* and the *Horizon Arctic* was taken to Rhode Island by the Coast Guard buoy tender *Sycamore*. The Coast Guard additionally contracted with the US Navy's Supervisor of Salvage (SUPSALV) to retrieve additional wreckage from the accident scene, accompanied by NTSB and Coast Guard investigators, in September 2023, retrieving the aft dome and an external camera among the wreckage. NTSB investigators also participated in the Coast Guard Marine Board of Investigation hearings in September 2024.

The US Coast Guard and SubC Imaging (owner of the external camera retrieved from the wreckage) were parties to the investigation. The United Kingdom, France, and Canada were Substantially Interested States.

Investigators recovered from the wreckage a camera designed to record video and still images underwater up to a rated depth of 6,000 meters (19,685 feet). The camera's outer casing was intact, but the lens had shattered. Investigators disassembled the casing and discovered an undamaged memory card on one of the camera's circuit boards. Twelve still images and nine videos were recovered from the device. However, none of the images were from mission 5, dive 88 (the accident dive).

Appendix B: Consolidated Recommendation Information

Title 49 *United States Code* 1117(b) requires the following information on the recommendations in this report.

For each recommendation–

(1) a brief summary of the Board's collection and analysis of the specific accident investigation information most relevant to the recommendation;

(2) a description of the Board's use of external information, including studies, reports, and experts, other than the findings of a specific accident investigation, if any were used to inform or support the recommendation, including a brief summary of the specific safety benefits and other effects identified by each study, report, or expert; and

(3) a brief summary of any examples of actions taken by regulated entities before the publication of the safety recommendation, to the extent such actions are known to the Board, that were consistent with the recommendation.

To the US Coast Guard

M-25-012
Commission a panel of experts to study current pressure vessel for human occupancy (PVHO) operations, including, at a minimum, the availability of domestic and international design and construction standards; the competency and credentialing of persons on board; the distinction between crew and passengers and whether all PVHOs should be inspected regardless of operational category; maintenance and operation of submersibles; the effects of operational changes, such as storage conditions and towing; failure modes and best practices; and emergency response procedures, and disseminate findings of the study to industry.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.6, OceanGate Submersible Operations and Industry Regulations. Information supporting (b)(1) can be found on pages 59-63; (b)(2) can be found on pages 46-48; and (b)(3) can be found on pages 48-49.

M-25-013
Implement US regulations for pressure vessels for human occupancy informed by the findings of the study recommended in Safety

Recommendation M-25-012. If necessary, obtain legislative authority to act on this recommendation.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.6, OceanGate Submersible Operations and Industry Regulations. Information supporting (b)(1) can be found on pages 59-63; (b)(2) can be found on pages 46-48; and (b)(3) can be found on pages 48-49.

M-25-014
Revise Navigation and Vessel Inspection Circular 05-93 to include the revised definition of small passenger vessel as reflected in the Passenger Vessel Safety Act of 1993 and to reflect the findings of the study recommended in Safety Recommendation M-25-012.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.6, OceanGate Submersible Operations and Industry Regulations. Information supporting (b)(1) can be found on pages 59-63; (b)(2) can be found on pages 46-48; and (b)(3) can be found on pages 48-49.

M-25-015
Propose that the International Maritime Organization make *MSC.1/Circ. 981* mandatory to promote consistent application of pressure vessel for human occupancy rules amongst member states.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.6, OceanGate Submersible Operations and Industry Regulations. Information supporting (b)(1) can be found on pages 63-64; (b)(2) can be found on pages 46-48; and (b)(3) can be found on pages 48-49.

Appendix C: *Titan* Dives During 2021, 2022, and 2023

Table C-1. *Titan* dives completed during the 2021, 2022, and 2023 using the second (v2) full-scale pressure vessel. (Data source: OceanGate)

Expedition	Mission	Dive	Date	Depth reached (meters)	Type of dive
Testing (V2 pressure vessel)	N/A	50[a]	4/29/2021	3	System test
		51	5/2/2021	7	System test
		52	5/6/2021	79	System test
		53	5/8/2021	8	System test
		54	5/12/2021	3	System test
		55	5/14/2021	3	System test
		56	5/17/2021	79	System test
		57	5/19/2021	3	System test
		58	5/20/2021	170	System test
		59	5/24/2021	3	System test
		60	5/25/2021	162	System test
2021	1	61	6/30/2021	7	System test
		62	7/3/2021	1,700	System test
	2	63	7/9/2021	3,840	System test
		64	7/13/2021	89	System test
	3	65	7/19/2021	3,500	Exploration
	4	66	7/24/2021	3,840	Exploration
		67	7/27/2021	3,840	Exploration
		68	7/28/2021	3,840	Exploration
	5	69	8/4/2021	3,840	Exploration

Expedition	Mission	Dive	Date	Depth reached (meters)	Type of dive
		70	8/5/2021	3,840	Exploration
2022	1	71	6/16/2022	7	System test
		72	6/18/2022	1,380	Exploration
		73	6/20/2022	3,840	Exploration
	2	74	7/1/2022	25	System test
		75	7/3/2022	3,840	Exploration
		76	7/6/2022	3,840	Exploration
		77	7/8/2022	30	System test
	3	78	7/11/2022	10	Exploration
		79	7/14/2022	3,840	Exploration
		80	7/15/2022	3,840	Exploration
	4	81	7/19/2022	3,840	Exploration
		82	7/22/2022	3,840	Exploration
		83	7/23/2022	2,954	Exploration
2023	1	N/A	N/A	N/A	No dives
	2	84	5/22/2023	8	Disabled sub drill
	3	85	5/31/2023	10	Test
		86	6/5/2023	10	Test
	4	87	6/12/2023	10	Aborted dive
	5	88	6/18/2023	3,363 (last known depth)	Casualty dive

[a] OceanGate numbered all dives—including test and exploration dives—sequentially, beginning with "1" and continuing to "49" using the first full-scale pressure vessel, and beginning with "50" and ending with "88" for the second full-scale pressure vessel.

Appendix D: Search and Rescue Assets

Table D-1. Search and rescue assets utilized to search for *Titan*.

Resource	Description	Role
106th Rescue Wing	US Air National Guard unit based at Francis S. Gabreski Air National Guard Base, Westhampton, New York	Provided C-130 for air search
910th Air Wing	US Air Force reserve unit based at Youngstown Air Reserve Station, Ohio	Transported remotely operated vehicle (ROV) *Odysseus* to Newfoundland and Labrador
Air Station Elizabeth City	US Coast Guard air station based in Elizabeth City, North Carolina	Provided C-130 for air search and International Air Patrol
CCGS *Ann Harvey*	Canadian Coast Guard buoy tender	Ferried French ROV team and Canadian Forces medical personnel
Atalante	Offshore supply vessel	Embarked 6,000-meter ROV *Victor 6000*
Atlantic Kingfisher	Offshore supply vessel	Loaded flyaway deep ocean salvage system 6000-meter-capable heave compensated lifting package
Atlantic Merlin	Canadian-flagged offshore tug/supply ship	Transported ROV package for *Skandi Vinland*
Deep Energy	Bahamas-flagged cable ship	Deployed the first ROV at the scene, a Schilling Robotics 3000-meter Working Class ROV
HMCS *Glace Bay*	Royal Canadian Navy coastal defense vessel	Transported mobile decompression chamber
Horizon Arctic	Canadian-flagged anchor handling tug supply vessel	Embarked 6,000-meter ROV *Odysseus*
CCGS *John Cabot*	Canadian Coast Guard offshore fisheries research vessel	On-scene coordinator; equipped with sonar
CCGS *Kopit Hopson*	Canadian Coast Guard icebreaking buoy tender	Surface search
Royal Canadian Air Force	CP-140 Aurora and P-8A Poseidon patrol aircraft	Air and sub-surface search
Skandi Vinland	Cable ship	On-scene ROV

Resource	Description	Role
US Coast Guard Cutter *Sycamore*	US Coast Guard buoy tender	Transported wreckage to Rhode Island
CCGS *Teleost*	Canadian Coast Guard fisheries research vessel	Ferried US Coast Guard Salvage Engineering Response Team to the scene
CCGS *Terry Fox*	Canadian Coast Guard icebreaker	Ferried medics and US Navy subject matter experts
Vizconde de Eza	Research vessel	Sonar capable

Appendix E: Other OceanGate Submersibles and Surface Tenders

Table E-1. Vessel Particulars for OceanGate submersibles *Antipodes* and *Cyclops I*.

Vessel	*Antipodes*	*Cyclops I*
NTSB Vessel Group	Specialty/Other (Submersible)	Specialty/Other (Submersible)
Owner/Operator	OceanGate (Commercial)	OceanGate (Commercial)
Flag	N/A	N/A
Port of registry	N/A	N/A
Year built	1973	2015 (rebuild)
Official number (US)	WN 9815 NZ	WN 6745 SF
IMO number	N/A	N/A
Classification society	American Bureau of Shipping	None
Length (overall)	13.0 ft (6.7 m)	22 ft (67.2 m)
Breadth (max.)	8.0 ft (2.8 m)	8.5 ft (14.6 m)
Draft (casualty)	N/A	N/A
Rated Depth	1,000.0 ft (304.8 m)	1,700 ft (518.2 m)
Number of Occupants (max.)	5	5
Tonnage	N/A	N/A
Engine power; manufacturer	N/A	N/A

Table E-2. Vessel particulars for surface tenders *Horizon Arctic* and *Polar Prince*.

Vessel	*Horizon Arctic*	*Polar Prince*
NTSB Vessel Group	Offshore (Offshore supply vessel)	Cargo, General (Cargo ship)
Owner/Operator	Horizon Maritime Services Ltd (Commercial)	Horizon Maritime Services Ltd (Commercial)
Flag	Canada	Canada
Port of registry	St. John's, Canada	St. John's, Canada
Year built	2016	1959
IMO number	9732838	5329566
Classification society	DNV	DNV
Length (overall)	307.0 ft (93.6 m)	220.4 ft (67.2 m)
Breadth (max.)	78.72 ft (24.0 m)	48.0 ft (14.6 m)
Draft (casualty)	25.6 ft (7.8m)	15.4 ft (4.7 m)
Tonnage	8,143 GT ITC	2,062 GT ITC
Engine power; manufacturer	2 x 6,000 kW (8,046 hp); Bergen B32:40V12A	4 x 954 kW (1,279 hp); Diesel Electric Fairbanks Morse 8-38D8-1/8

References

Bolotin, Vladimir V. "Delaminations in composite structures: Its origin, buckling, growth and stability." *Composites: Part B* 27B (1996), 129-145.

Hertzberg, R.W. and others. 2020. *Deformation and Fracture Mechanics of Engineering Materials: Sixth Edition.* John Wiley & Sons, Inc.

International Maritime Organization. 2001. *MSC.1/Circ. 981*, "Guidelines for the Design, Construction and Operation of Passenger Submersible Craft."

ISO (International Organization for Standardization). *Quality management systems—Requirements*. ISO 9001: 2015. ISO. September 15, 2015.

OceanGate Foundation. n.d. "About Us." Linkedin. https://www.linkedin.com/company/oceangate-foundation.

Tafreshi, Azam. "Delamination buckling and postbuckling in composite cylindrical shells under combined axial compression and external pressure." *Composite Structures* 72(4) (2006), 401-418.

US Coast Guard. 1993. "Navigation and Vessel Inspection Circular 05-93: Guidance for Certification of Passenger Carrying Submersibles."

______. 2025. "Report of the Marine Board of Investigation into the Implosion of the Submersible Titan (CG1788361) in the North Atlantic Ocean near the Wreck Site of the RMS Titanic Resulting in the Loss of Five Lives on June 18, 2023." Department of Homeland Security.

______. n.d. "Navigation and Vessel Inspection Circulars: Background Information."

OceanGate. 2023. "Why Isn't Titan Classed?" archived June 21, 2023, at https://web.archive.org/web/20230621082139/https://oceangate.com/news-and-media/blog/2019-0221-why-titan-is-not-classed.html

Casualty Summary

NTSB casualty category	Flooding/Hull Failure
Location	North Atlantic Ocean, 900 nm east of Cape Cod, Massachusetts 41°43.98′ N, 49°59.9′ W
Date	June 18, 2023
Time	1047 Newfoundland and Labrador daylight time (coordinated universal time –2.5 hours)
Injuries	5 fatal
Property damage	$5.6 million CAD (about $ 4.2 million USD) est.
Environmental damage	None
Persons on board	5

NTSB investigators worked closely with our counterparts from **Coast Guard Office of Investigations and Analysis** throughout this investigation.

National Transportation Safety Board
Records Management Division, CIO-40
490 L'Enfant Plaza, SW
Washington, DC 20594
(800) 877-6799 or (202) 314-6551