National Aeronautics and Space Administration

System Failure Case Studies

DECEMBER 2006 Volume 1 Issue 2

SUBMARINE DOWN

In the early years of the nuclear Navy, the most advanced submarine in the world sank during testing and was ultimately crushed by water pressure due to a chain of events that ostensibly started with a small leak of seawater. If so, the sub was destroyed by the simplest of causes—bad brazing in some of its pipes. The disaster killed all aboard the sub and led to the revamping of many of the manufacturing processes for both surface and undersea US naval vessels. It also helped spur the development of deep-sea exploration vehicles.

BACKGROUND: FASTER, DEEPER SUBMARINES

Early submarines were incapable of diving very deep or moving very fast because their engines required air. When they submerged deep enough that their conning tower or snorkel went underwater, they had to switch to battery-powered electric engines with limited life and power.

Published reports describe how in the 1950s, this problem was solved with the introduction of nuclear power, which did not require air to generate large amounts of electricity. This change permitted submarines to stay submerged for longer periods of time. These more powerful nuclear engines also allowed the subs to move much faster, while their smooth turbines made them quieter than the banging pistons of internal combustion engines.

In 1954, under the leadership of Admiral Hyman C. Rickover, nuclear power was introduced to the fleet on the U.S.S. Nautilus. Together with advances in hull design, silencing techniques, and sonic detection, nuclear power dramatically improved the speed, stealth, and range of U.S. submarines. The USS Thresher, which became the submarine class name as well, was launched in July of 1960 and, after preliminary trials for seaworthiness, was commissioned a little over a year later in August of 1961. As the first in her class, she underwent lengthy trials at sea over the next two years, participating in exercises that demonstrated the capability of the new design, such as the ability to travel 1300 feet deep at over twenty knots.

Launched in 1960, The USS THRESHER was the U.S. Navy's most advanced nuclear submarine built to date.

While on exercises in Florida, she was hit by a tug while moored at Port Canaveral and in the spring of 1963, after repairs and an overhaul for upgrades, she was sent back to sea off the coast of Massachusetts for post-overhaul trials.

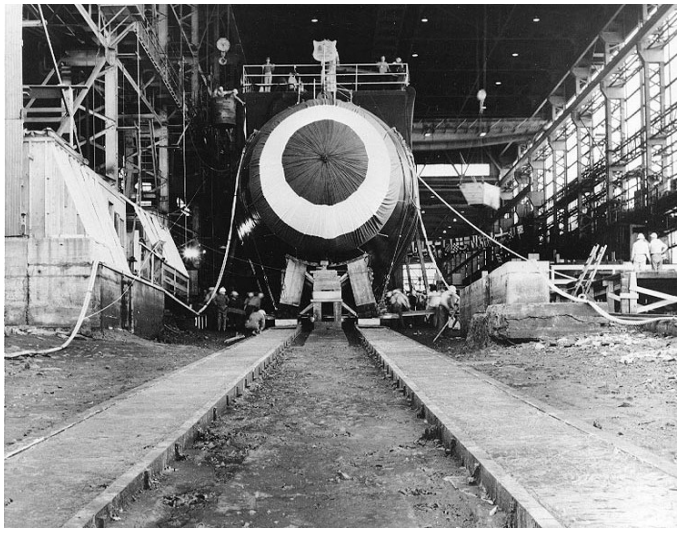
A submarine disaster in April of 1963 destroyed the USS Thresher and killed 129 American Sailors

Proximate Causes:

- Bad brazing in the sea water cooling systems
- Poor quality assurance in the installation process

Underlying Issues:

- Poor ballast system design
- Extreme depth of water for initial deep dive test after extensive overhaul



The USS THRESHER was launched in July of 1960.

What Happened?

Deep Waters

On April 9th, as described in public documents, the USS THRESHER was escorted by another Navy vessel, the USS SKYLARK, out to the edge of the continental shelf off Cape Cod, Massachusetts, where the Atlantic Ocean floor drops precipitously to 8000 feet. The USS SKYLARK was standing by for rescue if anything went wrong at a few hundred feet, though at the depths at which they were operating there would have been little she could do if the USS THRESHER went too deep. At 6:35 AM on the morning of April 10th, USS THRESHER spotted USS SKYLARK through her periscope to ensure she was in range, and prepared to dive in stages down to her maximum depth for testing

"Experiencing minor problem. Have positive angle."

Trouble Begins

At four hundred feet, the crew checked the sub for leaks in the hull, the fittings and the plumbing. Then the sub descended further. At 7:45 AM, she reported that she was at half her test depth.

A little over an hour later, at 9:02 AM, a request came from the USS THRESHER to USS SKYLARK's navigator to repeat a course heading. A minute later came a slightly more disturbing message: "Experiencing minor problem. Have positive angle."

It remains uncertain what was happening at this time, but the best theory, based on the Naval investigation report, is that some pipes had started to leak in the submarine's engine room. These leaks allowed electrically conductive seawater to get into the electronics that controlled the nuclear reactor, which in turn shorted out and shut the reactor down.

The crew presumably attempted to restart the reactor and probably also attempted to get their crippled vessel back to the surface. This would explain the "positive angle" as they attempted to point upward and climb with the propellers. Without the reactor, however, they would have been relying on auxiliary power, with far weaker thrust than the reactor had. The boat probably also had negative buoyancy, meaning that it would sink if no active measures were taken, and simply didn't have enough thrust to lift its weight to the surface.

A section of brass sea water piping recovered from the USS Thresher.

"Attempting to blow."

Emergency Measures

In order to lighten the vehicle, so that the weakened propellers could get it to the surface, or even allow the sub to float up on its own, the normal procedure would be to blow the water out of the ballast tanks and fill them with air, increasing the submarine's buoyancy. That the sub's crew were attempting to do so is evidenced by the next message from the stricken craft, shortly after the first troubling message—"Attempting to blow." The microphone then picked up sounds of compressed air being blown through the lines to the ballast tanks.

At this point, Navy investigators believe, based on tests performed later on another vessel, strainers in the lines upstream of the ballast tank valves iced up. This occurs because the high volume of air moving past the strainers at such high velocity would have caused them to cool rapidly. Icing up of the strainers would have reduced the air flow such that either the tanks couldn't be cleared at all, or at least not fast enough, because it's clear that the boat continued to sink. There was only one more ominous voice communication: "...test depth."

The only sounds were creaks of straining metal as the craft sank deeper...

From this point on, the only sounds picked up by the open microphone were the distinctive and dismaying creaks of straining metal and fasteners as the craft sank deeper and started to crush under the unimaginable external pressure. The submarine eventually broke into several pieces, killing almost instantly all 129 crew and observers aboard. It continued to sink, falling almost two miles to the floor of the Atlantic, prematurely ending the career of the most advanced submarine built to that date.

Proximate Cause

According to the Navy investigation, the proximate cause of the disaster was the leak of seawater into the reactor control electronics. This shut down the reactor, resulting in the inability of the boat to control itself or get back to the surface.

Underlying Issues

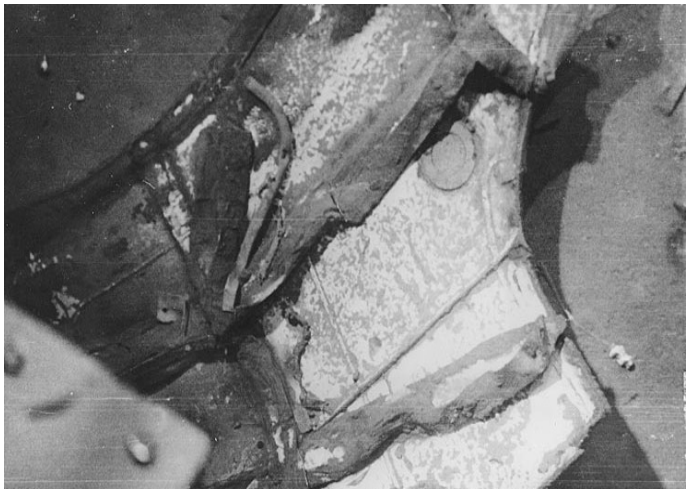
According to published reports, there were perhaps several factors that came together to destroy the USS THRESHER and its crew. The leak itself probably occurred because of faulty brazing of the piping at the shipyard. Prior to the USS THRESHER loss, the installation procedure for pipes less than four inches in diameter was to put a silver ring at the joint between two points and braze it with a torch.

Poorly brazed pipes led to the electrical shortage that led to the loss of the USS THRESHER.

Subsequent investigation of other ships after the accident showed that, though joints created in this manner appeared solid, when broken apart there was no silver in them, indicating that they were much weaker than had been previously estimated. In general, the design and standards for the non-nuclear portions of the vessel seemed to have been more lax than those for the nuclear reactor and its associated systems.

The icing of the line strainers, resulting in the failure of the ballast tanks to empty themselves of water fast enough, also contributed to events. This latter problem was a failure to meet design specification. Had either of these methods for surfacing been effective, the reactor loss would likely not have been catastrophic, because the crew could have dealt with the leaks and reactor problems on the surface.

Finally, had the testing occurred in shallower water (perhaps with the ocean bottom just slightly below test depth), in which the USS SKYLARK could have potentially come to their aid, the crew might have been saved, if not the USS THRESHER itself.



Wreckage from the USS THRESHER's sonar dome can be seen on the ocean floor.

Problem Resolution

As a result of the loss of the USS THRESHER, a major new initiative was undertaken by the Navy, called "SUBSAFE," to reform design and manufacturing processes (similar in many ways to changes at NASA following the Apollo 1, Challenger and Columbia disasters). Part of this initiative was to end the practice of brazing smaller pipes, and to instead start welding and doing x-ray inspection of joints to verify their integrity. It also resulted in changes in designs of the system that blows out the ballast tanks, providing a capability to do so seven times faster than the system used in the USS THRESHER.

It had another effect in that during the search for debris and clues on the deep ocean floor, the Navy recognized the need for better deep submersibles. This (combined with other requirements) helped result in the remarkable new designs that can now explore some of the deepest

trenches of the seas, and that helped discover the remains of the Titanic. In fact, part of the legacy of this accident was the development of the kinds of undersea rescue vehicles that recently saved seven Russian sailors trapped at six hundred feet off the Kamchatka peninsula, in early August of 2005.

Applicability To NASA

Like the Navy, NASA operates vessels that must endure harsh external environments (in this case a radiation-drenched vacuum), though the pressure differential of space is much lower (one atmosphere at most, compared to potentially many atmospheres under the ocean's surface). It is also somewhat easier to deal with, because constructing pressure vessels to keep pressure in is structurally easier than to keep it out. Nonetheless, both types of failures are equally unforgiving, and can kill people very quickly. This incident shows the importance of having multiple layers of defense against harsh outside environments, with redundant means of keeping functional those vital systems that protect us from it. It is also critical from a safety perspective that NASA simulate as close as possible to the real environments that a spacecraft or manned system will experience during flight and even include some margin above the flight expected loads and environments. These factors would include: Vibration; Acoustics; Thermal; Radiation; Vacuum, etc. This accident also indicates the importance of redundant systems and that NASA must assure that these systems will operate successfully when or if they are called upon. Finally, highly coupled and complex systems should have the benefit of a Failure Mode and Effect Analysis (FMEA) to identify potential failure modes and to control and mitigate them.

Questions for Discussion

- How could designers have prevented the leaks from causing other failures?
- What might have kept manufacturers from checking the brazing on their pipes?
- How should designers prioritize safety-critical elements of complex systems?
- How can we determine the appropriate level of redundancy to build into a system?
- How can test and verification procedures be defined to catch similar problems?
- How can test plans be modified to enhance the chances of survivability?

Questions for Discussion (cont.)

- How have post-incident initiatives such as the Navy's SUBSAFE program and the changes at NASA following the Apollo 1, Challenger and Columbia disasters helped prevent similar disasters? What makes them most effective? What challenges still remain?

References:

"Ocean Water: Pressure." Science and Technology Focus, Office of Naval Research. <http://www.onr.navy.mil/Focus/ocean/water/pressure1.htm>.

Photo #: NH 97553. [Online] Available http://www.history.navy.mil/photos/sh-usn/usnsh-t/ssn593-g.htm, March 30, 2001.

Photo #: NH 97562. [Online] Available http://www.history.navy.mil/photos/sh-usn/usnsh-t/ssn593-l.htm, March 30, 2001

"THRESHER Down," Mechanical Engineering Magazine, February, 1987

Photo #: NH 97570. [Online] Available http://www.history.navy.mil/photos/sh-usn/usnsh-t/ssn593-k.htm, March 30, 2001.

Picture of the USS Thresher. [Online] Available http://www.csp.navy.mil/othboats/593.htm, March 30, 2001.

Pictures of a Good Looking Brazed Joint and a Brazed Joint in Need of Patching. [Online] Available http://biketransplant.tripod.com/making_your_own_exhaust_manifold.htm, May 2001.

"USS Thresher (SS-593)." Arlington National Cemetary Website. <http://www.arlingtoncemetery.net/uss-thresher.htm>.

"USS Thresher (SSN-593)." Wikipedia, the Free Encyclopedia. <http://en.wikipedia.org/wiki/USS_Thresher_%28SSN-593%29>.

Prepared by the

OFFICE OF SAFETY & MISSION ASSURANCE

RAD

Knowledge . Understanding . Visibility

Review and Assessment Division

Director: John Castellano (Acting) john.p.castellano@nasa.gov
Executive Editor: Steve Wander stephen.m.wander@nasa.gov

To view this document online and/or to read about other System Failure Case Studies go to http://nsc.nasa.gov/SFCS