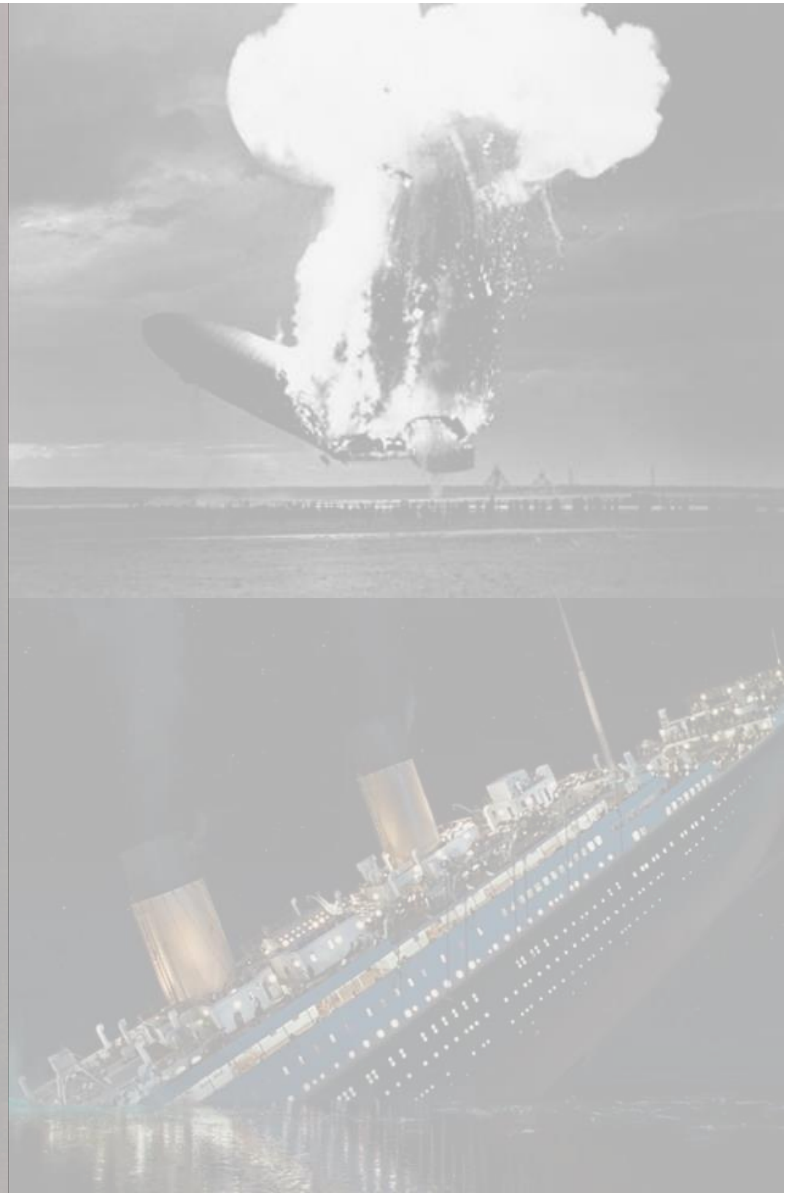
Engineering Disasters Unveiled: A Systems Engineer's Insight



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San Diego INCOSE Chapter

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Chains of Failure

Disaster – “a sudden event, such as an accident or a natural catastrophe, that causes great damage or loss of life, or an event or fact that has unfortunate consequences (1).

Natural disasters - storms, floods, droughts, fires, and heatwaves.

Man-made disasters - Technological, Transportation accidents, Public places failure, and production failure(2).

Hybrid disasters – Combination of human error and natural forces.

Over 182 identified over the last 400 years (Vasa, 1628) [My count, obviously low]

- Should these events have happened?
- There are no single event disasters, every event had multiple issues leading to the failure
- In each case, breaking one link may have averted the failure

Past Disasters

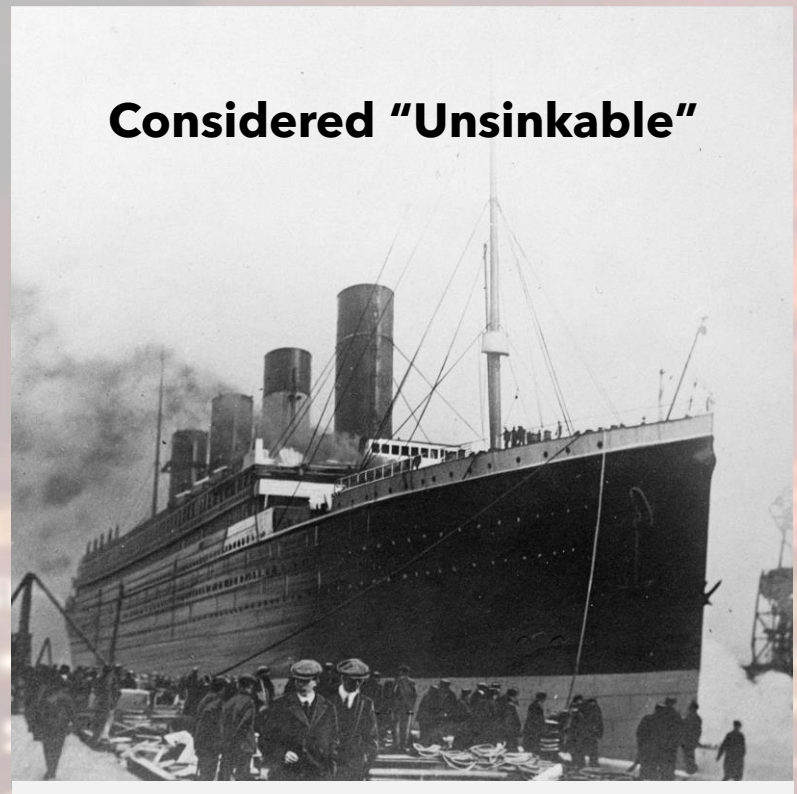
- RMS Titanic
- Steamship Sultana
- Hindenburg
- Ocean Ranger
- Chernobyl
- K-141 Kursk
- Titan Submersible

RMS Titanic

15 April 1912, 11:40PM. The RMS Titanic struck an iceberg and sank at 2:20AM while on its maiden voyage.

Failure modes: Glancing blow against the iceberg caused rivets to shear causing openings between hull plates.

Contributing Factors: High speed (22kts) in calm seas and moonless night in presence of icebergs, pressure to arrive New York early, inadequate lifeboats, ineffective watertight compartments, missed iceberg warnings, coal fire in a reserve bunker room



The Titanic sank within 2 hours of hitting the iceberg, at a cost of 1517 crew and passengers

“Iceberg right ahead.” Frederick Fleet, Titanic Lookout

RMS Titanic

Systems Engineering Thoughts:

Mission analysis should have regarded hazards to navigation, binoculars for the lookouts, better use of wireless for ice warnings, search lights to illuminate ahead of the ship

Stakeholder needs analysis didn't acknowledge need for more lifeboats (based on gross tonnage vice passenger capacity

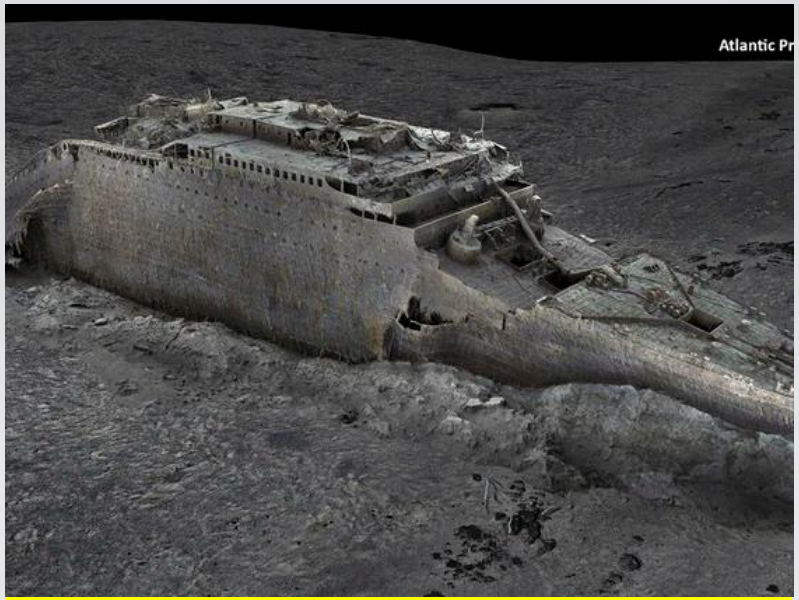
System analysis didn't account for flooding in five compartments and bulkheads didn't extend to the main deck

Improve casualty response to control flooding and dewater compartments

Verification processes didn't detect defective rivets

Operations didn't provide effective procedures to use lifeboats or fill them properly

Considered "Unsinkable"



A view of the bow of the Titanic from a digital scan released by Atlantic/Magellan in May 2023.

"Come at once, we have struck a berg, it's a CQD old man."
-Jack Phillips, Wireless Operator

Steamship Sultana

Sultana exploded and sank on ~2AM April 27, 1865 while transporting Union prisoners on the Mississippi River. 1,169 passengers were killed/lost.

Failure Modes: Explosion resulting from failed boiler repair, too much steam pressure, and sediment build up from using river water
Contributing Factors:
- Failure to reset the relief valves to lower pressure (should have been 100PSI)
- Loading the Sultana well over capacity (over 2000 passengers/crew)
- Ethical lapse by leadership (ships master driven by greed)
- Poor operations and maintenance practices (Chief engineer ignored safety warnings)
- No fire fighting capability (buckets taken and not returned)
- No emergency procedures
- Mississippi water temps

2,137 people were aboard for a ship rated for 368. The Sultana disaster coincided with the end of the Civil War and Lincoln's assassination, which overshadowed the extent of this event

Steamship Sultana

System Engineering Thoughts:

Stakeholder analysis should focus beyond only making a profit

Health and welfare of passengers and crew not a driving factor

Wooden boats and fire! No means to fight the fire or evacuate

Iron used to manufacture boilers susceptible to becoming brittle with prolonged heating and cooling

Boiler tube design was prone to clogging and sediment build up

Poor maintenance and operation caused erratic performance of boilers

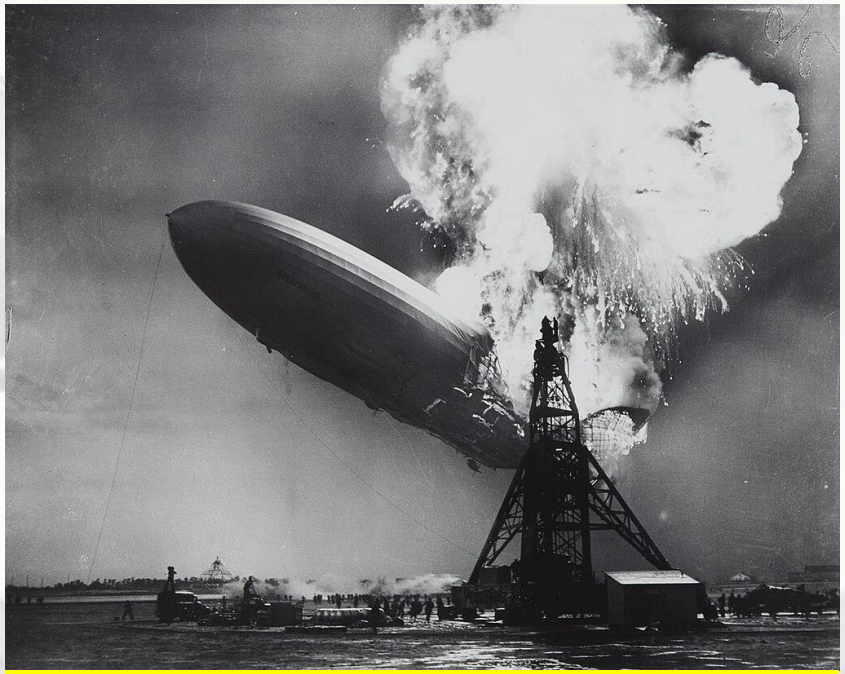
"Veterans of Gettysburg and Chickamauga thought the sight was worse than things they had seen on the battlefield." Stephen Taylor

LZ-129 Airship Hindenburg

May 6, 1937. Destroyed while attempting to dock with the mooring mast at Naval Air Station Lakehurst.

Failure Mode: Electrostatic spark ignited hydrogen gas leaking via air vents

Contributing Factors: Weather (rain, lightning); maneuvers prior to arrival (tight S-turn) may have snapped an internal cable slicing open a gas bag; gas valve stuck open; venting hydrogen during mooring; Inadequate fire suppression systems, grounding through the mooring lines



778ft long, 4.9MCuFt of Hydrogen
"32 seconds" from ignition to destruction. 36 people killed

"This is terrible; this is one of the worst of the worst catastrophes in the world."
Herbert Morris, WLS Radio Broadcast

LZ-129 Airship Hindenburg

System Engineering Thoughts:
The Hindenburg completed 17 trips between Germany, the United States and Brazil with no known mishaps

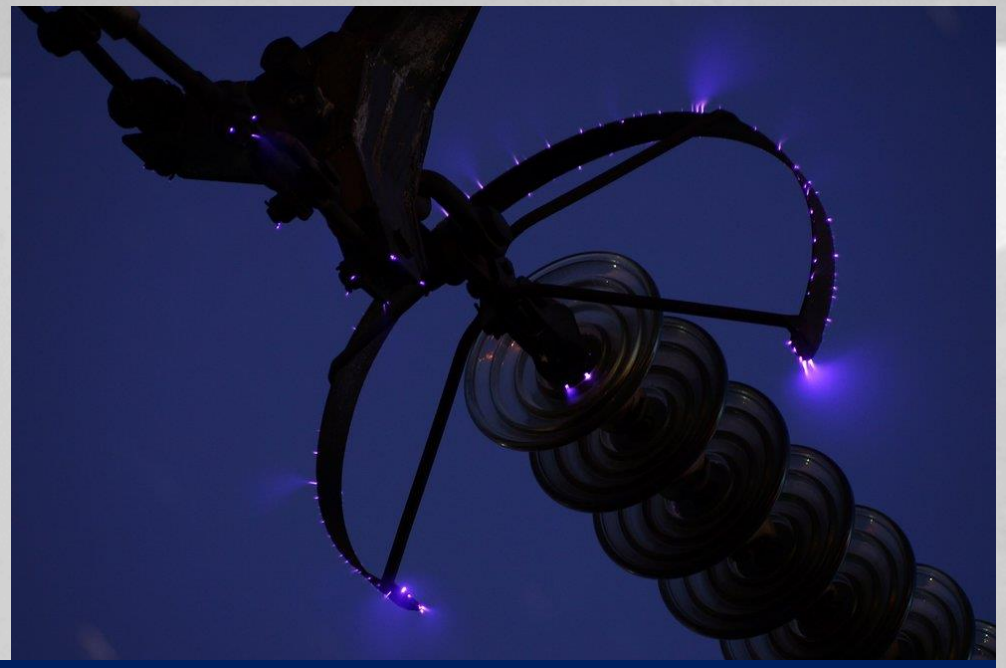
How do we counter the electrostatic buildup between the skin and the frame?

Helium would have been a better solution

Design structural framework with materials resistant to static buildup

Using a non-flammable skin material or one conducive to eliminating static discharge risk

Employing a hydrogen leak detection system



The accident essentially doomed the Airship age.

Ocean Ranger

15 February 1982. The *Ocean Ranger* sank during a winter storm off Newfoundland.

Failure Mode: Storm wave broke a porthole glass resulting in flooding the ballast control panel

84 casualties, only 22 bodies recovered

Contributing Factors:
Severe weather; confusing organizational structure; faulty design of ballast control system, porthole glass too weak; chain lockers open at the top; no alarms to indicate water in the chain lockers; training and documentation inadequate; safety equipment and procedures not written for foul weather, unclear communications with other units.

"We didn't have the gear then and, you know what, we still don't. How do you get people aboard a big steel vessel in 60 and 80ft seas? It's basically impossible. All the fancy lifesaving gear today? It's all for the mind." Rick Brown, Marine Engineer

Ocean Ranger

System Engineering Thoughts:

- Flawed business/stakeholder analysis skewed by confusing regulatory oversight
- CONOPS to clarify platform personnel roles
- Design definition insufficient in chain lockers were not sealed
- Operation and maintenance processes poor/confusing
- Crew training on ballast operations and potential failure modes

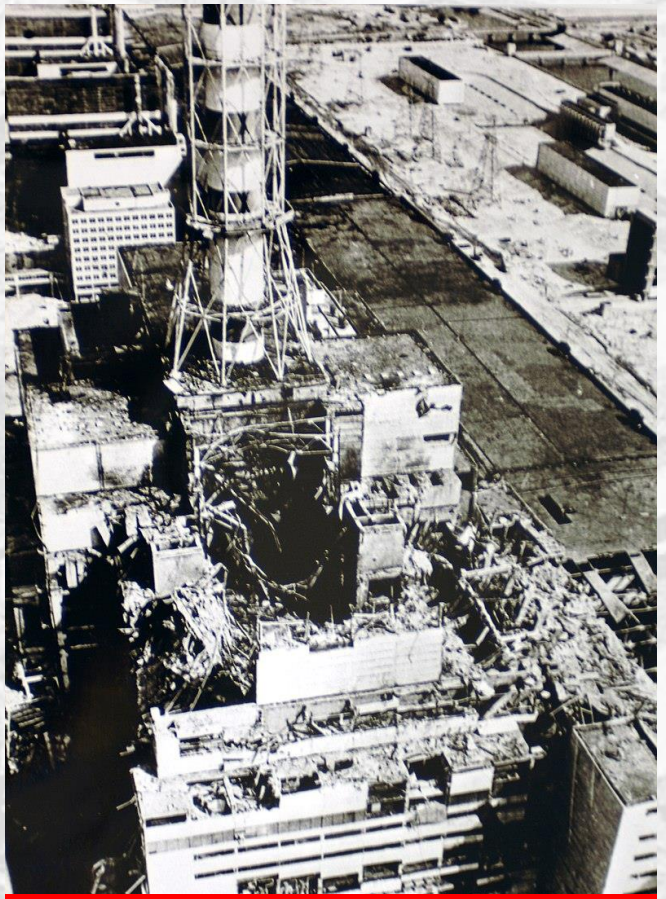
- Increased emphasis on emergency preparedness
- Preplanned communications plan
- Improved indicators for valve status and control

Chernobyl

April 26, 1986. Chernobyl occurred as a result of an explosion in the #4 Reactor following a scheduled test.

Failure Mode: Improper operations leading to loss of reactor control

Contributing factors:
Loss of cooling water; unknown buildup of Xenon-135; poor reactor design; inexperienced personnel; ineffective communications across shift changes; deliberately disabling safety systems; loss of another reactor on the power grid; test delays; poor safety culture; hierarchal org structure; testing focused on turbine generators not the reactor.



Considered a level 7 event on the International Nuclear Event Scale. 350,000 people relocated

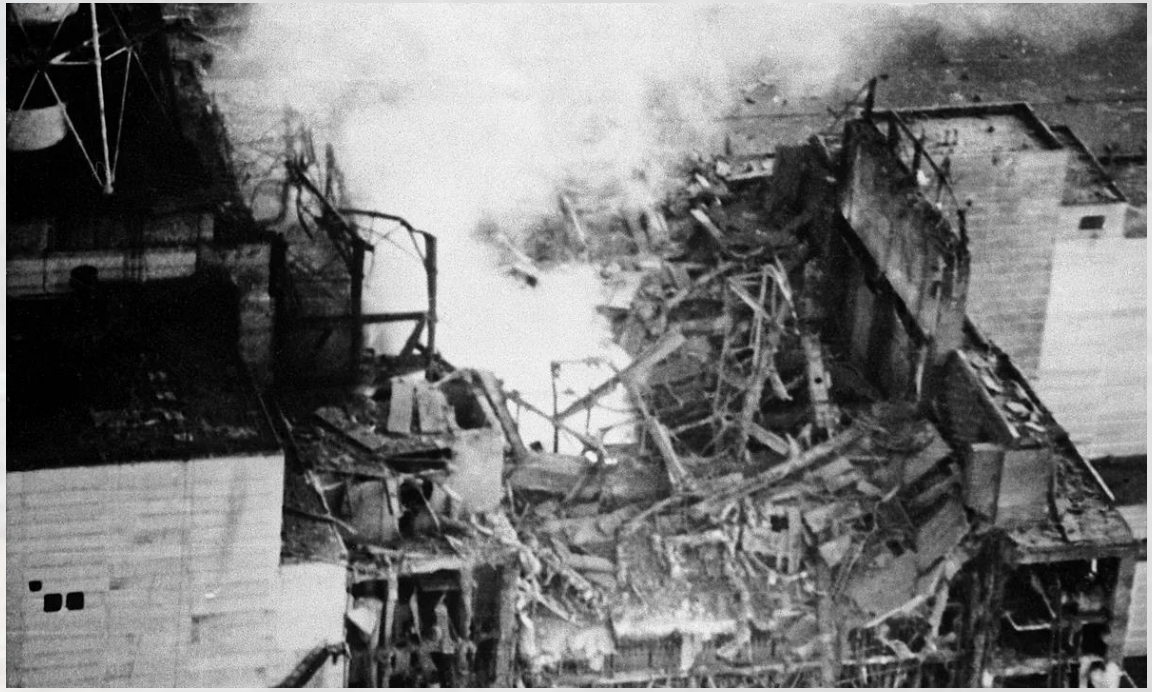
The accident at the Chernobyl nuclear power station was graphic evidence, not only of how obsolete our technology was, but also of the failure of the old system….” Mikhail Gorbachev, Memoirs

Chernobyl

Systems Engineering Thoughts:

- No real Systems Thinking – testing focused on the turbine generator
- System Analysis to evaluate testing dangers not done
- The reactor design was flawed, driven by need to keep pace with the west
- Operations and maintenance processes not effective

- No emergency notification system for the communities
- Fire fighters not trained or equipped with radiological protection
- Operator training needed improvement
- Communications and coordination



K-141 Russian Sub Kursk

August 12, 2000. The Russian submarine K-141 Kursk sank following a torpedo explosion in a torpedo tube. All Hands (118 crew) lost.

Failure Mode: Faulty weld on a torpedo leaked high-test peroxide in the torpedo tube to initiate a catalytic reaction and explosion; explosion caused follow on sympathetic explosions of 5-7 torpedoes in the torpedo room

Considered "Unsinkable"

Wreck of Russian submarine Kursk (K-141) in a floating dock at Roslyakovo.

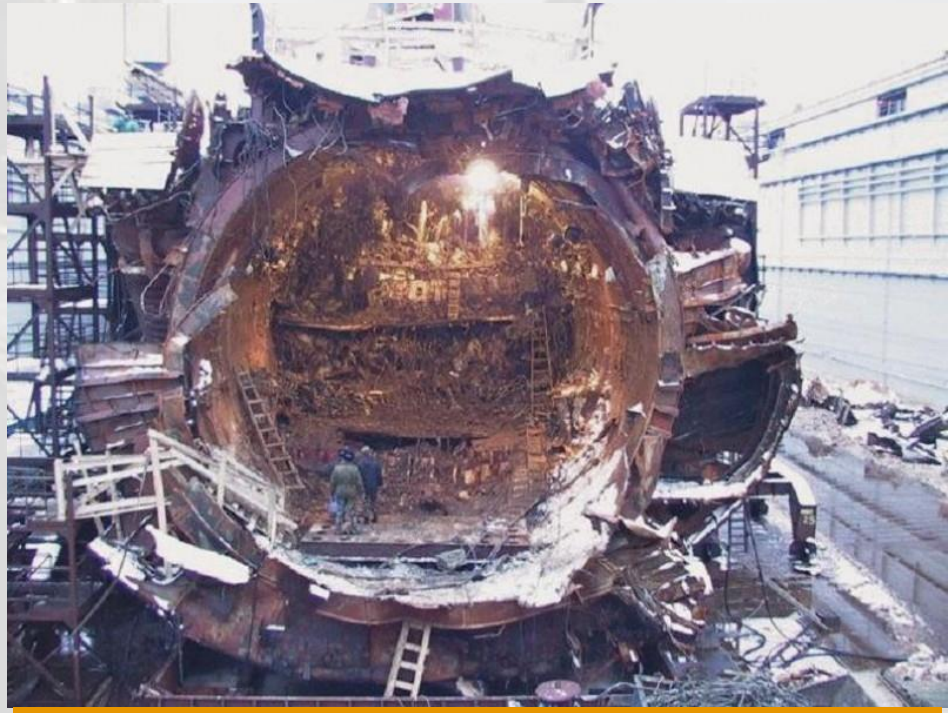
"All personnel from sections six, seven and eight have moved to section nine. There are 23 of us here. We have made this decision because none of us can escape." Captain-lieutenant Dmitri Kolesnikov

K-141 Russian Sub Kursk

System Engineering Thoughts:

- Lack of effective Life Cycle Management
- Poor torpedo design
- Poor stakeholder understanding of system complexity
- Failure of Quality Management Processes, Poor Quality Assurance
- Improve rescue capability
- Provide escape procedures

Considered "Unsinkable"



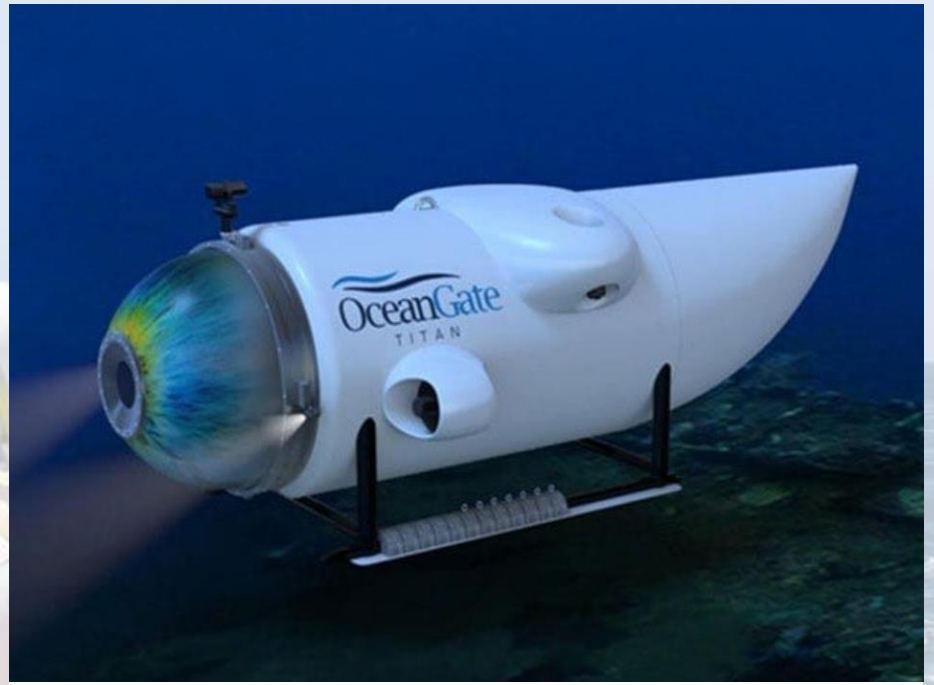
Explosions registered 2.2 and 3.4 on the Richter scale.

OceanGate Titan Submersible

18 June 2023. The OceanGate submersible Titan was lost during their 5th dive to the RMS Titanic. Five persons lost.

Failure Mode: Under Investigation, but suspected to be an implosion caused from carbon fiber "snapbuckling"

Contributing Factors: Designer ignored expert advice, no certification of design, use of new materials, stress caused by repeated use, installed safety systems ineffective



The vessel seemed to have a "MacGyver jerry-riggedness," CBS correspondent David Pogue

"that sub is an accident waiting to happen."
David Lockridge Oceangate Director of Marine Operations

OceanGate Titan Submersible

System Engineering Thoughts:

- Quality Management poor/ineffective (“hindered innovation”)
- Information management biased
- Little to no system analysis beyond wreck diving
- Business analysis not broad enough
- Little to no prototyping
- Not subject to safety regulations in international waters
- Not certified as seaworthy

Common Factors

- Each case exhibited breaking one link may have averted disaster
- Shortsightedness in Systems Thinking
  - Titanic – Operating differently, slowing down, monitoring ice warnings, different rules for lifeboats
  - Hindenburg – Using Helium, more effective means to ventilate hydrogen, political climate a factor
  - Kursk – Political climate also a factor, better training on maintenance and operations, sub distress system operational, stop torpedo leaks
- Each illustrated pressure from external stakeholders
  - Sultana, Titanic and Titan – Owners desire to make a profit/scene despite clear signs of danger
  - Titan – Owner refused to certify despite pleas from certification bodies
  - Ocean Ranger – Owners met minimum legal obligations
- Each highlighted Systems Complexity and the dangers in the lack of familiarity with the overall systems
  - Chernobyl – Operators didn't understand interrelationships
  - Ocean Ranger – Operators and Owners

Reactions to these disasters

- Titanic (1912)
  - Lifeboats quantity, capacity and inspections
  - Improved ship designs
  - 24 hour radio watches
  - International Ice Patrol
  - Safety of Life at Sea (SOLAS)
- Sultana (1865)
  - Sadly very little due to the Civil War and Lincolns death
- Hindenburg (1937)
  - Ended the airship era
  - Highlighted political tensions re Helium
  - Landing procedures changed
- Ocean Ranger (1982)
  - Design changes to the platforms (portlight)
  - Change to operational procedures
  - Co-locate Search & Rescue resources
  - Lifeboats, and safety equipment
- Chernobyl (1986)
  - Reactor design and construction
  - Proper procedures & controls
  - Decontamination measures
  - Backup safety systems
  - Trained and motivated staff
  - Safety Inspections
- Kursk (2000)
  - Design changes to torpedoes and torpedo tubes
  - Updated safety equipment
  - Emergency response procedures
  - Public relations
- Titan Submersible (2023)
  - Still under investigation
  - Importance of proper testing and certification
  - Backup systems
  - Suspended operations
  - Emergency Search & Rescue response

One link could have likely prevented any of these

Thoughts Going Forward

Think about emergence. We live in a very complex and integrated world (A affects B affects C…..)

Regardless of technology our world is still people centric.

Apply systems thinking to develop the whole picture

Risk management: Balancing financial/ego motives and safety always necessary

It’s impossible to make something failure proof but failure resistant is always achievable

Things change, looking at a project from all angles should happen frequently

Don’t <u>assume</u> for the obvious reason

You show me a successful complex system, and I will show you a system that has evolved through trial and error.

— Tim Harford —

AZ QUOTES

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