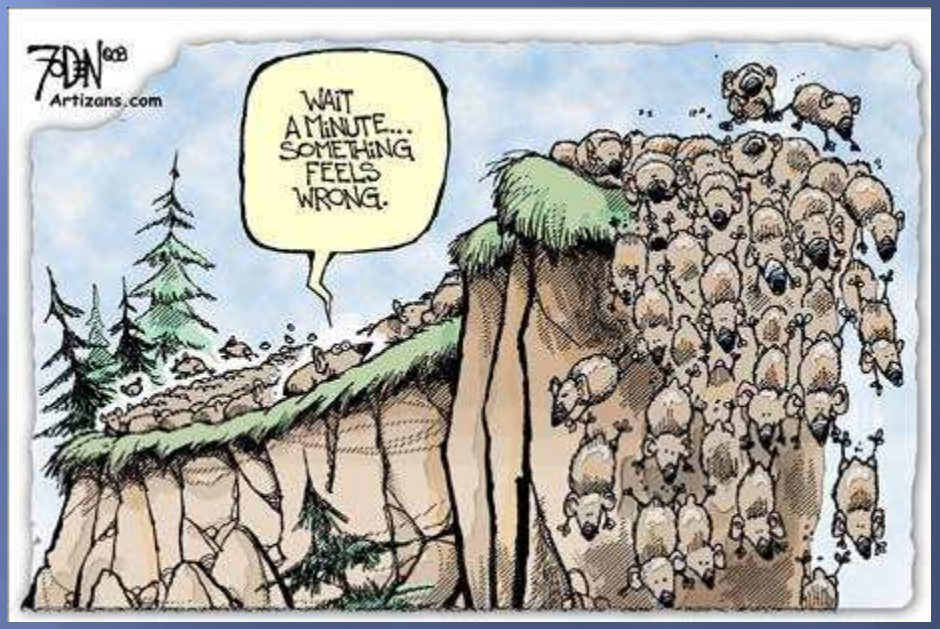
HISTORICAL PERSPECTIVES



IF SOMETHING DOESN'T' SEEM RIGHT…

Lack of wonder and openness lead to failures or at least failed to prevent failure:

- In 1984, Abbeystead (UK) water pumping station explosion killed 16 people, could it have been prevented if someone would have question why the water was bubbling? (The bubbles were caused be methane gas having seeped into the water – the methane gas is what exploded).
- It had been noticed by engineers that space shuttle solid rocket o-rings became eroded – especially on cold launch days. Why was detailed testing not conducted prior to the Challenger explosion?
- Similarly, foam had been noted to fall off of the liquid oxygen tank on space shuttle launches well before the Columbia accident. Why did NASA consider this to be acceptable?
- Reportedly, a boarding passenger noticed cracks in the fuselage on Aloha Airlines flight 243 in 1998 but said nothing assuming it was normal. During the flight, the crack propagated resulting in loss of the top of the fuselage, causing one flight attendant her life, and nearly causing the loss of the aircraft in flight.
- Boeing engineers noticed sharp corners on superplastic formed, diffusion bonded titanium test panel undergoing nondestructive inspection, yet said nothing. Had they (okay, me) pursued this, would I have prevented testing of this poorly designed test panel and given SPF/DB a fair opportunity at proving its value?

French chemist and microbiologist Louis Pasteur once stated that "***In the fields of observation, chance favors only prepared minds***."

Another philosopher, poet, and baseball legend Yogi Berra has his own way of communicating a similar thought "***You can observe a lot by just watching***."

One man sees an annoyance, another sees discovery and opportunity.

Humility is a virtue!

- An annoying hiss was turned into a 1978 Nobel Prize for Arno Penzias and Robert W. Wilson for the discovery of cosmic microwave background radiation.
- Realizing the radar energy may have caused his candy bar to melt lead Percy Spencer to create the microwave oven. (Radar is an acronym for RAdio Detection And Ranging).
- Annoying, sticky and potentially painful cockleburs made George de Mestral wonder how they worked. He came to realize that when applied properly, the physics behind cockleburs could be applied to human benefit (Velcro).
- A Du Pont chemist, Roy Plunkett, was trying to develop a non-toxic refrigerant. Instead, the Freon gas he was using became a "useless" white powder. While useless as a refrigerant, the curious mind did not dismiss this as a failure. His pursuit led to the useful discovery of Teflon. Teflon is an excellent, high temperature low friction material.
- While trying to develop synthetic rubber during World War II, scientist failed, but instead found a cure for boredom: Silly Putty.
- Highly respected structural engineer William J. LeMessurier listened to a college student he'd never met. The student claimed LeMessurier's 59-story Manhattan skyscraper could be knocked over in a strong wind. "Repairs" were conducted, it is still standing.

What we don't know is what we don't know

Engineers should also have an understanding of failure.

We often have the sense that we understand failure mechanisms relatively well

If we don't know there is a potential for failure how can we guard against it?

Ship Building, Titanic Era

[The following information for the Titanic was from Felkins, et al.]
1907 - Lusitania & Mauritania introduced by Cunard Steamship
1907 - White Star decides to build three large ships
Olympic, Titanic, Britanic
Ship Building Construction Norms (early 1900's):
Steel plates attached to other plates and/or frames
Holes punched in plates
Wrought iron rivets heated to austenite temperature
Rivets hydraulically squeezed to fill hole and form heads
Commercial Airplane Construction Norms (early 2000's):
Aluminum plates attached to other plates and/or frames and stiffeners
Holes drilled in plates
Aluminum rivets hydraulically squeezed to fill hole and form heads

Olympic (Titanic's sister ship) launched October 20, 1910
Titanic launched May 31, 1911
Power Plant:
159 furnaces, 29 boilers
650 tons coal burned per day
coal shoveled by hand
top speed: 22 knots
Olympic: retired in 1935 - successful service
Britannic: Sister ship of Titanic and Olympic
used as a hospital ship in W.W.I
Sunk November 21, 1916 - mine in Aegean Sea
Lusitania: Sunk May 7, 1915 - German U-boat

Titanic

April 12, 1912 - Titanic left Southampton, maiden voyage to New York

April 14, 1912

- Moon-less night
- Warnings of icebergs
- 22 knot speed (full throttle)
- Titanic strikes iceberg
  - 3 to 6 times its own mass
  - contact for 10 seconds
  - contact for about 100 meters

Few hours later, Titanic lay in water over 2 miles deep, over 1500 dead.

Titanic Today

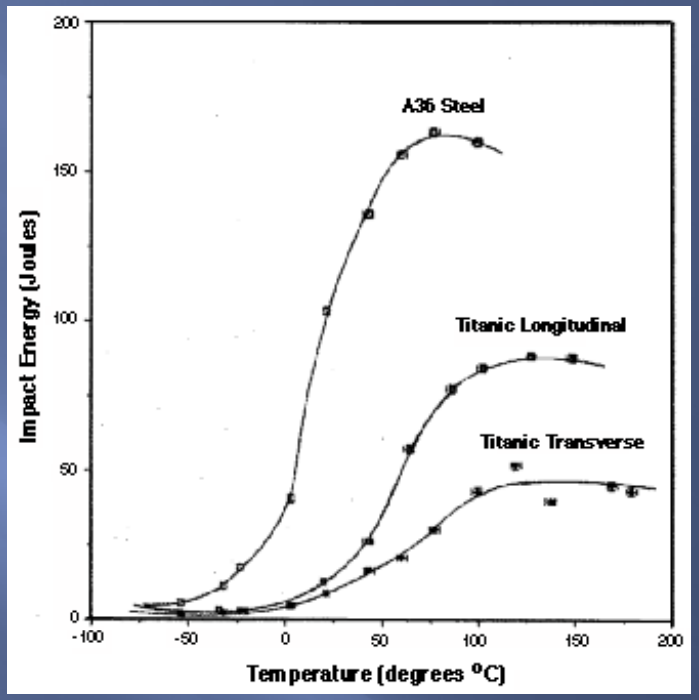
September 1, 1985 - Robert Ballard and his team finds Titanic

August 1986 - Steel samples brought to University of Missouri-Rolla

Analysis:

- Chemical Composition: similar to A-36 but:
  - higher S:Mn ratio
  - higher phosphorous content
  - both these increase ductile-brittle transition temp
- Tensile strength: slightly lower strength than 1020, more elongation
- Charpy Impact: Brittle at 0 °C
- Steel was of HIGH QUALITY for 1910 period.

Titanic: Lessons Learned



Don't travel fast in icy conditions - you are always "sinkable"
The unknown and unseen can be dangerous
Carry more life boats - anticipate "failure"
No metallurgic knowledge gained since no wreckage recovered

Questions:

Would Titanic have sunk if made of A-36?

Gulf of Mexico, 2010 – where were the “life boats”?

World War II

30 years after the Titanic sank, W.W.II was underway

Aviation:

Boeing produced one B-17 every hour, 24 hours/day, 7 days/week

•A “plywood” city covered much of the factory (Plant II) to “camouflage” it from enemy bombers (i.e. a method of “failure prevention”)

Rosie the Riveter – Women enter the work force in large numbers to support the war effort

W.W.II Merchant Ships

US Ship yards produced merchant ships:
Welded structure used to reduce production time
•Liberty, Victory, Tankers

Liberty Ships:
•Cargo ship
•One per day was produced on Swan Island in Portland,

Oregon (Kaiser Shipyard)
•2500 ships built at various shipyards
•700 – experienced sever fractures
•145 - broke

The USS Schenectady a new tanker breaks apart, sinks at Swan Island Dock, Portland, Oregon, January 16, 1943. Temperature that day was in the low 40's.

In fact ten USMC ships, eight of them standard Liberty's, had already suffered a serious fracture by the time of the Schenectady incident. But the Schenectady fracture was the first to happen in full view of the population of a major city, and hence the first to attract widespread attention.

Study was conducted to determine failure cause (1943-1946)

- ~5000 Merchant ships
- ~1000 Had structural failures
- 8 Lost at sea
- 4 Broke in part, but not lost
- 26 Lives lost

Findings:

1) Most failures occurred under low temperature, heavy seas
2) Age of vessel, no effect
3) Loading, no effect
4) Sub-average construction practices, more failures
5) All steel met specifications
6) Most failures were on Liberty ships
7) **Every fracture originated at a discontinuity or notch**
8) The steel had a large variation in notch sensitivity

The effect of the design changes was a decline in the fracture rate from thirty percent for ships with keels laid in February 1943 to about five percent only four months later.

W.W.II Merchant Ships

Riveted Ships
- Ships constructed using rivets were investigated
- Cracks existed
- Cracks stopped at riveted joints

Welded Ships
Fractures did not show any plastic deformation
- no shear lips
- no “necking”

Welded vs. Riveted
- “Monolithic” structures produce stress concentrations and residual stress
- Welding alters local microstructure
- Riveted joints allowed for retardation of crack propagation

W.W.II Merchant Ships

Cause of Failures: Notches existed in material that was notch sensitive at cold operating temperature.

Remedial Steps/Lessons Learned:

- reduce sharp corners (make them round)
- install crack arresters
- improve construction/welding practices
- welding can produce high quality ships

NOTE: commercial airplanes are riveted, but increasing use of monolithic designs. Composites facilitate monolithic design. The 787 is highly monolithic.

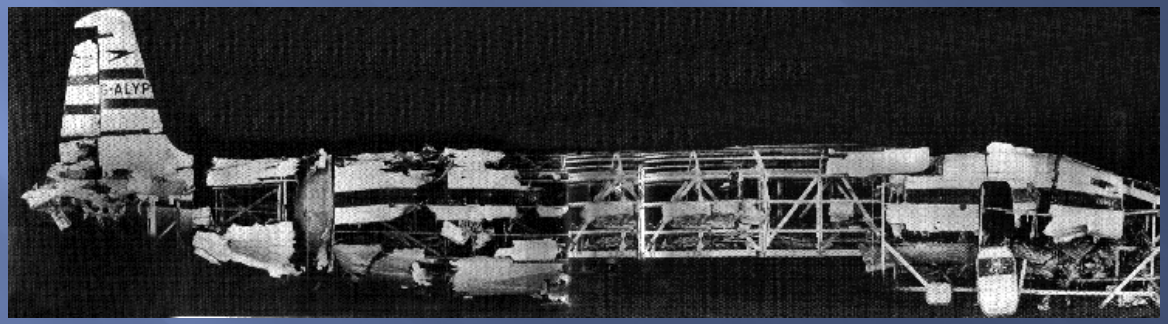
HISTORY OF FATIGUE

- *Fatigue*: "exhaustion resulting from extreme physical, mental, or emotional exertion."
- The term was first used around 1838 to describe the "wearing out" of metal due to cyclic loading.
- **Extensive research in metal fatigue began after the 1842 railroad accident near Versailles, France. Over 1500 lives were lost in this accident** *(note: I have not confirmed this number with other sources, Lulay)*.
- Within a year or so, W. J. M. Rankine identified sharp corners and other stress concentrations has having a significant role in fatigue failures.

In the 1860's Wohler studied the relationship between the stress amplitude and the number of cycles till failures (S-N curves), and he identified that steel has an endurance limit (if the stress amplitude is below the endurance limit, the part will never fatigue) [Suresh 1991].

COMET, A CASE STUDY

They believed… that a cabin that would survive undamaged in a test to double its working pressure, 2 P, should not fail in service under the action of fatigue. *(Why?)*



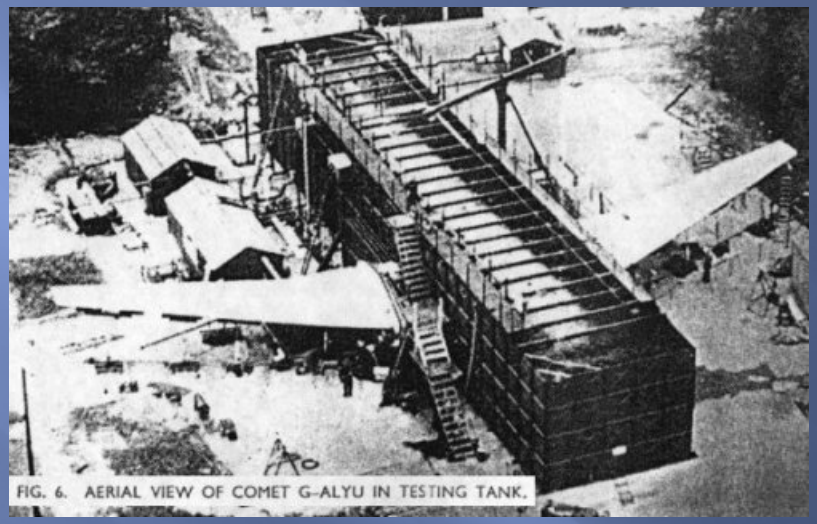


FIG. 6. AERIAL VIEW OF COMET G-ALYU IN TESTING TANK.

... They recognized, however, that testing alone is not sufficient. Every test is to some extent a compromise, since the conditions to be met in service can seldom be represented completely in the laboratory and in many cases are not accurately known. ***The result must therefore, be reviewed in the light of calculations based on fundamental knowledge, and on general experience and practice***.

And the rest is for you to read….