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The Moon, an optical illusion and an iceberg

Did these sink the Titanic?

The Titanic in Cobh Harbour, Ireland, just two days before she sank

Key words

pressure

strength

tides

refraction

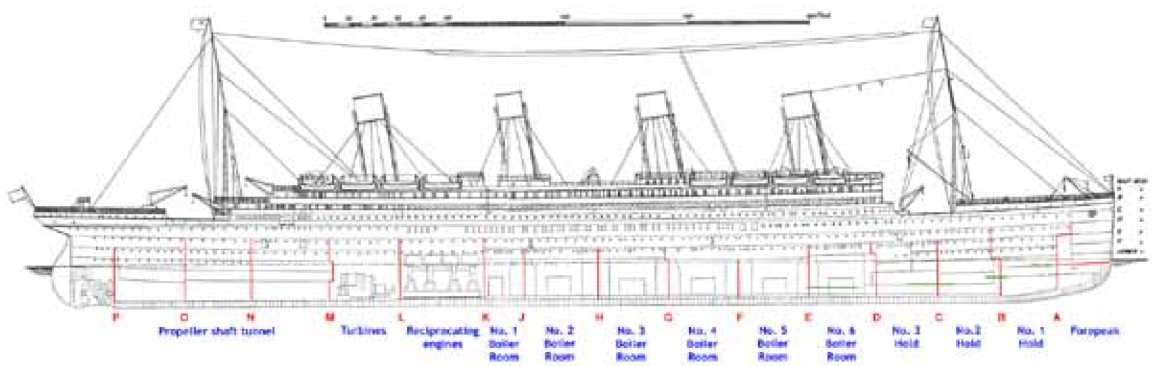
Just over one century ago the RMS Titanic sank on her maiden voyage, an event that shocked a public that had been led to believe she was 'unsinkable'. At 11:40 pm on Sunday 14 April 1912, while bound for New York from Southampton and steaming at nearly 22½ knots just off the Grand Banks of Newfoundland, she struck an iceberg. She sank just three hours later, taking two-thirds of her 2224 passengers and crew to a watery grave. Titanic has attracted her share of conspiracy theories but some simple Physics may have doomed the Titanic to her resting place four kilometres below the surface of the North Atlantic.

The 'unsinkable' ship

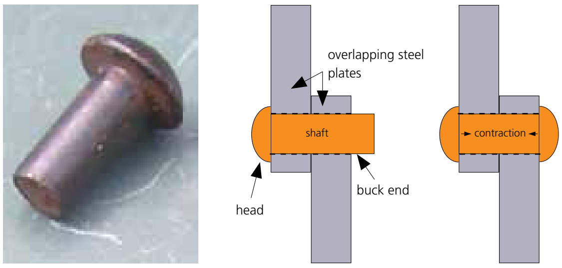
The hull of a ship can be divided into a series of compartments by partitions called bulkheads. If these bulkheads are watertight, a ship can stay afloat even when some of the compartments are flooded. Titanic was divided into 16 compartments. She was designed to float with flooding of any two compartments or, because they were narrower and therefore smaller, all four of her front compartments. Thomas Andrews, her chief designer, was aboard Titanic for her maiden voyage. When he learned that five compartments had been breached, he told Captain Smith, "It is a mathematical certainty that the ship will sink."

A complex metal joint, held together by rivets.

Titanic's hull was composed of mild steel plates held together by three million rivets. A rivet consists of a smooth cylindrical shaft with a head at one end. It is heated until it is red-hot so that it expands. Then it is hammered into a hole that has been punched through two overlapping plates. The head stops the rivet passing all the way through the hole. The other end of the long shaft is then flattened so that its diameter exceeds that of the hole and the rivet cannot fall out. The rivets contract as they cool down, pulling the two plates together with such a tremendous force that the join becomes watertight.



Transverse bulkheads divided Titanic's hull into separate, watertight compartments. The fourth (rear) funnel was a dummy, to make the ship look more symmetrical.



Joining metal plates with a rivet

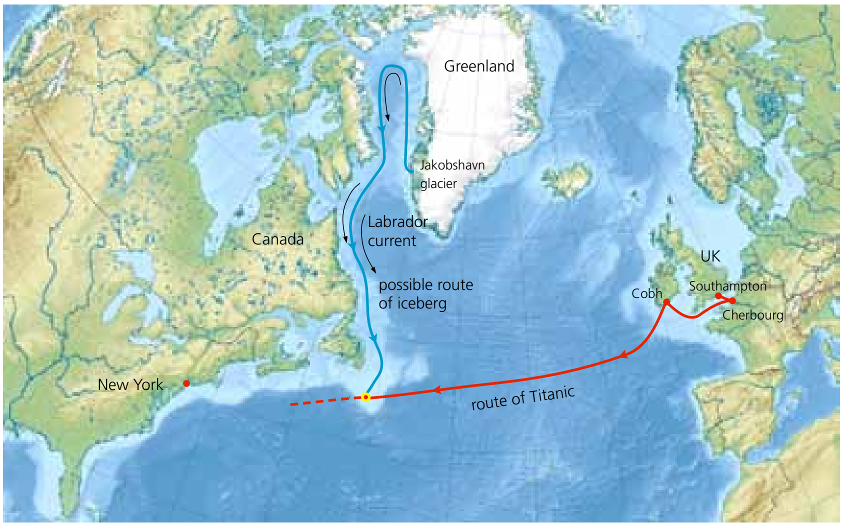
The ice did not gouge a tear along Titanic's hull. It was the force of the collision that caused the plates to buckle or rivets to pop. Experiments showed that the plates would have flexed (and not fractured) in response to the collision. Two metallurgists, Tim Foecke and Jennifer Hooper McCarty, studied the rivets. They scoured the records kept by the Harland and Wolff Shipyard in Belfast, where Titanic was built, and discovered that rivets at the front and rear fifths of Titanic were made only of 'best' quality iron, not 'best-best'. Furthermore, these were inserted by hand because the hydraulic presses used to insert rivets in the middle of the ship could not be operated at the bow and stern where the curvature of the hull was too acute.

Though 'best' rivets were cheaper, it is doubtful that cost-cutting was the motivation for using them. They were probably preferred because they would have been easier to work by hand. But they were weaker, because they had a higher concentration of impurities known as slag. Mathematical modelling of the collision suggests that each rivet would have been put under '14000 pounds of pressure' (equivalent to 100 megapascals or 1000 atmospheres) but laboratory tests showed them failing at about 70 per cent of this. Their strength was inadequate.

'Iceberg Alley'

When glaciers reach the coast their ends break off, creating icebergs, in a process known as calving. Every year, 10 000 to 15 000 icebergs and smaller chunks of ice find their way into the North Atlantic. Ninety-five per cent of them are calved on Greenland's western seaboard. The icebergs circulate anti-clockwise around the Labrador Sea until the Labrador Current carries them south, where they regularly run aground in the shallow waters off Newfoundland.

An iceberg, aground in a bay in north-west Greenland



Astronomical event	Date and time
Earth at perihelion	3 January 1912, 10h 44m UT
Spring tide (full moon)	4 January 1912, 13h 29m UT
Lunar perigee	4 January 1912, 13h 35m UT

The table lists three astronomical events spotted by the late oceanographer Fergus Wood that coincided in early January 1912 and may have increased the number of icebergs.

Tides are bigger than usual when the Sun, Moon and Earth are lined up. These spring tides occur twice every month so are not unusual. In early January 1912, the Sun and Moon were lined up on opposite sides of the Earth. However, the orbits of the Moon around the Earth and of the Earth around the Sun are both eccentric (i.e. not quite circular). On 3 January, the Earth was at its closest point to the Sun (perihelion) in its annual orbit and, the following day, the Moon was at its closest point to the Earth (lunar perigee) in 1400 years. The increased gravitational pull of the Moon and Sun led to a significant increase in the height of the tides. This allowed more grounded icebergs than usual to be re-floated so that they could continue their journey into the North Atlantic and into the path of the Titanic.

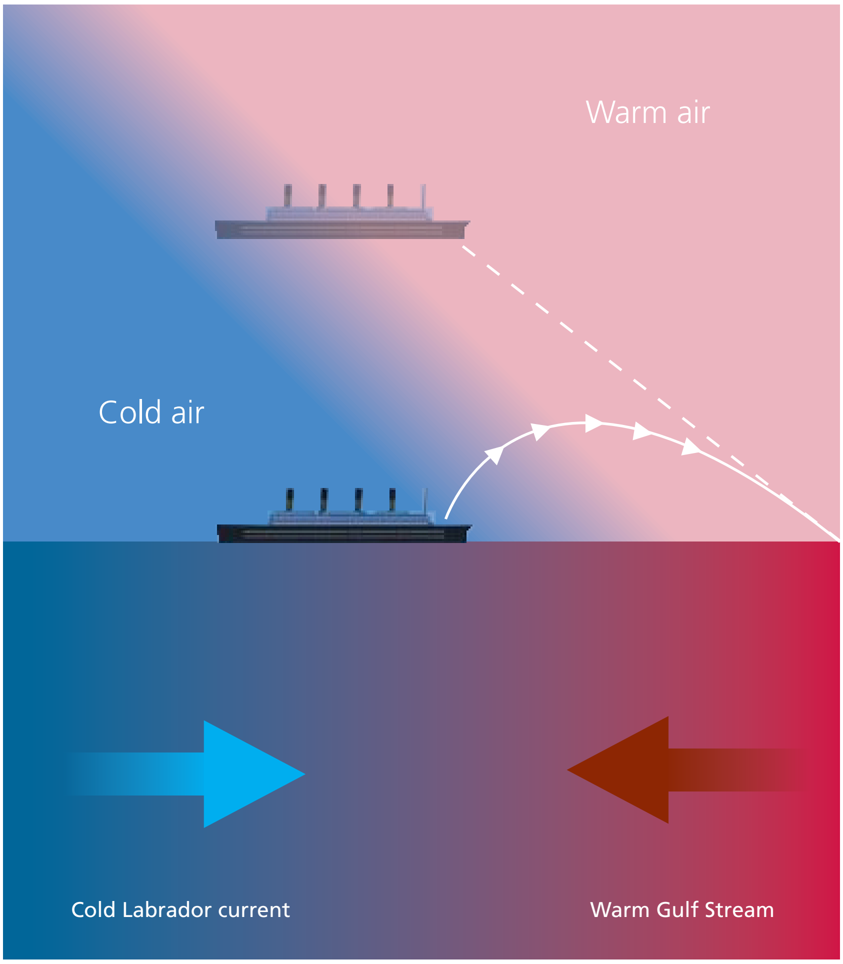
A full moon brings spring tides (not to scale).

An optical illusion

On the night that Titanic sank, the SS Californian had stopped in order to avoid the risk of colliding with ice, which was proving difficult to spot in the darkness. It was a still and moonless night, so there were no waves breaking against the icebergs and no moonlight to reflect off any surf.

Compelling research by British historian Tim Maltin suggests that an optical phenomenon called super refraction might explain why the SS Californian failed to offer assistance, despite being the closest ship to the stricken Titanic, and why efforts by both crews to communicate by Morse lamp met with no response – because neither crew could see the other's signal.

Titanic was steaming from the 'warm' waters of the Gulf Stream into the 'cold' Labrador Current, creating ideal conditions for super refraction. Under normal conditions, the atmosphere is warmed by the Earth's surface so that temperature usually falls with increasing altitude by around 7°C for every 1000 m gain in altitude (the 'lapse rate'). However, as the diagram shows, warm air associated with the Gulf Stream was sitting above the cold air of the Labrador Current, creating a temperature inversion. The refractive index would have been higher in the Gulf Stream air – because it was warmer and carried more water vapour – so light followed a curved path.



Temperature inversion can lead to super refraction. Light rays from the ship are bent as they pass from cold air into warmer air – a mirage is the result.

A Fata Morgana mirage of a ship, seen from an Australian beach.

This creates a superior mirage, with objects appearing higher or taller (and therefore nearer and smaller) than they really are. Images sometimes sit on a false horizon, which is above the true horizon, with a hazy band in between. In these conditions it is possible to see objects beyond the horizon and for intermediate objects to become lost in the haze. In this way, the iceberg that sank Titanic may have been concealed from her lookouts and this may explain why the crew of the SS Californian could only see the top half of a ship and, because it appeared to be closer than it really was, may have been dismissed as too small to be Titanic.

We know that super refraction creates the Fata Morgana mirages seen at sea. Such mirages are common in Arctic regions and were first observed and documented in 1596 by Willem Barents while he was searching for the Northeast Passage. His ship became stuck in the ice at Novaya Zemlya, where the crew was forced to endure the polar winter. However, their midwinter night came to a premature end with the rise of a distorted Sun about a fortnight earlier than expected – light carried to them over the curve of the Earth by super refraction.

The verdict

Captain Smith of the Titanic should have heeded the many and detailed ice warnings by changing course or reducing speed. One positive legacy of the tragedy was the establishment in 1914 of the International Convention for the Safety of Life at Sea (SOLAS), which still governs maritime safety today. As well as limiting speed and ensuring sufficient lifeboats, a ship's radio has to be monitored 24 hours a day – any of these could have averted or reduced the scale of the Titanic disaster.

Mike Follows teaches Physics and enjoys scientific explanations.