***Titanic* 100 years on — the Continuing Challenge of Passenger Ship Safety**

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On 14 April 1912 the White Star liner *Titanic*, on her maiden voyage to New York, was steaming at 21.5 knots under a clear sky on a flat calm sea – so calm that it even reflected star light. It was unusually cold for that time of the year. Ahead of her lay a large ice field, some 10 miles wide and 300 miles long, one of the largest of the 20th century, smaller only to that of 1986. Having received seven warnings from other ships during the day, her Captain had altered course twice to pass south of the usual shipping routes of April.

At about 2340 a lookout spotted the dark shape of an iceberg some 500 m directly ahead. On his report the ship began a hard turn to port, the watertight doors were closed and the engines ordered to stop. *Titanic* had insufficient room to avoid the iceberg which was very broad and estimated to have a mass of some 180,000 to 300,000 tons. She hit the iceberg with a glancing blow — passengers and crew felt a series of grinding shocks as the ship scraped by the iceberg — with a sound like thunder to those in the engine rooms.

By 0010 *Titanic* was stopped and drifting on the flat calm sea. An inspection by Captain Smith and Thomas Andrews, the naval architect from Harland and Wolff responsible for her design, revealed that the ship was rapidly taking water in six compartments and water was also seeping into a seventh (Boiler Room 4), although that was initially being controlled by pumps. Had the damage been confined to the first four compartments the ship could perhaps have remained afloat, but with six flooding her sinking was inevitable.

During the enquiry into her loss in 1915 it was estimated that the penetrations into the ship must have been about 12 square feet. We now know that this estimate was quite accurate as sonar analysis has revealed the extent of the damage to be about 12.6 square feet.

Titanic sank gracefully. The seas were calm and, apart from an initial list caused by asymmetric flooding, she remained upright and substantially stable until just before the end.

Evacuation of the ship began at about 0025 on the morning of 15 April. Whilst *Titanic* had greater lifeboat capacity than was required at the time, her boats could only accommodate about half the number of people on board. Many factors combined to delay the evacuation, including disbelief that the ship could actually sink, concern that the boats might not be strong enough to take the rated numbers, crew unfamiliarity with the boat launching arrangements and lack of communication. After an hour only six boats had been launched.

When *Titanic* sank at 0220, there were still 1,522 people on board. The ship left 705 survivors floating around the site of her sinking in boats which still had some 450 unfilled seats. It has been argued that, had *Titanic* been fitted with two tiers of lifeboats as her shipbuilder had originally designed her, many more lives would have been saved. However, the time taken to launch her boats and the difficulties which would have been apparent recovering falls and launching the second tier as the ship's trim increased suggest that there would have been insufficient time to make a substantial difference.

The sinking of *Titanic* and the loss of so many lives had a profound effect on public perceptions of the safety of sea travel. In those days, before the advent of modern air travel, passage by sea was the normal way to travel across oceans and seas. Not that this travel was necessarily safe. Although the advent of steam propulsion provided ships with the means to avoid storms, rocks and other ships it is estimated that, in the two decades after 1840, when Samuel Cunard began a regular service across the Atlantic, 13 vessels sank with the loss of 2,200 lives. Many people were still in peril on the sea and in the late 19th and early 20th Century between 700 and 800 lives were lost annually from British ships alone.

During the first decade of the 20th Century the size of passenger ships grew rapidly, and *Titanic* and her sisters typified the modern high-speed passenger ship and fostered a sense of security which was destroyed when *Titanic* went down.

In response to this disaster the British Government organised an international conference in London to develop international regulations for the safety of ships. Representatives of 13 countries attended the conference and the Convention which resulted was adopted on 20 January 1914. The Convention was to enter into force from July 1915 but World War I intervened although many of the Convention's provisions were adopted by individual nations.

The 1914 Convention introduced international requirements for the safe navigation of all merchant ships; the provision of watertight and fire-resistant bulkheads; life-saving appliances and fire prevention and fire fighting appliances on passenger ships. Other requirements dealt with the carriage of radiotelegraphy equipment for ships carrying more than 50 persons and the Conference also agreed on the establishment of a North Atlantic ice patrol.

Another conference was held in London in 1929 attended by 18 countries. It updated the 1914 convention and revised the international collision regulations.

Spurred by advancing technology the third SOLAS Convention was held in 1948. In the same year a United Nations conference in Geneva established the Inter-Governmental Maritime Consultative Organisation — now the International Maritime Organisation (IMO). It was intended that this body would keep the Convention up to date.

In 1948 improvements were made to requirements for watertight subdivision in passenger ships; stability standards; the maintenance of essential services in emergencies; structural fire protection, including the introduction of three alternative methods of subdivision by means of fire resistant bulkheads, and the enclosure of main stairways. The Collision Regulations were also revised and regulations concerning the safety of navigation, meteorology and ice patrols were brought up to date.

It took so long for the IMO Convention to be ratified that the new organization did not meet until 1959 when it was decided to adopt a new Convention rather than update that of 1948. Fifty five countries attended the 1960 SOLAS conference and the new Convention included many technical improvements. Many safety measures which had once applied only to passenger ships were extended to cargo ships, notably those dealing with emergency power and lighting and fire protection. The radio requirements were again revised and provision was made for the carriage of liferafts, which had developed to such an extent that they could be regarded as a partial substitute for lifeboats in some cases.

SOLAS 1960 was amended several times over the following years however the time it took for sufficient countries to accept the amendments so that they could come into force prevented the process from being effective. The Convention provided for amendments to come into effect 12 months after two thirds of the contracting parties to the parent convention accepted them. It soon became apparent that amendments would be out of date before they became international law.

Accordingly IMO decided to introduce a new SOLAS Convention which would enable future amendments to become effective in a reasonable period of time. Seventy-one countries attended the 1974 SOLAS conference and the Convention it adopted included a new tacit acceptance procedure which reversed the approval process – that is, amendments are deemed to be accepted within two years unless they are rejected within a specified period by one third of the contracting governments or by contracting governments whose combined merchant fleets represent not less than 50% of world gross tonnage.

The 1974 Convention finally came into force on 25 May 1980. Meanwhile a number of accidents to tankers prompted a conference on tanker safety which resulted in a 1978 Protocol which came into effect in May 1981. Since it came into effect, SOLAS 1974 has been amended many times. Notably, the 1983 amendments made changes to lifeboat requirements. Partially or totally enclosed lifeboats were required to have engines and, on passenger ships, such boats were required to be provided on each side for not less than 50% of the persons on board. Totally enclosed lifeboats must be capable of righting themselves automatically if they capsize. Rescue boats — that is, boats which are designed to rescue persons in distress and to marshal survival craft — were also required.

One important new 1983 requirement was that survival craft on passenger ships must be capable of being launched with their full complement of persons and equipment within 30 minutes from the time the abandon ship signal is given. Survival craft must also be capable of being launched when the ship has a list of 20 degrees in either direction, an increase on the 15 degrees required by SOLAS 1974.

In most of the passenger ship losses which have involved large loss of life, hypothermia has severely affected the survival prospects for people in the water. None of the 1500 people who ended up in the sea when *Titanic* sank were alive when rescue arrived one hour and fifty minutes later. During World War II, the Royal Navy lost some 45,000 men at sea, of whom it is estimated 30,000 died of drowning and hypothermia. The 1983 SOLAS amendments addressed this problem with the requirement for partially or totally enclosed lifeboats, some of which may be substituted by liferafts, and the provision of immersion suits and thermal protective aids. The amendments also took into account modern technology like the development of marine evacuation systems involving the use of slides, similar to those installed on aircraft.

In March 1987 the roll-on/roll-off passenger ferry *Herald of Free Enterprise* capsized and sank shortly after leaving Zeebrugge in Belgium. The accident resulted in the deaths of 193 passengers and crew members and led to demands for action to improve the safety of a ship type which had proved outstandingly successful from a commercial point of view. Shortly after the accident the United Kingdom came to IMO with a request that a series of emergency measures be considered for adoption. The subsequent amendments dealt with the integrity of the hull and superstructure, damage prevention and control and required that indicators be provided on the navigating bridge for all doors which, if left open, could lead to major flooding of a special category space or a ro-ro cargo space. A new regulation included requirements for supplementary emergency lighting for ro-ro passenger ships.

One of the most important amendments was designed to improve the stability of passenger ships in the damaged condition. It took into account such factors as the crowding of passengers on to one side of the ship, the launching of survival craft on one side of the ship and wind pressure. It also stipulated that the maximum angle of heel after flooding should not exceed 15 degrees.

In 1990 important changes were made to the way in which the subdivision and damage stability of cargo ships is determined. They apply to ships of 100 metres or more in length built on or after 1 February 1992.

The amendments introduce subdivision and damage stability requirements for cargo ships based upon the so-called "probabilistic" concept of survival, which was originally developed through the study of data collected by IMO relating to collisions. This showed a pattern in accidents which could be used in improving the design of ships: most damage, for example, is sustained in the forward part of ships and it seemed logical, therefore, to improve the standard of subdivision there rather than towards the stern. Because it is based on statistical evidence as to what actually happens when ships collide, the probabilistic concept provides a far more realistic scenario than the earlier "deterministic" method, whose principles regarding subdivision were theoretical rather than practical in concept.

I don't intend to spend too much time tonight outlining all the changes made during the 1980s and 1990s. Suffice to say that there were many changes to communications, fire protection, emergency systems and ship operation.

Since the 1974 SOLAS conference the size of merchant ships has increased enormously. This drawing illustrates just how much ships have changed since the time of *Titanic*. Whilst liner services by passenger ships may have been superseded by aircraft, cruise ships have grown dramatically in size and number and have introduced new features which present particular safety challenges. For example, many incorporate large atriums within the superstructure. Atriums are defined as public spaces which span three or more decks and contain combustibles such as furniture and enclosed spaces such as shops, offices and restaurants. 1991 regulations made it mandatory for such spaces to be provided with two means of escape, one of which gives direct access to an enclosed vertical means of escape. Such spaces must be fitted with a smoke extraction system, which can be activated manually as well as by a smoke detection system, and are to be fitted with automatic sprinkler systems.

For ro-ro passenger ships further major changes to rules were designed to improve safety after the *Estonia* loss in September 1994 when more than 850 people died. *Estonia,* like *Herald of Free Enterprise* in 1987, sank because so much water had built up on the cargo decks that stability was impaired and the ship capsized. New regulations seek to ensure that ships remain safe even with 0.5 m of water on the vehicle deck.

I have already mentioned the changes which took effect in 1992 for the determination of the damaged stability of cargo ships. When this new method of probabilistic damage stability was adopted a proposal was put to IMO that it should be extended to passenger ships. This extension was completed on 1 January 2009 when the methodology was harmonised for passenger and cargo ships by regulations which are known as SOLAS 2009.

Many factors affect the capability of a ship to sustain damage arising from a collision at sea, including location of the damage, subdivision, loading, permeability, and sea state. It is possible to assess the ability of a ship to survive given the probability that the ship may experience an incident will result in the flooding of a certain compartments and yet retain sufficient stability and buoyancy. Assessing a ship design to SOLAS 2009 is not a trivial task — it must not only take into account watertight subdivision but also fire bulkheads, openings, cross flooding sections, permeability, horizontal escape routes, access hatches, air pipes and other penetrations. It has been estimated that designers of even small cruise ships may have to assess some 15,000 damage cases taking up to 12 hours of computing time. This methodology would be impossible without the modern computer.

Whilst many of the SOLAS regulations have been developed as a result of tragedies like *Titanic*, *Herald of Free Enterprise* and *Estonia*, the rapid increase in the size of modern cruise liners has prompted the industry itself to become proactive to ensure the safety of these large ships and the passengers and crew who may number up to six thousand. In May 2000 the entire IMO membership agreed to consider passenger ship safety issues as a whole with the result that in July 2010 new regulations came into force for new passenger ships over 120 m with three or more vertical fire zones.

The guiding principals adopted by the Maritime Safety Committee, the IMO body responsible, were:

- The regulatory framework should place more emphasis on the prevention of a casualty from occurring in the first place.

- Future passenger ships should be designed for improved survivability so that, in the event of a casualty, persons can stay safely on board as the ship proceeds to port.

- The regulatory framework should permit alternative designs and arrangements in lieu of the prescriptive regulations provided that at least an equivalent level of safety is achieved.

- Passenger ships should be crewed, equipped and have arrangements to ensure the safety of persons on board for survival in the area of operation, taking into account climatic conditions and the availability of SAR functions.

- Passenger ships should be crewed and equipped to ensure the health-safety, medical care and security of persons on board until more specialised assistance is available.

Draft regulations and guidelines were accepted in November 2006. They incorporate two new concepts: “casualty thresholds” and “safe areas”. The new “casualty threshold” provisions specify the design criteria for the extent of damage future passenger ships must be able to withstand and still safely return to port under their own power. If this casualty threshold is exceeded (i.e., the damage is such that return to port under power is not possible), then the ship is to remain viable for a minimum of 3 hours to allow for safe and orderly abandonment.

During the development of the “safe return to port” criteria a number of questions began to surface, such as where the passengers and crew go during such a casualty bearing in mind that the fire and/or flooding may still be active (but contained) as the ship proceeds to the nearest port. The new “safe area” provisions establish that the persons on board the ship must be protected from hazards to life or health and provided with basic services. Essentially, a safe area is any space which is not flooded or any space outside the main vertical (fire) zone in which a fire has occurred. The basic services, which include such necessities as water, medical care, protection from weather, etc., must be available in the safe areas.

Safe Return to Port

New passenger ships will have to be designed to be capable of safely returning to port after fire or flooding damage which has resulted in any one space or watertight compartment becoming a complete loss — even main propulsion spaces or the bridge. The following essential services must remain operational:

- Propulsion
- Steering systems and steering-control systems
- Navigational systems
- Systems for fill, transfer and service of fuel oil
- Internal communication between the bridge, engineering spaces, safety centre, fire-fighting and damage control teams, and as required for passenger and crew notification and mustering
- External communication

- Fire main system
- Fixed fire-extinguishing systems
- Fire and smoke detection system
- Bilge and ballast system
- Power-operated watertight and semi-watertight doors
- Systems intended to support "safe areas"
- Flooding detection systems
- Other systems vital to damage control efforts

Safe Areas

In safe areas the following basic services must be available:

- Sanitation
- Water
- Food
- Alternate space for medical care
- Shelter from the weather
- Means of preventing heat stress and hypothermia
- Light
- Ventilation

If the return-to-port casualty threshold is exceeded then the following essential systems must remain operational to support an orderly evacuation and abandonment of the ship:

- Fire Main
- Internal communications (in support of fire-fighting as required for passenger and crew notification and evacuation)
- Means of external communications
- Bilge systems for removal of fire-fighting water
- Lighting along escape routes, at assembly stations and at embarkation stations of life-saving appliances
- Guidance systems for evacuation

Safety Centres

To assist the management of emergencies, safety centres are now required on or adjacent to the bridge. The centre must be able to monitor and control:

- All powered ventilation systems
- Fire doors
- General emergency alarm system
- Public address system
- Electrically powered evacuation guidance systems
- Watertight and semi-watertight doors
- Indicators for shell doors, loading doors and other closing appliances
- Water leakage of inner/outer bow doors, stern doors and any other shell door
- Television surveillance system
- Fire detection and alarm system
- Fixed fire-fighting local application systems
- Sprinkler and equivalent systems

- Water-based systems for machinery spaces
- Alarm to summon the crew
- Atrium smoke extraction system
- Flooding detection systems
- Fire pumps and emergency fire pumps

Remote Area Operations

The Maritime Safety Committee of IMO has given considerable consideration to the risks of operation of passenger ships in remote areas. Whilst Antarctica is clearly a remote area, it also depends very much on the number of people at risk and the availability of search and rescue services.

The loss of the Antarctic expedition ship *Explorer* in November 2007 after striking hard ice drew attention to the problems faced in Antarctic waters when a ship has to be abandoned. This time other ships were fortunately not far away and all passengers and crew survived after having been adrift in boats for five hours but the outcome could have been very different.

The solution largely lies with ship management but mandatory performance standards have been drafted to require that all types of ships be equipped with an efficient means for rapidly recovering people from survivor craft.

One of the most onerous requirements of the 1983 SOLAS amendments is the requirement that it should take no more than 30 minutes to prepare and launch the lifeboats and life rafts from a passenger ship once the passengers are actually assembled. There were no specific regulations on the complete timeframe for the total evacuation process. The IMO MSC has since issued guidelines for evacuation analysis for new and existing passenger ships.

Passengers do not respond immediately to an emergency and there was little data on the behaviour of passengers in an emergency environment. In 2005 sea trials of ship evacuation response times took place on the ferry *Grimaldi* during a voyage between Rome and Barcelona. This data was incorporated into a new analysis protocol. The guidelines call for ship evacuation times to be assessed during the design process. The recommended maximum allowable total passenger ship evacuation time is 60 to 80 minutes, depending on the size of the ship. The protocol specifies a minimum of four evacuation scenarios based on a number of assumptions about passenger and crew behaviour. Advanced methods of assessment may include computer simulations which seek to model the passengers and crew as unique individuals with specific capabilities and response times. On hearing an alarm passengers may do nothing until they see some evidence of the emergency. People may try to leave by the route they arrived in a space rather than taking the emergency exit route. Some may search for members of family or other groups. Much work has been done on evacuation simulation in buildings and aircraft and modern computer simulations build on the technology of the gaming and film CGI industries. However, the simulations assume that the crew will immediately be at evacuation duty stations ready to assist the passengers and that the passengers will follow the signage and crew instructions.

There are, however a number of significant differences between an evacuation from a ship or a building or aircraft. Both the latter may be full of smoke, panic and other distractions but in a ship the following factors also come into play:

- Ship motion
- Ship floating position
- The evacuation system

- The lifejacket retrieval process
- The ratio of the number of crew to number of passengers

A current project, SAFEGUARD, is aimed at providing realistic information to software designers based on further actual trials. The information gathered will be presented at a conference in December this year and it is hoped that IMO will use it to improve present simulation guidelines.

All this work has been brought into sharp focus by the loss of the 114,000 GRT liner *Costa Concordia* on 13 January 2012. The ship suffered massive underwater damage when she hit a reef close to shore which opened up a 50 m gash in her port side flooding the engine room and resulting in loss of power, apart from emergency supplies. Her complement comprised 3,229 passengers and 1,023 crew. *Costa Concordia* was a relatively new ship, completed in July 2006.

Fortunately, the incident occurred in clear weather and calm seas, close to shore and rescue services. Nevertheless, it took six hours to evacuate the ship. The operation was complicated by her capsize but fortunately the ship did not sink in deep water. Had the incident occurred in a more remote area and in less benign conditions, the outcome could have been very different.

Following this accident, IMO issued interim safety recommendations for operators of passenger ships on 25 May 2012. The recommendations include:

• carrying additional lifejackets, to be readily accessible in public spaces, at the muster/assembly stations, on deck or in lifeboats, so that in the event of an emergency passengers need not return to their cabins to retrieve the lifejacket stored there;

• reviewing the adequacy of the dissemination and communication of the emergency instructions on board ships;

• carrying out the muster for embarking passengers prior to departure from every port of embarkation, if the duration is 24 hours or more;

• limiting access to the bridge to those with operational or operationally related functions, during any period of restricted manoeuvring, or while manoeuvring in conditions that the master or company bridge procedures/policy deems to require increased vigilance (e.g. arrival/departure from port, heavy traffic, poor visibility); and

• ensuring that the ship's voyage plan has taken into account IMO's Guidelines for voyage planning, and, if appropriate, guidelines on voyage planning for passenger ships operating in remote areas.

How safe are modern passenger ships? The answer is: Very. A recent report, *Safety and Shipping 1912–2012*, prepared by Cardiff University and Allianz Insurance makes very interesting reading. The report observes that:

• Despite a trebling of the world fleet to over 100,000 ships in 2010, and a total fleet tonnage now approaching 1 billion gross tonnes, shipping losses have decreased significantly from 1 ship per 100 per year (1912) to 1 ship per 670 per year in 2009.

• Marine transport can be regarded as one of the safest means of passenger transport overall: in Europe, it is ranked after rail, air and bus/coach as the fourth safest means, with far lower fatal accident rates than car, motorcycle, bicycle or walking.

• However, seafaring remains dangerous as a profession. While professional seafarer fatality rates have fallen – for example, in the UK per 100,000 seafarer-years, from 358 (in 1919) to 11 in 1996-2005 – this fatality rate is still twelve times higher than in the general workforce. Despite inconsistent data, other country statistics appear to be considerably higher.

• Most losses can be attributed to 'human error' – a broad category estimated to be responsible for between 75%-96% of marine casualties. Pressures of competition (often shore-based) and fatigue are frequently cited as significant causes.

This last point is significant. We can design very safe ships but the human element is mostly out of the naval architect's control. Safety of passengers is greatly enhanced if the accident can be prevented in the first place. In the event that an accident occurs, then passenger survival will be further enhanced if the crew of the ship is well drilled, experienced and disciplined and can supervise evacuation in an orderly manner.

It is not surprising that the Cardiff University/Allianz report places human error at the top of the list of key risks to the future safety of shipping. The other risks identified by the report are shown on this slide:

• Human error
• Competition
• Piracy
• Use of non-OEM parts
• Over-dependence on technology
• Lack of skilled workforce
• Increasing ship sizes
• Ice shipping
• Non-standardized training
• Poor monitoring and enforcement of regulation
• Complacency
• Non-sector specific Safety Management systems
• Reduced crewing numbers
• Crew fatigue
• Classification and Flag: potential for conflicts of interest
• Poor communications
• Operational pressures
• Bureaucracy onboard
• Build quality
• Inspections
• ECDIS implementation
• Commerciality of Class and flag

There is another factor which we must keep in mind. Most of the very large cruise ships in service today are relatively new and are operated by large and, hopefully, responsible and competent companies. The Carnival Corporation alone owns and operates about 49% of them. One day the ships will be replaced in these fleets and sold on to other owners who might not maintain them to a high standard or operate them as safely. A major accident with very large loss of life at some time in the future is not inconceivable.

Footnote

This paper was presented at the Boulton Lecture in Sydney 20th September 2012, which was a joint function of the Navy League of Australia and the Company of Master Mariners of Australia.

The Boulton Lecture was inaugurated in 1991 in honour of the founder of the Company of Master Mariners of Australia, Captain Norman Boulton MBE, VRD B.Com, M.Inst. N., AAUG.

Captain Boulton was born in England in 1904 and died in 1992. The Company was founded in 1938 and currently has a membership throughout Australia of over 600 members.

About the Author

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