

Catamaran Cruise Ship

TRA VISIONS 2014 Submission

Student Competition

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Chris McNair

Wojciech Westphal

Rachel Billimore

Stefanos Psomopoulos

Niall MacLennan



TRA Visions 2014

Final Project Template – This template is to be used for submitting the final version of the project. The final deliverable should be submitted by the 31st of January 2014

Idea Number:

PILLAR / TRANSPORT MODE	
ROAD ☐	RAIL ☐ MARINE ☒ CROSS MODAL ☐
Project Related to:	☐ RA1: Environment and Energy ☐ RA2: Industry Competitiveness ☐ RA3: Logistics and Mobility Systems and Services ☐ RA4: Safety and Security ☒ RA5: Transport Infrastructures ☐ RA6: Transp. Policy Res./Socio-econ./Human sci. ☐ RA7: Vehicles & Vessels Technologies

Project Title: Deep-Vee Catamaran Cruise Ship

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Introduction

The aim of this project is to evaluate the potential success and feasibility of a Catamaran Cruise Ship. A critical approach is taken to analyse a range of influencing factors relating to technological operation and economic performance in a twin-hulled design.

Since the 1980's the number of new build cruise ships has increased significantly. The Cruise Lines International Association (CLIA) predicts that in 2013, there were 21 million passengers globally. This growth is forecasted to reach 36 million passengers in 2025. To accommodate this expansion, 5 new cruise ships would need to be built in 2014, with a further 9-13 new builds entering the market every year till 2025. In 2011, the Cruise industry generated an unprecedented €36.7 million for the European economy alone with 5.6 million passengers departing from Europe.

This project considers the volumetric advantages provided by a catamaran vessel for a large cruise ship. The catamaran provides the same volume as a conventional monohull cruise liner at a lower length. This application opens a new market, offering every passenger with a large seaview cabin at no extra cost. As well as this, the combination of large deck space and considerable transverse stability provide greater passenger comfort. With a large GM and considerably lower motions than a monohull, this could permit higher accommodation. To consider the effects of different hullform designs on the overall performance, different geometries are considered including Round bilged, Wave piercing and Deep Vee hull shapes. The Catamaran Cruise Ship is also shown to be considerably safer in a damaged condition compared to that of a monohull vessel, this gives this design yet another competitive edge. As well as this, the aim is to provide an exciting new design which can address various openings in the current market. The final design will be optimised for manufacture in European shipyards.

Solving the Problem

EU residents need a maritime mode of transport for tourist and leisure purposes. The purpose of this submission is to solve an EU transport problem. The W-class Catamaran Cruise Ships solves this problem of windowless, confined cabins and overpriced vista accommodation. It offers every passenger a sea view cabin that is 40%

larger than that offered by competitors, at more affordable price, whilst retaining a healthy profit. This is the vehicle to drive maritime EU economy both through onboard transactions and onshore tourist spending. Its voluminous decks and innovative attractions reinvent the way passengers travel. By including a real-snow ski-slope, the vessel combines the best of the north and south of Europe's climates into one unforgettable experience. With many public areas and shopping malls, there is plenty space to unite Europeans that choose to cruise on this catamaran cruise ship.

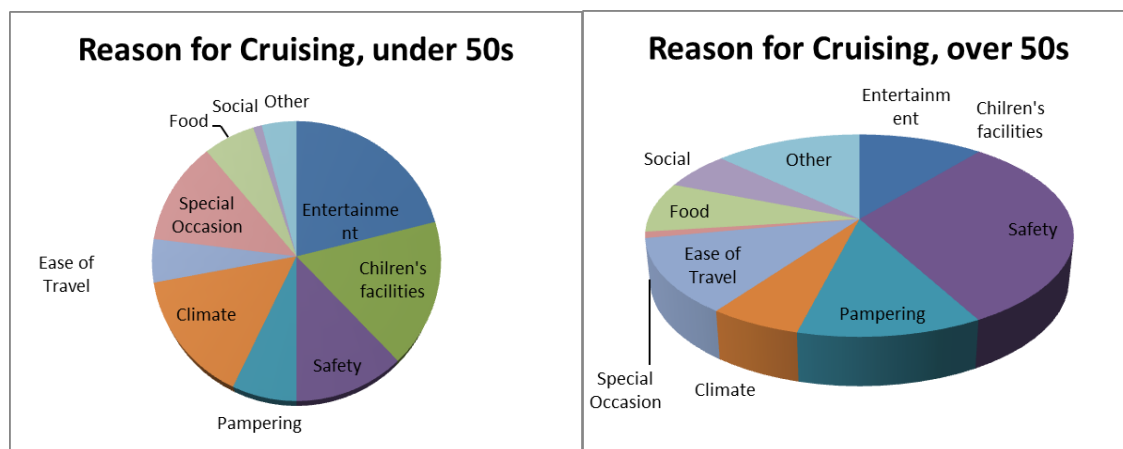
Target Market

The demographics of cruise passengers are fairly broad with cruisers being all ages and walks of life. Although it can be seen that the longer and more expensive the cruise, the older and wealthier the passenger, on the whole there is not a significant difference in age, sex or income within the group of people who are interested in cruising. For example 57 percent of men are interested in cruising compared to 63% of women, 59% married couples and 60% singles. (Dickinson & Vladimir, 1997)

In order for the market to grow, you could assume that targeting first time cruisers would be a good option. As well as this, it is essential to maintain the current customer base through relationship marketing. Continuous customers are going to be regular vacationers, i.e. adventurous types who like to experience new things, new locations and new people. In-between cruisers and non-cruisers there are those who would go on a cruise who are face barriers from entry into the market due to factors such as price, boredom, confinement and seasickness.

The following figure shows the reasons which would attract someone to embark on a cruise. Straight away it can be seen that under those under 50 are concerned with children's facilities, climate and special occasions. For over 50s there is more demand for pampering, ease of travel, social. From this it could be said that over 50's look for a laid back social cruise while under 50's are more concerned with facilitating for the family with activities in a safe environment.

reason for cruising	Under 50	Over 50
Entertainment	21	11
Children's facilities	17	0
Safety	12	31
Pampering	7	12
Climate	15	6
Ease of Travel	5	12
Special Occasion	12	1
Food	6	8
Social	1	6
Other	4	13



Literature Survey

Cruise Market

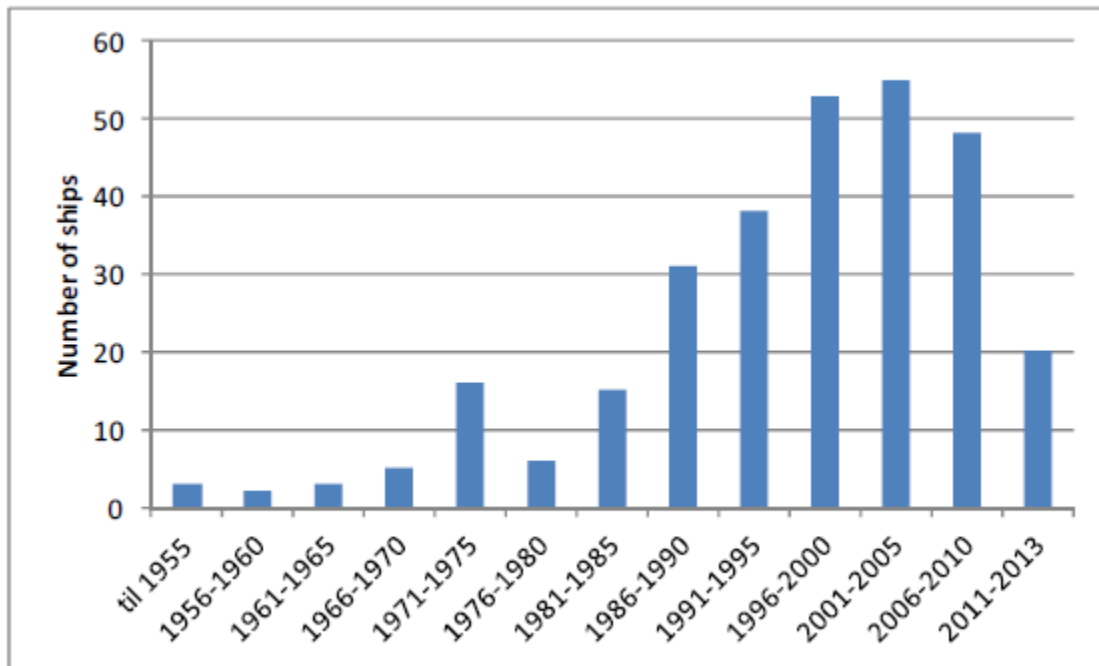
With the amount of new cruise ships doubling from decade to decade since the 1980's the Cruise Lines International Association (CLIA) predicts that 2013 will see a global passenger complement of 20.97 million for the year, with North American based cruises accommodating 17.6 million of these passengers. This is up more than 500,000 on the year before. In 2011, the Cruise industry generated an unprecedented €36.7 billion for the European economy, with 5.6 million passengers departing on cruises from the continent. With all this growth in the past couple years it is no surprise that the next 5 to 7 years are expected to see further growth worldwide.

The Institute of Shipping Economics and Logistics (ISL) has for approximately 30 years monitored the state, capacity and development of the global cruise ship fleet. The Institute has categorised the vessels within its research by considering an ocean-going

cruise vessel as a vessel larger than 1000 gross tonnes, with a passenger capacity of more than 100 beds. The vessels within the scope of this research are also engaged in cruise operations year-round, or at least for the majority of the year. Furthermore, the Institute has defined the passenger capacity of the fleet as the number of main beds in each cabin, mainly sufficient to accommodate 2 passengers per cabin. Although some cabins on board offer more beds for use by families and similar groups, "double occupancy" cabins can also be booked for single occupancy use. It is for this reason that the ISL has made the assumption that all cabins are full to double occupancy. ISL have stated that this assumption carries a fair degree of accuracy, as the major operators generally report that on average the capacity of the ships is little over 100% when considering the double occupancy rule.

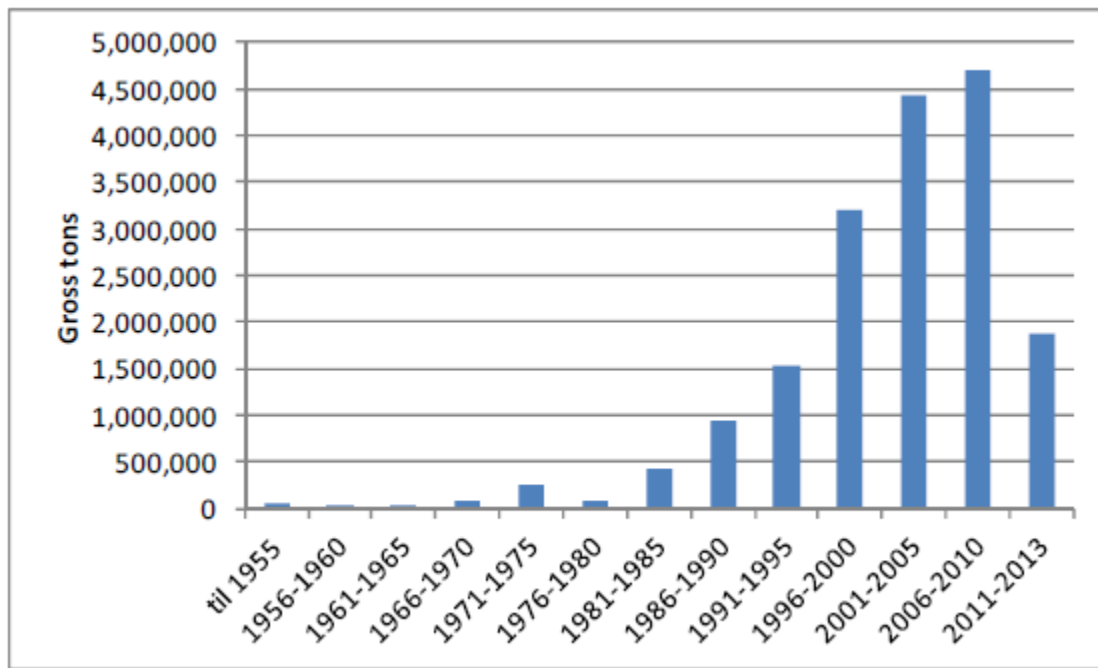
To date the existing cruise ship fleet comprises of a total of 295 ocean-going cruise vessels, accommodating the combined 464,000-bed capacity. This fleet measures on average 59,667 tonnes per cruise vessel, with an average capacity of 1,515 souls per ship. The smallest of which accommodates 100 passengers with a weight of 2,191 gross tonnes. The largest cruise vessels in the market are the Oasis-class ships operated by Royal Caribbean Cruises. The sister ships can each accommodate 5,408 passengers and have a gross tonnage of 252,282 tonnes. The passengers are accommodated in 2,706 suites that are spread across the vessels that are 362 meters long, 65 meters wide and reach 65 meters above the waterline, with a total of 16 passenger decks.

The average period of operation for the fleet overall is approximately 17 years, however the age profile of the entire fleet is in fact quite widespread, with some of the oldest vessel as old as 60 years old. These older vessels however would not have been initially classed as cruise ships as we know them today, as the appearance of the earlier modern cruise ships did not occur until about 1970. In this period only a small number of the ships appeared as the concept of the cruise ship was in its infancy in comparison with the cruise liners that had been around for decades beforehand. It wasn't until the 1980's that the amount of cruise ships started to steadily increase as shown in the graph below.



Age of the Fleet in numbers of ships.

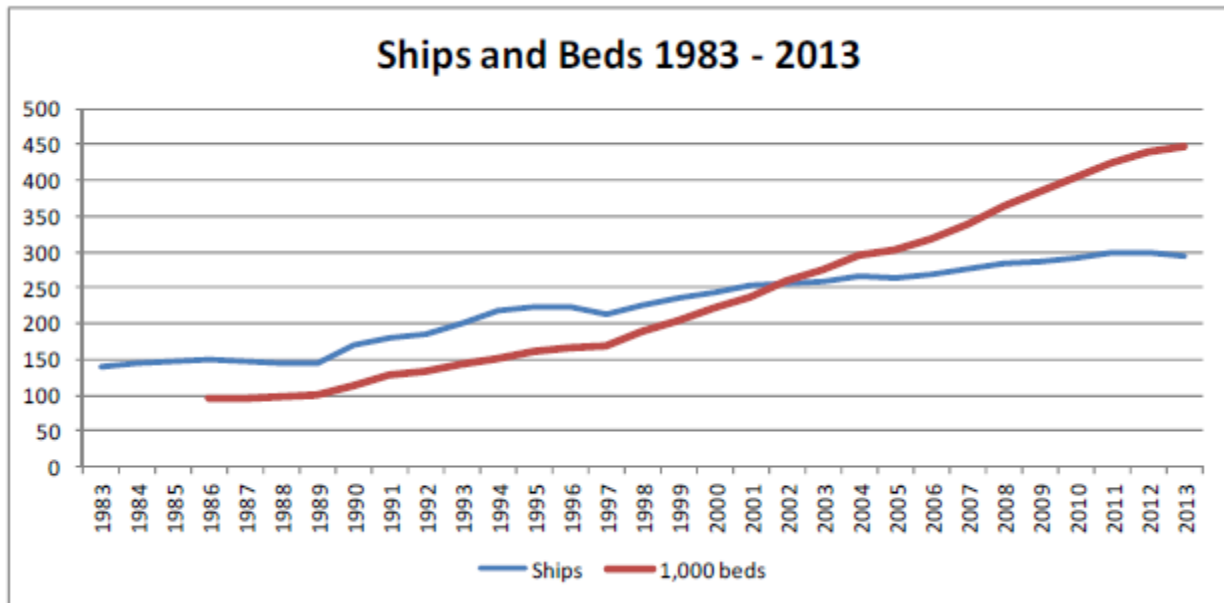
The increase in tonnage may have been sooner, as early as the 1970's, however the energy crisis that hit the global economy from 1973-1979 slowed the output of industry, including shipbuilding. The increase of the amount of new cruise ships however been in decline since the turn of the millennium, this has not been as a result of down turn in the market but an increase in the size of the vessels being ordered by cruise operators. This is shown in the graph below, where the produced tonnage for each half-decade is displayed.



Gross Tonnage of Cruise ships produced per half-decade.

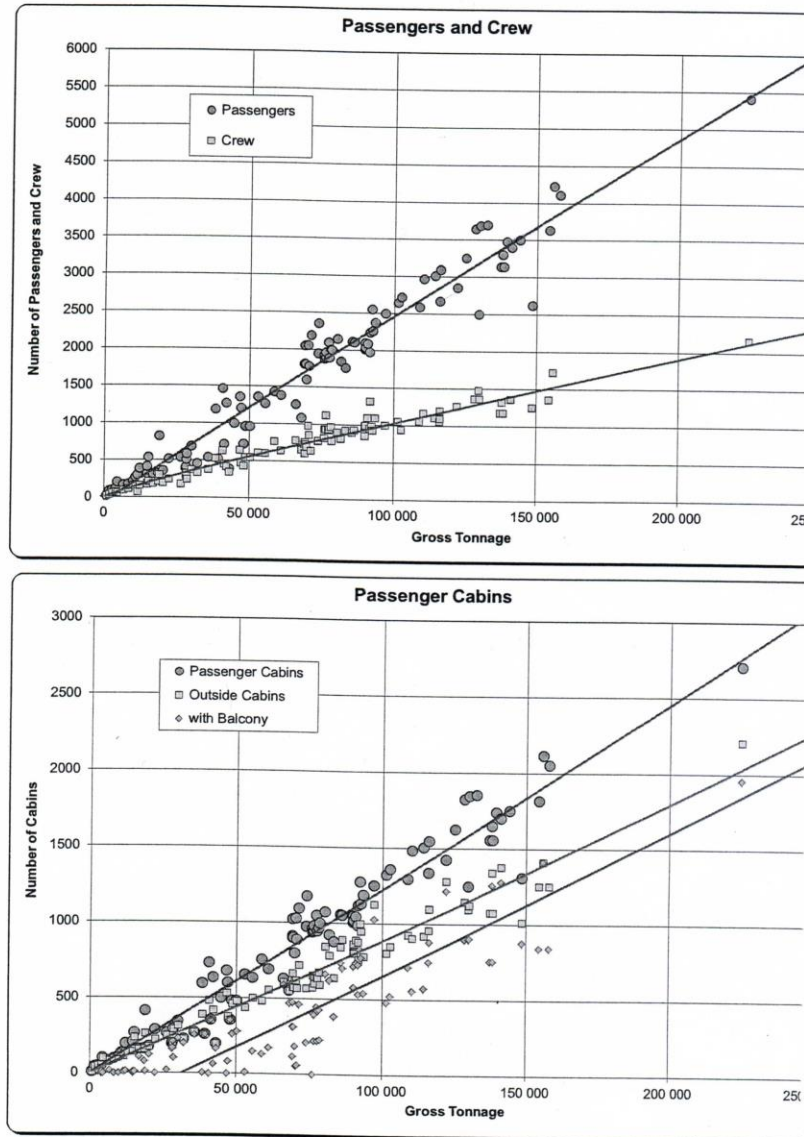
There is, as would be expected, a dip in the produced output tonnage for the current period, as this half-decade is not yet over.

As a result of the combination of older vessels coming out of service due to their age, with the desire within the industry to increase the capacity, and not necessarily the quantity for the future cruise fleet, the Institute of Shipping Economics and Logistics has stated that it is unlikely that the number of cruise ships will not reach over 300 vessels in the near future. This is apparent in the orders placed by operators such as Royal Caribbean Cruises Limited (RCCL) who have ordered an additional Oasis-class cruise vessel that have been mentioned previously, as well as 3 new Quantum-class ships. The Quantum-class will accommodate 4,152 passengers at double-occupancy on a 167,800GT platform. This trend is also reflected in the orders made by RCCL's competitor Norwegian Cruise Lines who have ordered 3 vessels of 4000-4200-bed capacity, measuring in at 146,000 – 163,000 Gross Tonnes. The extent of the size of the cruise ships that have been delivered over the past 30 years is shown in the figure below, it distinctively shows the overall number of beds increasing and the number of ships has started to decrease in the new-build cruise vessels, as discussed so far.



Development of the number of ships and beds in new build Cruise ships since 1983.

Both the following graphs show the relationship between the amount of crew required for the passengers on board a cruise ship with regards to its Gross Tonnage. The first graph shows that for 2,000 passengers approximately 800 crew members would be required to look after them whilst at sea, and that this amount of passengers and personnel would require a ship of approximately 70,000GT. Additionally for 3,500 passenger capacity, approximately 1,400 crew members and a vessel to the scale of 140,000GT. These results are fairly consistent with the average passenger/crew ratio across the scale shown in the graph below.



CRUISE statistics

With regards to the amount of rooms required for the 2 cases mentioned, the latter graph here displays the amount of cabins on board for respective vessel sizes. For a ship of 140,000 GT approximately 1,600 – 1,700 are on board.

The former graph shows the variance of tonnage per passenger for the varying quality of ship and the service on board. On average, the breakdown of this average is as follows:

Type of Cruise	Tonnage per Passenger
Budget Cruises	25GT/passenger
Contemporary Cruises	35GT – 45 GT/passenger
Premium Cruises	45GT – 50GT/passenger
Luxury Cruises	50GT – 75GT/passenger

Tonnage per passenger of various cruises.

In 2012, the distribution of overall resources in the cruise industry was heavily based in the Caribbean and the Mediterranean regions, accounting for 34.4% and 21.7% of the global assets respectively.



Global Distribution of passenger carrying capacity

Other smaller markets were apparent in the rest of Europe (10.9%), Australasia (5%), Alaska (4.8%), South America (3.9%) and Asia (3.4%). The remaining 15.8% of the distributed cruise capacity for 2012 was used in other markets, assumed as being Expeditionary and Antarctic cruising.

It has been predicted by Ocean Shipping Consultants that there will be significant growth across the global cruise industry up till 2025, predicting passenger numbers to reach 36.4 million at the end of that period. With this increase in customers, it is expected that the required accommodation would approximately double from the

current 464,000 beds, to 866,000 beds. This would mean that considering the average size of the vessels today, another 5 cruise ships would need to be built in 2014. Then considering the increasing trend in the average size of vessels, along with the operational life, 9-13 new builds would require to be built every year up to 2025.

Despite the recent development in more sectors of the shipbuilding industry in the Far East, Europe is still at the top when it comes to designing, building and outfitting intricate and cutting-edge cruise ships. With 2012 seeing the continent having 24 new builds in the order books over a 4 year period. This will see Europe build a fleet for a further 67,000 passengers, costing an excess of €12 billion.

The growth of the cruise market to date has not followed a smooth trend since the initial slow start in production after the 1970 energy crisis stated before. A number of key events also effected the development of the cruise market industry as a result of supply and demand from customers globally: the fall of the 2 towers of the world trade center as a result of the terrorist attacks made on the United States of America in September of 2001, resulted in a significant reduction in passengers attending flights through state or personal inhibitions at that time. As the cruise industry is fairly symbiotic to the airline industry this had an impact on the people going on cruises. This did not have an effect on the shipbuilding industry however until 2005 as a result of the extensive planning and construction phase that is involved in building a cruise ship. Another recent case of this type of impact was the financial crisis that effected the world in 2008, due to the same reasons as the with the terror attacks in 2001, this did not impact the industry until 2012. Research shows that for the delivered, cancelled and forecasted output for the period 1987 – 2016, the instances of difficulty explained previously are shown by the increased amount of cancellations from the order books during these periods. For the years beyond 2013 only the forecasted builds are shown.

According to CLIA 11 new ships were to be introduced to the global fleet in 2013, and another 13 in 2012 resulting in a total capital investment in excess of \$6.7 billion in to the industry. Of these new vessels, 15 were small river cruise boats, the largest having a passenger capacity of 210 souls, 8 of the remaining ships were significantly larger with capacities ranging from 2,500 to 3,969 passengers. The last of these 24 ships was a vessel of 1,260 passenger capacity, a medium sized, short distance vessel.

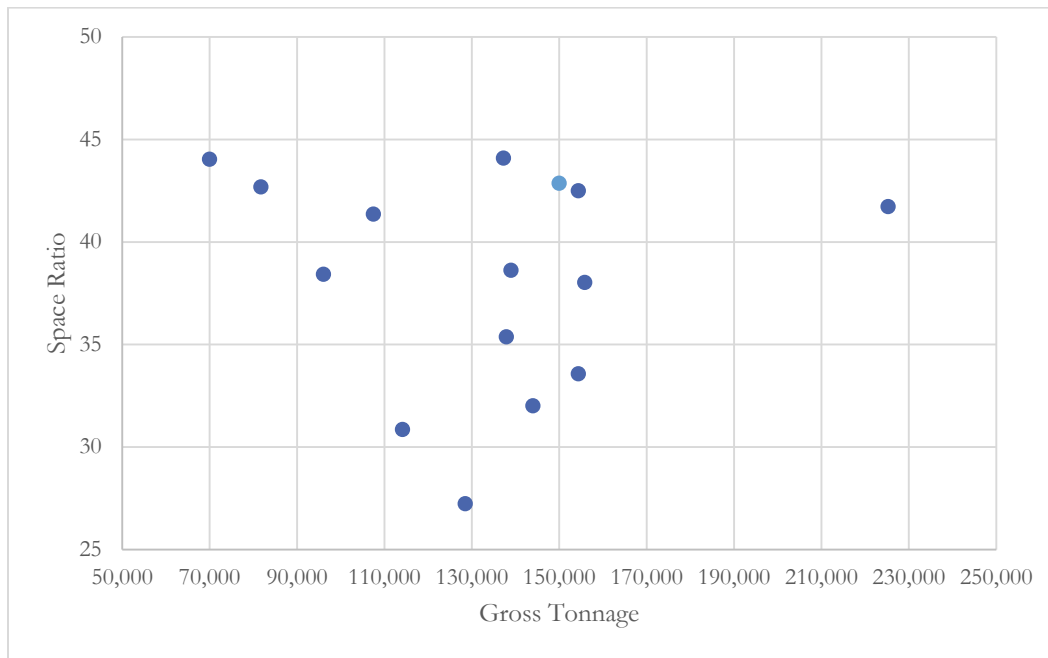
The Institute for Shipping Economics and Logistics data includes the suggested order book for 2014 – 2018, it shows that in this period there are 23 ships on order at present. Of these orders 17 are larger ocean-going cruise ships; with the European yards producing 14 of these vessels, continuing to show their dominance and performance in the cruise ship building industry moving forward into the future. The data concludes that the increase in beds being introduced to the market will not deviate far from about 20,000 beds per year and will take the form in an addition to the fleet of 3 large vessels and 1 or 2 smaller vessels.

Metrics

Space Ratio:

Travel writers like to use parameters such as “space ratios” as parameters to rate the public and private spaces onboard cruise ships. This is calculated as the Gross Tonnage divided by the double occupancy capacity of the vessel. As gross tonnage is not a weight parameter but rather a volumetric one for the amount of useable space per passenger on the ship where 1 gross ton is 100 cubic feet of volume. (Dickinson & Vladimir, 1997) Therefore the space ratio was calculated for a range of ships in order to identify an acceptable value to aim for.

The following figure shows the range of space ratios for 14 different cruise ships. Ships such as Crown Princess which at 70,000 tons, carries 1590 passengers have a space ratio of more than 44, the highest found in this analysis. Even Oasis of the seas which at 225282 GT, carrying 5400 passengers at double occupancy has a SR of 41071. With our current design, as shown in red, we can achieve a SR of 42.86, exceeding that of Oasis of the seas and approaching the top of the range found. Space ratios exceeding this would likely only be found on intimate yacht like vessels where it would be around 50. (Travel Weekly, 2013) (Critic, 2013)



Entertainment areas:

Using the available information on the capacity of different entertainment areas onboard Freedom of the Seas and Oasis of the Seas, along with deck plans of said vessels, metric values were created on the area per passenger on board.

Freedom of the Seas	Pax Capacity	Area (m ²)	Area/Pax capacity
Theatre	1320	2608	1.975757576
The Crypt	218	1425.50877	6.539031055
Studio B	760	2012.35133	2.647830697
Viking crown lounge	134	606.328934	4.524842791
Casino Royale	447	1972.61278	4.413003978
Parohs palace	299	915.989783	3.06351098

Oasis of the Seas	Pax Capacity	Area (m ²)	Area/Pax
Opal theatre	1380	1663.25026	1.20525381
Aqua theater	735	1490.17814	2.027453249
Studio B	775	1531.32901	1.975908399
Casino Royale	900	3241.89525	3.602105832
Blaze	193	1119.40466	5.800024129
Comedy Live	120	341.729542	2.847746183

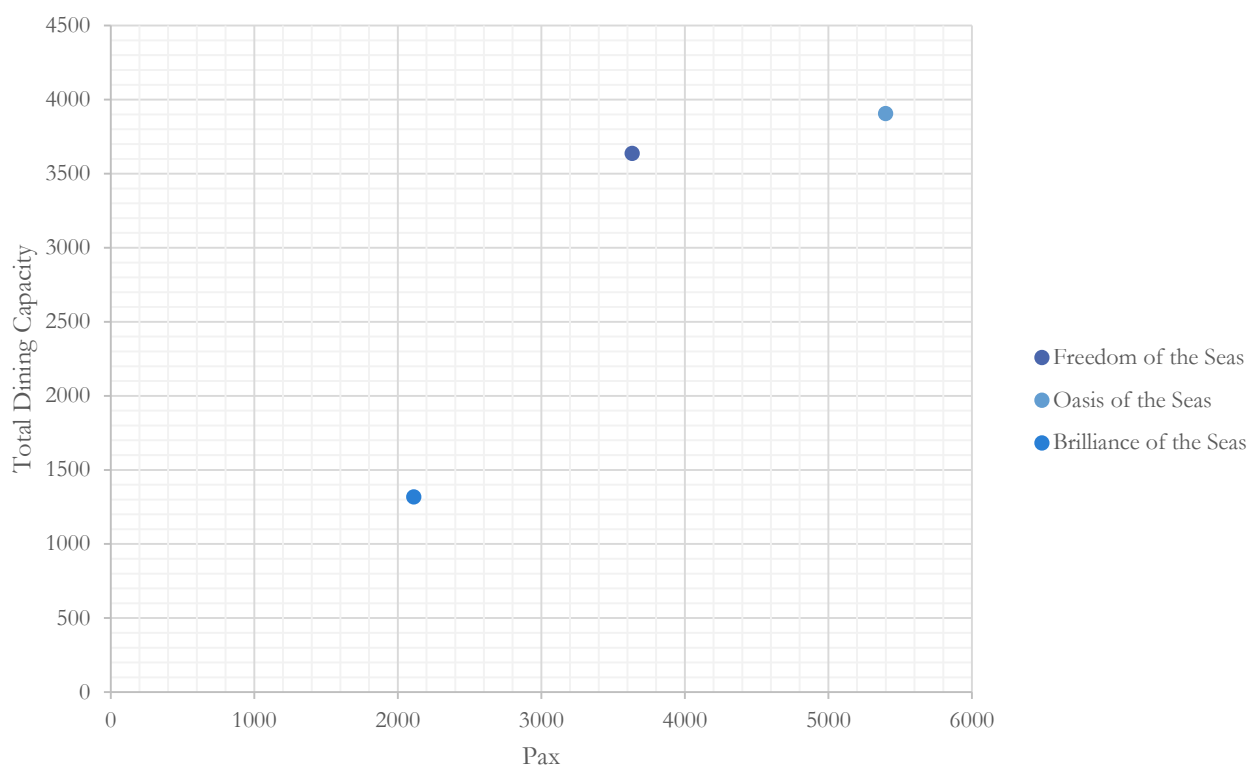
Using the data in the above tables, average area per passenger was calculated for different types of entertainment areas. As expected the dancing area is the most spacious with the seated theatre area the most compact. These values will act as a

guide when dividing the public areas onboard the vessel into specific entertainment areas.

Description	Average area per pax (m ²)
Theatre	1.736154878
Casino	4.007554905
Dancing Area	5.800024129
Bars	3.478699985

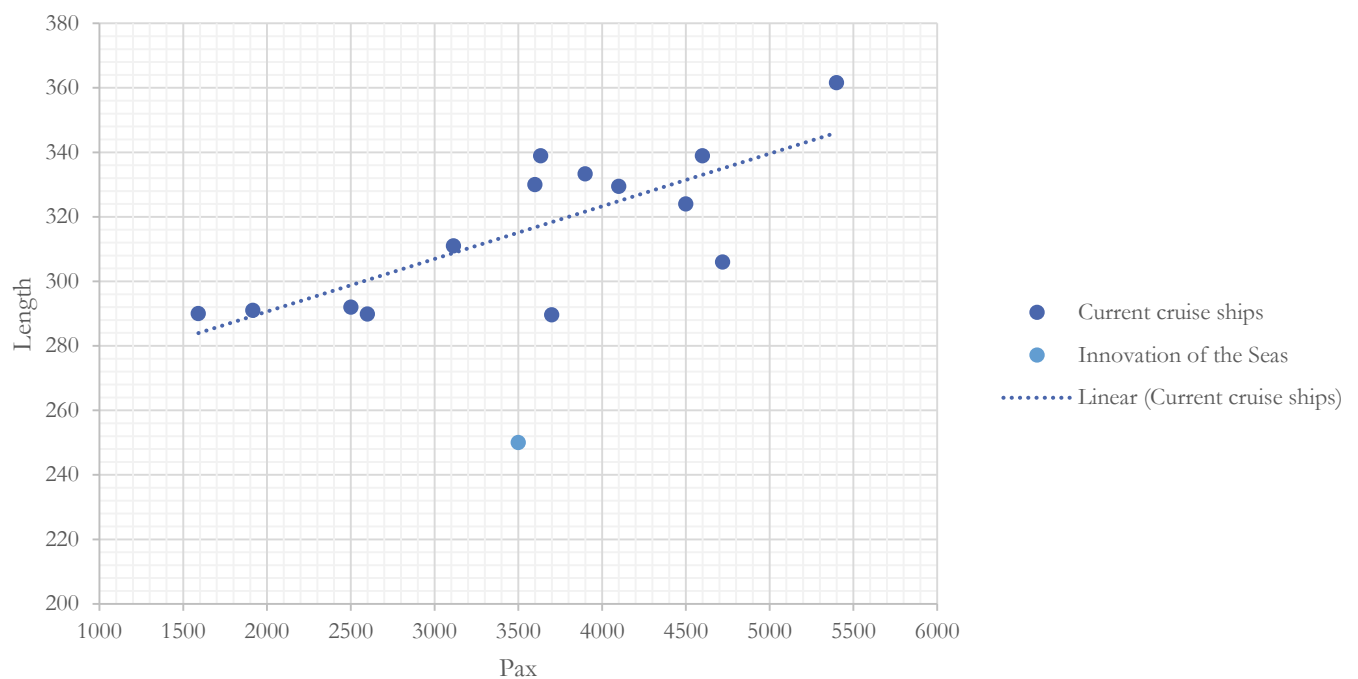
Dining Capacity:

In order to look at the dining capacity required for the number of passengers on board, the capacity for 3 large vessels was looked at. Whereas Brilliance of the Seas only has a dining capacity for 62.35 % of its passengers, Freedom of the Seas has the capacity to accommodate every passenger at once. Oasis of the Seas has an intermediate value of 72.31%.

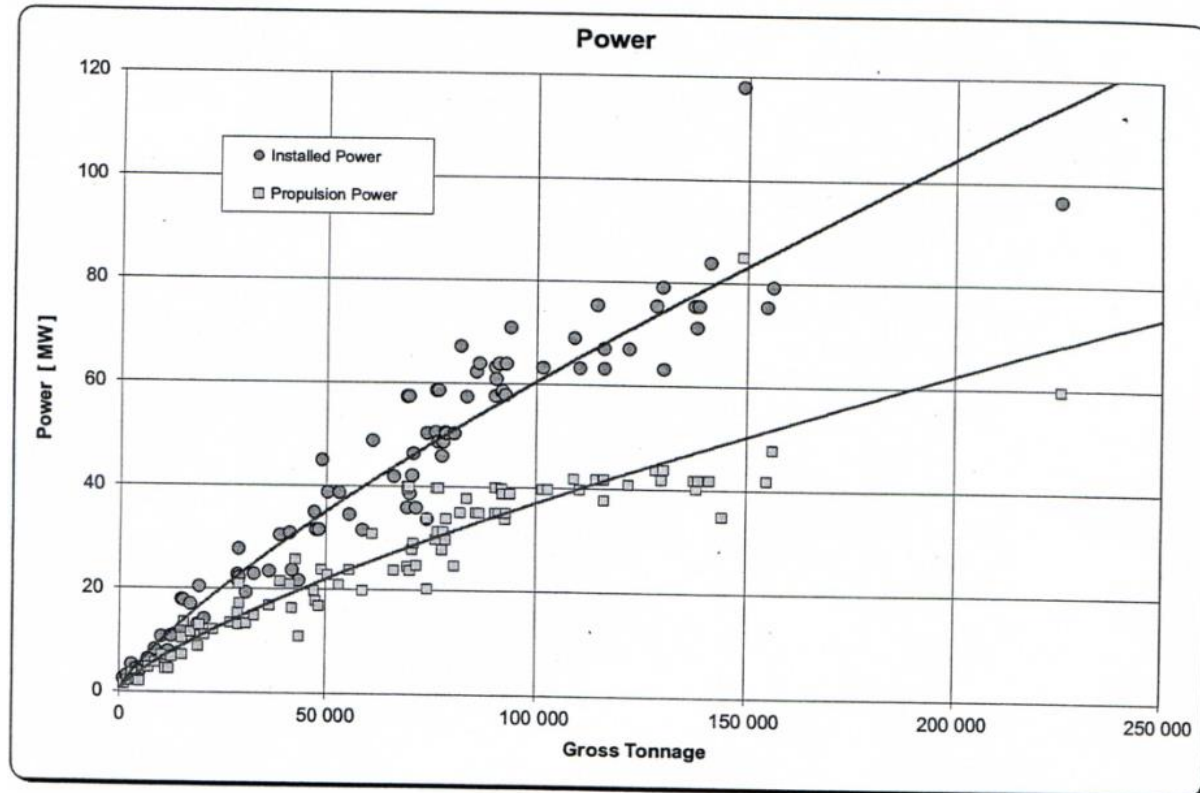


Length:

One aim of this project is to create a vessel which has a greater passenger carrying capacity with a shorter length compared to that of other cruise ships. By looking at currently operating vessels, it is obvious the catamaran cruise ship can offer a higher capacity for a shorter length. According to the trendline calculated, our vessel would need to be around 68m longer to accommodate the 3500 passengers if it were a conventional monohull vessel.



Powering of fleet



The above graph displays the overall trend of how power generation is distributed between propulsion loads and hotel loads across the global fleet. As shown the trends for both Propulsive and Overall installed power can be approximated fairly linearly. Not only is there a linear relation apparent across the range of the power per Gross Tonnage but there is also a steady variation between the Propulsive power and Installed power for the respective Gross Tonnage. For example: a 50,000GT ship has an installed power of 34MW and a propulsive load of 21MW; also a 100,000GT cruise vessel would have installed and propulsive powers of 38MW and 50MW respectively. With this data in mind, this means that these 2 case vessels would provide 13MW and 22MW hotel loads respectively. This shows that on average the ratio of hotel load to propulsive load installed on a cruise ship regardless of its size is approximately 2:3.

Ports and Routes

Mediterranean Sea

The cruise industry, despite the global economic downturn, is one of the major growth areas of international tourism and the economy generally. Cruise market introducing a long-term annual growth rate of 8.5%, this sector poses a major incentive for each port to try to actively involved in this. The Mediterranean Sea as a cruise destination has already climbed to second place in the preferences of passengers around the world and has overtaken Alaska and the Caribbean sea. The entire Mediterranean region constitute by twenty two countries, whose common feature is their borders with the Mare Nostrum.



The cruise ports, based on their functional characteristics, can be classified into two categories.

- **Cruise home port (hubs)** is the port where cruise-ship passengers board (or embark) to start their cruise and disembark the cruise ship at the end of their cruise. It is also where the cruise ship's supplies are loaded for the cruise, which includes everything from fresh water and fuel to fruits, vegetable, champagne, and any other supplies needed for the cruise.
- **Port of call** is an intermediate stop for a ship on its sailing itinerary, which may include up to half a dozen ports. At these ports, a cargo ship may take on supplies or fuel, as well as unloading and loading cargo. But for a cruise ship, it is

their premier stop where the cruise lines take on passengers to enjoy their vacation.

Cruise ports of Italy

Venice

Venice is a major cruise ship hub in the Mediterranean, with over a thousand cruise ship movements, and a million cruise passengers per year. The Venice Cruise Terminal (or Terminal Venezia Passeggeri, or VCT) is situated at the Venice end of the four kilometer road that joins Venice to the rest of Italy. Venice port is not directly on the Mediterranean, but is located in the Venetian Lagoon, this is joined to the Adriatic by a narrow channel called the Porto di Lido. The Venice Cruise Terminal contains three main quays: the Marittima basin, which can berth the biggest cruise ships that visit Venice, and the smaller Santa Marta and San Basilio quays. These two are just around the corner in the Giudecca Canal. Marittima is the biggest of the ship basins at the Port of Venice's Venezia Terminal Passeggeri, with 3 terminal buildings and enough docking space to handle several large ships at once.

- Max. Size: Passengers: Draft 8.7 m.
- Fuel: All grades.

Livorno

Multipurpose port, handles most types of cargo and ferry/cruise vessels. It has 95 berths, totalling 11,000 m. and 1,600,000 sq.m. of usable harbour land area.

- Max. Size: Draft 12.0 m.
- Fuel: All grades.

Cruise ports of France

Marseille Fos

Port of Marseille is the largest port in France, fifth in Europe and the third largest petroleum port worldwide. Facilities are located in the East Harbours (port of Marseille) or the West Harbours (Gulf of Fos). The port of Marseille is a multipurpose port, handles Ro-Ro, containers, dry and liquid bulk and passengers.

- Max. Size: Passengers: Draft 13.0 m.
- Fuel: By barge.
- Repairs/Drydocks: 465 m. x 84 m. x 10 m.

Cruise port of Malta

Valletta

The port comprises Valletta Gateway Terminals (VGT) that operate and manage tanker, general cargo, container, Ro-Ro and bulk wharves in the Grand Harbour and the Valletta Cruise Port plc that manages the cruise terminal. There is a large ship repair yard at the port.

LOCATION: On the NE coast of Malta.

- Max. Size: Passengers: Depth 11.0 m.
- Fuel: Gas oil, fuel oil.
- Repairs/Drydocks: Length 362 m., beam 62 m., draft 9.14 m., capacity 300,000 d.w.t.

Cruise ports of Spain

Barcelona

Major regional port handling most types of cargo and cruise vessels, located at the NE coast of Spain.

- Max. Size: Passengers: Draft 12.0 m.
- Fuel: Fuel and gas oil.
- Passengers: Draft 8.7 m.

Algeciras

Strategic port for international maritime trade, situated within a large and deep-water natural bay. It offers facilities for most types of vessels, ship repair and bunkering.

LOCATION: West side of Algeciras Bay on the SE tip of Spain, opposite Gibraltar.

La Linea is located next to the border with Gibraltar on the eastern side of Algeciras Bay, and Tarifa to the SW beyond Algeciras Bay.

- Max. Size: Passengers: Length 207 m., depth 10.5 m.
- Largest Vessel: 423,000 d.w.t., draft 22.9 m.
- Fuel: Available.
- Repairs/Drydocks: Length 400 m., breadth 50 m., depth 6.0 m.

Ibiza

Port handles general cargo, tankers, Ro-Ro and Lo-Lo vessels, ferries, cruise and local traffic.

LOCATION: On the SE of Ibiza, the westernmost island of the Balearic Islands.

- Max. Size: LOA 393 m., draft 20.0 m.
- Largest Vessel: 138,279 g.t., LOA 311 m., beam 39.04 m., draft 8.60 m.
- Fuel: Available.

Cruise ports of Greece

Piraeus: has had the function of the port for Athens since the Golden Age of Greece. The port at Piraeus was conceived at the beginning of the fifth century BC by Themistocles, who realized the possibilities for its 3 deepwater harbors. The early

fortifications were extended by Pericles with the construction of 'the Long Walls' to line and fortify the road to Athens. Piraeus has been a major port even since the Golden Age of Greece. The Port of Piraeus is an important destination for cruise ships in the Mediterranean Sea. It has 11 places for the simultaneous berthing of vessels and can accommodate even the largest cruise ships. It has two fully equipped passenger terminals, and soon a third terminal with all the services and facilities for passengers, such as: air-conditioned spaces, passenger and baggage control systems, check-in services, free transportation of passengers by bus, application of the security code ISPS, luggage, catering, souvenir shops, free wireless internet, hop on / off buses etc. Opposite the harbor is the site of the Battle of Salamis.

Cruise ports of Turkey

Alanya

Alanya has the fastest growing population in Turkey and according to the Ministry of Culture and Tourism, the city accounted for 9 million tourist arrivals in Turkey in 2009, about 32.5 percent of the total number of tourists that came to the country that year.

The port serves only international cruise ships and fast ferries plying between Kyrenia and Alanya.

LOCATION: The port is located on the east coast of Antalya Bay, approx. 60 n.m. ESE of Antalya. The port is at the heart of the city, enclosed by a 209 m. high promontory and is well sheltered.

- Max. Size: Largest Vessel: LOA 293 m., draft 8.0 m.
- Fuel: Available.

Cruise ports of Cyprus

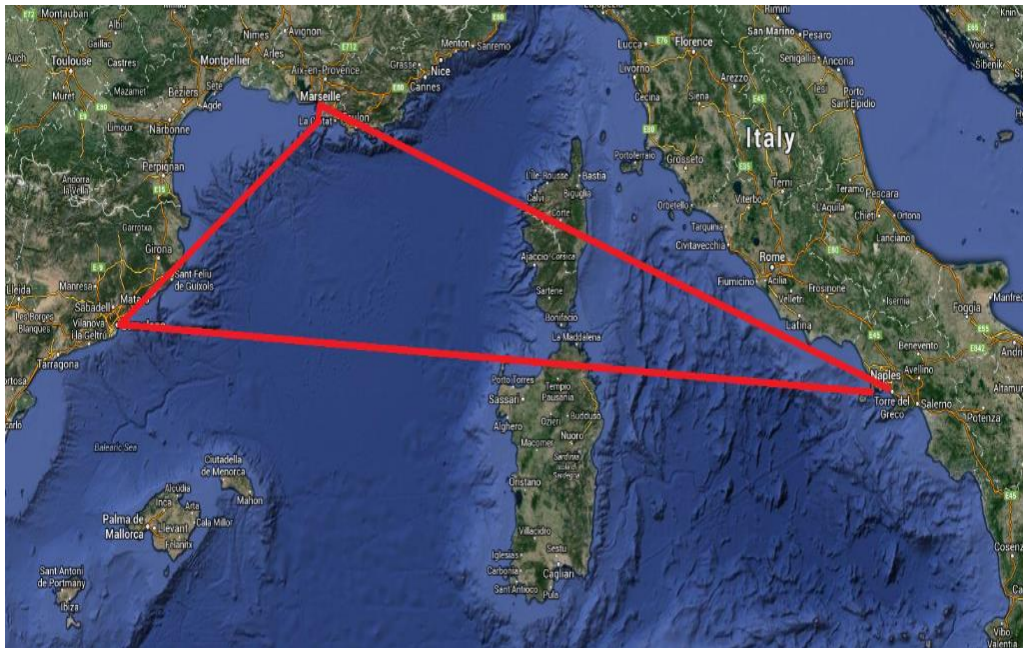
Protected by a breakwater. Facilities for general cargo, dry bulk, Ro-Ro, citrus fruits and passengers. A Free Port and Industrial Free Zone are adjacent.

LOCATION: On the east coast of Cyprus within Famagusta Bay.

- Max. Size: LOA 220 m., draft 9.15 m.
- Fuel: By road tanker.

Proposed Route

The duration of most cruises is seven days, although some cruises last three days and others can take up to months. Thus, one option of destination port is proposed for Mediterrean Sea due to the limitation of ports beam and draught. This route includes three ports of call: Barcelona (Spain), Marseille Fos (France) and Naples(Italy).

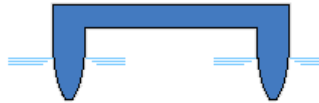


Proposed Solution

Characteristics/Advantages of a Catamaran

The significantly greater area of deck found on a multihull vessel, makes the it perfect for shipping payload such as passengers or cars. Transverse stability is independent of the aspect ratio of the hulls and can be comparable with longitudinal stability or even exceed it. This means greater possibilities in terms of dimension optimisation and possibility to also increase the survivability by creating water tight volumes above-water by dividing bulkheads. These aspects give multihulls an advantage in terms of design for safety when compared to monohulls.

The basic catamaran hull shape consists of two parallel hulls of equal size, deriving stability from the resultant wide beam. The hulls which are also typically much more slender than that of a mono-hull, reduce the lightweight of the vessel giving it a shallow draught and therefore reducing overall resistance and allowing for higher speeds.



Basic catamaran

The wave piercing catamaran is a concept which began in Australia for short distance ferry routes, aimed at reducing dynamic ship motions. Characteristically, wave piercing hulls are long and thin and so are most practical for use in multihull vessels. The fine bow with reduced buoyancy in the forward end, enables the hull to pierce the water rather than floating on top. The advantage of this hull shape and increased waterline length is reduced wave making resistance and a generally less turbulence, while maintaining speeds in increasing sea states.



Wave piercing ferry

The SWATH (Small Waterplane Area Twin Hull) vessel is a variation of the basic catamaran shape which was first developed for use in oceanographic research vessels or submarine rescue ships. The advantage of this design is a broad deck and greater stability in rough seas. These vessels have a high proportion of deck area for the displacement, in other words it can be large and lightweight. In terms of multi-hull forms, SWATHs have higher heave and pitch natural periods and lower vertical excitation loads than a similar sized catamaran. The seakeeping behaviour of this type of vessel is therefore best in head seas. However beyond a certain Froude number, can become unstable in the vertical plane and may not be a suitable choice if operating in severe sea states. Resistance is greatly reduced by having majority of displacement

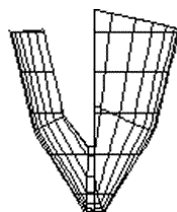
underwater with narrow struts supporting the superstructure. The ship's flotation therefore runs mostly under the waves, bringing the smooth run that would be found with a submarine.



SWATH

A semi-SWATH has also been developed, which has the features of a SWATH in the forward part but broadens towards the aft of the vessel, meaning the engine room can be positioned the same as that of a conventional catamaran. This obviously brings increased frictional resistance but also an improvement in wave making resistance and substantial improvement in seakeeping.

One disadvantage of the typically large beam is a large metacentric height, which results in stiff absolute vertical accelerations. These motions are known to adversely affect passenger comfort and seasickness, vitally important if this concept were to be applied to a passenger vessel or cruise ship. Variations of the multi-hull concept have been looked at in order to improve seakeeping characteristics of high speed vessels. A 'deep vee' hull is defined as having a deadrise angle greater than 17 degrees as shown in the figure below. Although there is limited research carried out in this specific area, the 'deep vee' when applied to a mono-hull, has shown better seakeeping characteristics but high calm water drag than a conventional round bilged hull. However when applied to a multi-hull, the resistance characteristics are more favourable.



'Deep Vee'

Something which is particularly important for passenger vessels is survivability. Multihulls characteristically have high survivability due to the widely separated hulls. If damage occurs, the probability that the other hull is also damaged is low, providing buoyancy. In a monohull vessel, if damage occurs it depends on watertight bulkheads to prevent progressive flooding. As well as this, passenger accommodation is usually above deck with the hulls left as void spaces, with the exception of the engine room. This leaves for a multiplicity of watertight bulkhead arrangements. Usually the number of bulkheads is minimised in order to maximise usable space while meeting the safety requirement, with this it would be easy to design a ship which exceeds what is required of the damage stability regulations without compromising on space.

Summary

Overall, when compared with a monohull, catamaran hulls provide greater stability and less motion in the same sea states as monohulls, whilst also being measurably safer in a damaged condition. Secondly, a catamaran will be able to provide the same volume as a conventional modern cruise liner, whilst having a massively lower length. The application of this is significant, as many ports cannot currently facilitate for the 300m+ cruise ships which are now commonplace. The new design of a cruise hull would therefor capitalize on this large gap in the market.

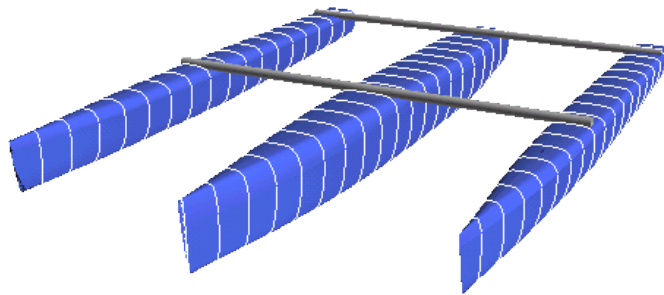
The group has investigated, rather successfully, the potential advantages of carrying out a project to design a catamaran cruise ship:

- The main selling point of this design will be in the unique qualities a catamaran can bring to the cruise market: Enhanced stability and motion reduction coupled with a more compact size in the water – for a significantly reduced length, a catamaran can provide the same volume for accommodation blocks and other functions. Cruise ships are inherently volume-sensitive, so this idea capitalises an area which has not yet been exploited.
- There is significant growth in the market, which is forecasted to continue for another decade at least. This will be fuelled by the projected rise in customers, which inflates demand.

- We are afforded an exciting opportunity to implement a hybrid diesel-electric system, which could incorporate many different renewable technologies.
- This is a unique design which has not been attempted before and shows considerable benefits. A new take on the cruise ship design could attract new customers to the already increasing market.

Trimaran Characteristics

Typically a trimaran hullform would consist of a larger central hull with two smaller hulls on each side of it, as shown below. As with other multihull setups, the trimaran will generally have lower fuel consumption than monohulls at a given operating speed. In one sense, they can out-perform catamarans with regard to wave resistance, as the three-hull configuration allows the design of the central main hull to be very slender. The same equivalent stability can be easily generated by the two side hulls. A trimaran would therefore be a wise choice if performance at high speeds was the concern of a main objective.



Typical trimaran hullform

However, for a cruise ship it is far preferable to analyse the potential benefits and downfalls when the vessel operates at low speeds. The trimaran will inevitably lose its advantage over catamarans at slow speeds as the design will most likely yield an increase in the total wetted surface. This reduces the fuel economy due to the prevalence of frictional resistance. It is highly unlikely that a situation would arise that would cause a cruise vessel will travel at high enough speed over a substantial length

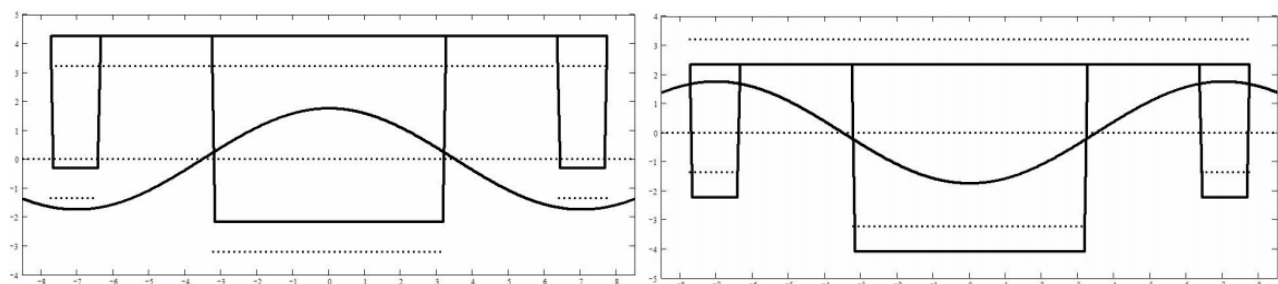
of time to justify the implementation of a trimaran over a catamaran for this particular case.

As with the catamaran hullform, trimaran hulls allow for additional upper-ship space, although no specific extra benefit arises from three hulls generating that space rather than two. Both research and experience can attest to the good performance of trimarans, whilst in head seas in particular; Austal USA published data which argued favourably against a catamaran (Van Griethuysen, 2001) of the same length as a model trimaran operating at high speeds. The resulting difference in operability was 23% in favour of the trimaran. It was found that pitch motions were significantly reduced due to the real-time increase in length to displacement of the main hull.

Wave Loading: Longitudinal

The terms of hogging and sagging apply in two forms: regarding the main hull and the outer hulls. Studies conducted (M.W Ash, 1993) have found that the longitudinal bending loads were significant for the outer hulls in all test cases. Research has also determined that the hogging and sagging of the main hull was not significantly different than any conventional monohull ship.

Much like the catamaran, structural loading is primarily considered transversely due to the two new forms of transverse bending that occur; “transverse hogging and bending”. Changes in buoyancy due to significantly large transverse waves can lead to effective sagging and hogging, depending on the proximity of the outer hulls to the central hull. These are very unstable states in reality and are the primary focus of concern for structural analyses. Below are visualisations of transverse hogging and sagging, respectively.



Hogging and Sagging States

With the objectives of this project considered, it seems reasonable to assert that a catamaran is the best choice of hullform. This is with full respect to the clear performance advantages provided through the use of trimarans, pentamarans and other multihull configurations. In this instance, the benefits of the aforementioned do not seem applicable.

Review of Existing Concepts

	HSC Leonora Christina	Pieter Schelte Offshore Cat	SWATH China Star	STX Pentamaran EOSEAS	Jangs' Cruise Cat	Jules Verne trimaran
Tonnage <v>	6402	365000	18400	105000	11000	50000
Length <m>	112.6	382	131.2	305	366	280
Beam <m>	26.2	124	31.96	60	58	60
Hull Beam <m>					22	
B/L	0.23	0.32	0.24	0.20	0.16	0.21
Height <m>	28.5			100 (mast)	32 (to up deck)	
Draft <m>	4.85	11.5-22.7	8	8	9	
Deck clearance <m>					7	
Freeboard <m>					16	
Depth <m>	8.5	30				
Decks (no.)	5		12	14 (6 passenger, 4 public)	25	
Speed <kn>	40	14	12.5			24
Passenger Capacity	1400	571 in 275 cabins	324 in 176 cabins	3310 in 1403 cabins		3400 in 1700 cabins 20m²
Passenger/Space ratio			55	32-37		? (Public spaces 28k m²)
Cost	€60M	€2.2b	PW €153M			
launched/[designed]	2011	2014	1991	[2009]	[2011]	[2005]
Propulsion	4 diesel MAN 20V 28/33D KaMeWa jets	8 diesel MAN 11.2 MW 13 5.5 MW azim. thrusters 95MW total inst. power	2 diesel Wartsila Vasa 6R32E Wartsila Vasa 8R32E KaMeWa contr. pitch prop. heavy fuel 380 cSt Wartsila Vasa 12V22HF-D 1,740 kw Wartsila Vasa 8R22HF-D	4 dual-fuel LNG diesel electric generators 8MW for propulsion and hotel load 1/2 of conventional cruise ships 108MW 8,300m² photovoltaic panels sials 12,440m² 17% incr. efficiency		60 MW
Fuel Consumption						
Auxiliaries						

Table: Principal dimensions and date for 6 analysed multihulls

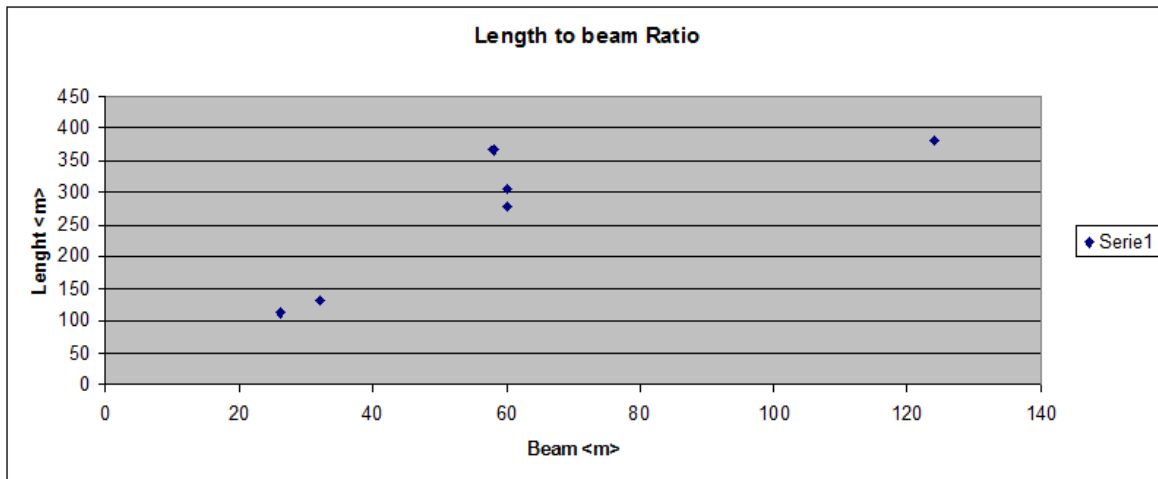
This section of the critical review focuses on reviewing relevant designs that were build. The novelty of a multihull cruise ship restricts the number of suitable design found amount of data obtained. There are only two large existing passenger-carrying twin-hulled vessels. The first one is 113 m ferry for 1400 passengers - the High Speed Craft

(HSC) *Leonora Christina*. The second one is a 131m SWATH cruise ship *Radisson Diamond/China Star*.

The biggest catamaran reviewed in section 1 is the 382m rig-dismantling *Pieter Schelte*, which structural soundness with its incredible heavy lift capacity inspired the group to overcome any obstacle in the structural design of our Catamaran Cruise Ship.

The interesting observation can be made in the field of hull spacing and Length to Beam Ratio. The latter ranges from 1:6 to 1:3 in the analysed sample. This is illustrated on the graph below.

Table. Principal dimensions and date for 6 analysed multihulls



Graph: Length to Beam Ratio of the 6 analysed multihulls

HSC *Leonora Christina* Catamaran

Leonora Christina is Austal's largest catamaran made to date with length of 113 m. This ferry is only 18m shorter than the largest passenger twin-hulled vessel, SWATH *China Star*, the former *Radisson Diamond*. *Leonora Christina* is the largest High Speed Craft build to date, and cruises at 40 kn (76 km/h). According to Halvorsen (2011), the vessel has seakeeping capabilities that ensure maximum passenger comfort on the 90 minute cruise from Danish Bornholm to Swedish Ystad. The vessel complies with strict Danish regulations that cover environmental noise, wave-wash and exhaust emissions. It is also noted that the vessel complies with ergonomic working arrangements for its crew as

well as rigorous fire and safety regulations. The vessel has seats for 1,400 passengers on the upper and bridge decks.



Leonora Christina 113m long hull overview

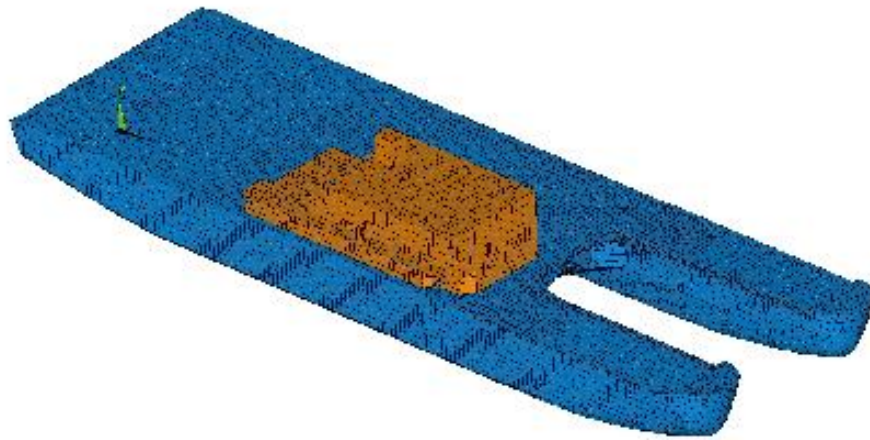
Rig-dismantling Catamaran Pieter Schelte

Undoubtedly the largest catamaran that has ever been under construction, is the rig-dismantling 382 m long *Pieter Schelte*, expected to enter service in 2014 when completed by Korean shipyard Daewoo. It has a lifting capacity of 48,000 t, i.e. 4 times more than current top vessels. Allseas (2013) confirms the vessel will remove platforms from Shell's Brent North Sea field in 2015. The €2.2billion catamaran vessel is 124m wide and is dynamically positioned. She is powered by 8 MAN 11,2 MW plants. The total installed power is 95 MW, driving 13 Rolls Royce 5.5 MW thrusters for dynamic positioning (DP3) and for propulsion, reaching the maximum speed of 14 Kn. The vessel can accommodate 571 persons in two-berth cabins.

According to Eisenhammer (2013), the concept of the vessel is 25 years old and is Allseas' CEO - Edward Heerema's - "biggest bet of his career". The CEO said "We determined the width of the slot a long, long time ago, 20 years ago, and in those days we established that the widest docks available were 120m wide". The basic design of *Pieter Schelte* has been attributed to Swan Hunter of Newcastle-upon-tyne.



The 382m rig-dismantling catamaran Pieter Schelte in construction



Pieter Schelte's Hull and Deck arrangement

The big size of *Pieter Schelte* provides great stability and allows operations in severe sea conditions. A hydraulic motion compensation system reduces load impacts and accelerations. According to Allseas (2013), AQWA 3D software for hydrodynamic diffraction was used. The software calculated *Pieter Schelte's* motions in waves and hydrodynamic pressure distributions on hulls, then transferred to ANSYS. Due to the size of the vessel and its purpose, the design could not be based on class rules alone. The overall hull girder had to be analysed by Vuyk Engineering Rotterdam using Finite Element Model in ANSYS. The critical hull girder loads in waves were determined. A specific bending modes were found, relating to split bow shape. The structural feasibility of the structure was confirmed with the calculation of maximum stress levels, and appropriate scantlings were then chosen.

SWATH Cruise Ship China Star (Radisson Diamond)

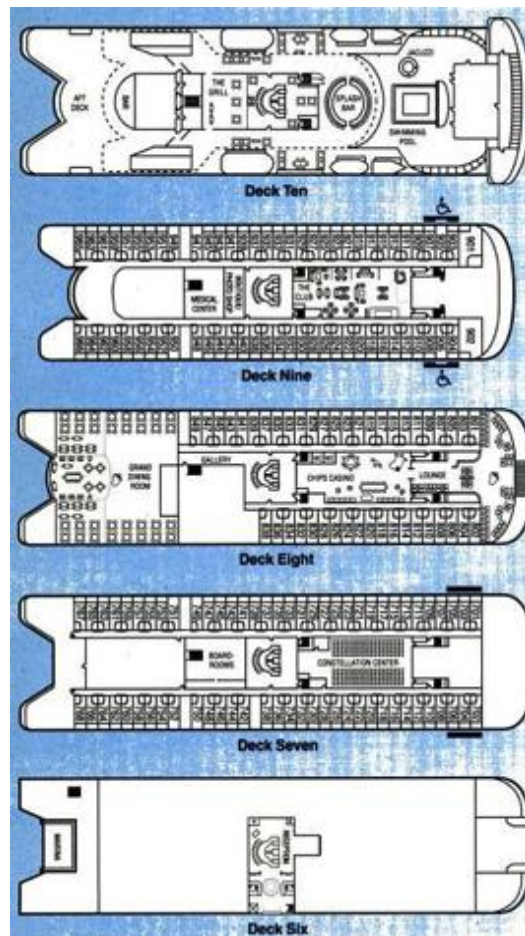
MV *China Star*, the former *Radisson Diamond*, is the world's biggest SWATH. It is the only twin-hull cruise ship build to date. SWATH means Small Waterplane Area Twin Hull. The hull is similar to a catamaran, but features hull extensions underwater. The hull is narrow at waterline to minimise motions, and bulbous and voluminous underwater to provide buoyancy. Klein (2009) notes that inside of the hulls, there are 4 stabilising fins providing the vessel with enormous stability during passage. The 4 stabiliser fins were made by Brown Brothers and were one of the largest ever made. In combination with a KaMeWa fault tolerant control system, there is an independent control of pitch, roll and heave. The 2 controllable pitch propellers were supplied by KaMeWa as well. The propulsion was provided by 2 Wartsila diesel engines.



China Star's SWATH hulls

Klein (2009) mentioned, that due to larger drag the ship can sail at only 12,5 knots. Radisson Diamond is 131 m long and has a beam of 32 m with a draft is 8m. The ship was initially made in Finnyards at Rauma for Diamond Cruise of Finnish banks. Radisson Diamond displaces 18.400 tons and has the capacity of 345 passengers in 176 cabins on six passenger decks. The public spaces are located between cabins, and feature a lounge, a casino and The Club on decks 8 and 9. The restaurant overlooks the stern and sits on deck 8. *Radisson Diamond* has a 6-deck high atrium. The vessel was finished in 1991 and entered service in 1992. *Radisson Diamond's* cruise services ended after only 13 years the vessel was sold to Conning Shipping company of Stanley Ho, rebuilt significantly on the inside and converted to a floating casino.

Snow (1992:41) suggests that this radically designed catamaran could be a forerunner of 21st century cruise ships. He concludes, that in the first year of operation, the former Radisson Diamond gained a reputable position in luxury cruise market niche and she



Radisson Diamond Deck Plans (Snow, 1992)

became the favourite vessel for full time charters. A sister ship, *Radisson Ruby*, was planned when the article was written. It is argued, that her Small Waterplane Area Twin Hull design provides “unyielding” stability and will still be novel and innovative in 21st century. Ship's motions are minimal, and in one occasion, in gale of 70 kn, no breakage was noticed. The same storm cause severe damage in gift shops and restaurants of other conventional cruise ships in the vicinity (Snow, 1993:40). It is said that the initial concept for a twin hulled passenger ship was made in mid-1800s by an unnamed English Naval Architect.

Even though *Radisson Diamond/China Star* is not a full catamaran, it is so far the best example of a large twin-hulled passenger vessel, and experience gained from its design, construction and operation will form the basis of this project

Review of Future Cruise Ships

The critical review briefly reviews several concept design for multihull cruise ships in section 2 and discuss elements of those ships that are useful for the development of this project's basic design.

Eco-Cruise Pentamaran EOSEAS

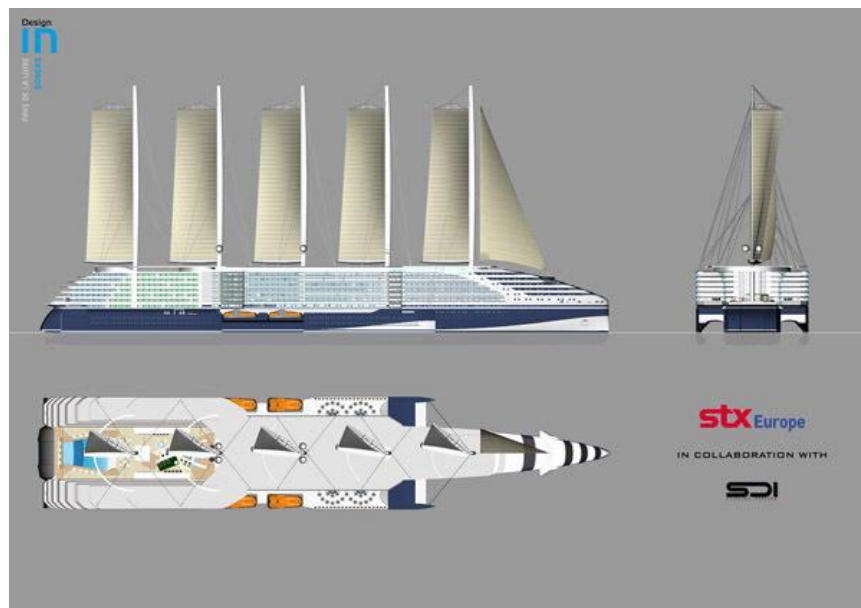


Stern and Bow of pentamaran EOSEAS

Eoseas is a 305m pentamaran hull design, or more specifically, a trimaran on five hulls. It was designed in 2009 by STX Europe with Stirling Design International and features latest eco-friendly technologies. The vessel displaces 105,000 t and has a breadth of 60 m (Kable, 2009). The pentamaran has 1,403 cabins for 3,311 passengers, served by

1,089 crew living in 555 cabins. Cabins are designed to maximise natural lighting have light sensors to reduce energy consumption by 30%.

The hydrodynamic characteristics are optimised by an air cushion under the principal hull, reducing frictional resistance. Kable (2009) notes that Froude number is reduced by incorporating vertical bow. There is double skin to act as natural air conditioning, which reduces fuel consumption for the hotel load. Efficient multistage evaporators and reverse osmosis systems produce fresh water. Wastewater is purified, and grey and black water is treated. Rain water from the upper decks is collected and used onboard. The heat engines generate is recovered through an advanced heat recovery plant. The objectives of the design were to reduce power requirement by 50%, CO₂ emissions by 50%, SO₂ by 100%, NO_x by 90% and ash by 100%, according to Kable (2009).



General arrangement of pentamaran EOSEAS

Eoseas is planned with 20,000 MW propulsion, powered by 4 dual-fuel LNG diesel-electric generators, 8MW each. The generators produce power for both propulsion and hotel load. The power is transmitted by 4 screws, 4 pump propellers with shafts on the outriggers and 2 further pump propeller pods on the main hull. LNG is stored similarly to systems on LNG carriers and is moved to pressurised service tanks. Kable (2009) further adds that there are 8,300m² photovoltaic panels generating additional 108MW. The organic waste gasification plant produces further 300kWe gas for the generators. STX France equipped the concept design with 5 masts with sails covering 12,440m²

significantly use wind energy for propulsion. Griffin (2011) criticises *Eoseas'* dimensions, and argues that her 100m high masts would not allow her to enter ports with bridges or pass through Suez Canal. According to Kable (2009), 13 tank tests with various hull models and propulsion configurations proved a 17% improvement over conventional propulsion systems.

Jang's Twin Hull Cruise Ship Project

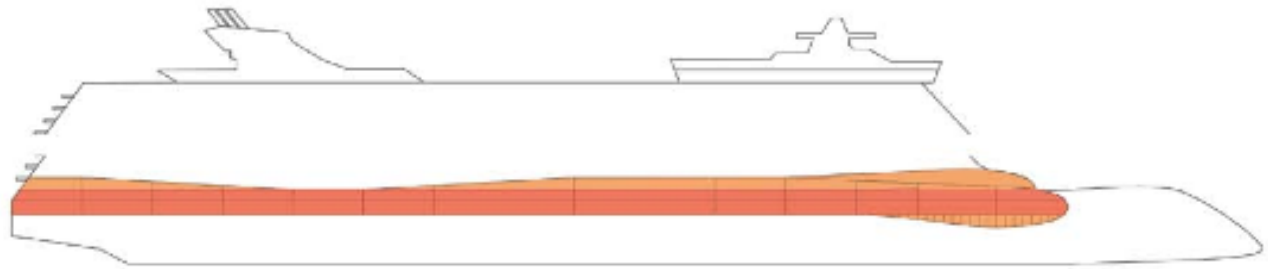
Jang's (2011) thesis focuses on the visual and functional aspect of a new type of a cruise ship as the author is an architect. The author performed basic resistance and deck strength calculations as part of his project. He claims that his twin hull cruise ship is superior to a similar size monohull cruise ship in terms of stability and lower roll amplitudes. His wave-piercing hulls are said to reduce pitching. The vessel is 366m long, with the deck length of 300m, breath of 58m and draught of 9m. It is clear that the length to beam ratio is almost identical with single-hulled cruise ship. The breadth was limited by the size of the new Panama Canal. Therefore the potential for greater volume, stability and staca was not fully explored by increasing beam to more typical length to beam ratio of a catamaran of 1:3 or 1:4. Furthermore, much space in the front is wasted and could have been used for accommodation. Jang (2011) notices that the deck area is nevertheless expanded compared with single-hulled vessels, which provides a larger and more voluminous space for passengers.



Jang's 366m catamaran architectural design

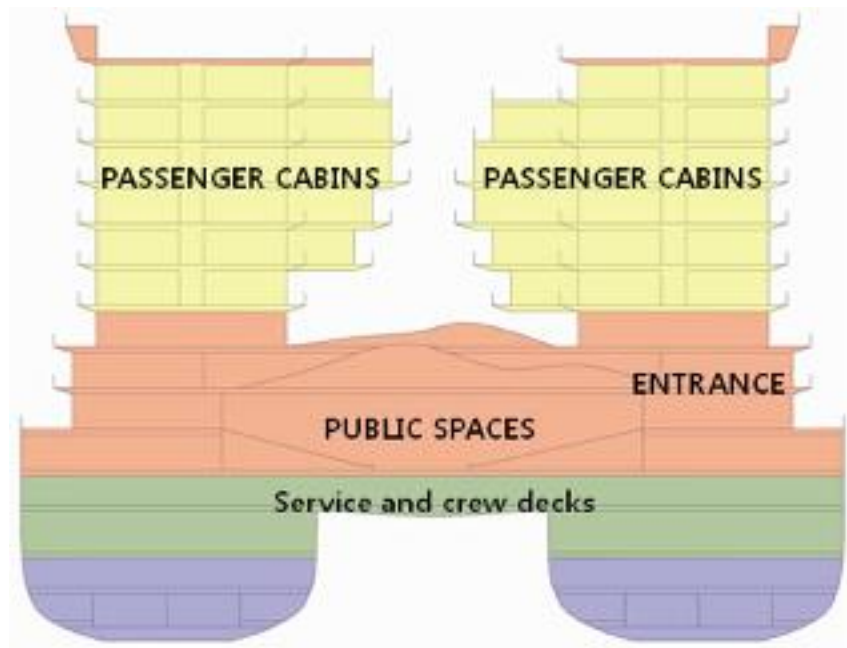
The thesis is limited to architectural aspect of ship design, and calculations in e.g. stability or propulsion were not performed. No systems were selected, and from the

naval architectural point of view, work on our Catamaran Cruise Ship will be innovative and novel. The author recommends further work on hydrodynamic simulations and tank testing.



Section of Jang's catamaran cellular deck structure

As far as basic structural analysis is concerned, Jang (2011) argues that deck will be subjected to extreme forces in severe weather. The deck links two hulls, which might be found to exert opposing forces in quartering seas, causing great torsional loads. Jang (2011) notices that the warping forces on the hulls are the biggest challenge. He tackled the problem by simplifying it into an orthotropic plate model to be used in structural analysis programme ANSYS. Jang (2011) observations about materials used on a catamaran cruise ship are sound. He suggests to use carbon steel to reduce hull weight and to prevent corrosion. He also advises the use of aluminium for the superstructure. A broadly-used transition welding method is suggested to join steel with aluminium.



Deck-revealing cross-section of Jang's Catamaran

A Trimaran Cruise Ship Jules Verne

Jules Verne is a futuristic trimaran cruise ship concept design by Chantiers de l'Atlantique from France. The vessel re-defines the conventional layout of public spaces providing new options for onboard leisure facilities.

The vessel comes in two sizes: length 280 or 320 m with Beam of 60 to 80 m respectively. The trimaran displaces from 50 to 60,000 t. *Jules Verne*'s draught is 8 m and the cruising speed is 24 knots, with power provided by plants generating 60 to 80 MW. *Jules Verne* concept was shown in 2005 at ALSTOM Marine Stand at SEATRADE Cruise Ship Convention in Miami.



Streamlined shape of Trimaran *Jules Verne* Concept Design

According to MarineTalk (2005) *Jules Verne's* trimaran arrangement consists of the central monocoque hull and two SWATH outriggers, which gives the vessel a stable platform, with great comfort for her passengers. The shape of bows and stern was optimised to minimise the sea motions.

Additional 2 large decks can be incorporated by using a trimaran platform. Marine Talk (2005) mentions that the outrigger arms reinforce the hull structurally enabling more surface area of the superstructure to be glazed. This ensures better views for passengers and window sizes matching those of modern land-based architecture. The interior design possibilities in terms of size and location are unlimited, and can include private decks. The concept design has a capacity of 3400 passengers in 1,700 passenger cabins occupying 34,000 m², and the public spaces occupy 26,000 m². *Jules Verne* is home to 4 onboard glass-dome marinas, enabling stowage of small boats and submarines.

For propulsion, the vessel uses pod diesel electric systems which according to MarineTalk (2005) guarantee: superior sea keeping, maneuverability, reduced vibration and best performance. Additionally, solar panels are installed for extra power onboard.

SWATH Personal Cruise Ship Designs

Superyacht News (2011) presented 2 SWATH designs from Yacht Island Design. Both cater for individual cruises. The smaller SWATH, at 90m, is a superyacht called *Tropical Island Paradise*. The theme for the vessel is derived from tropical volcanic island, which was recreated on the main deck, inspired by the Indian Ocean and Polynesian vistas. This superyacht accommodates 10 charter guests.

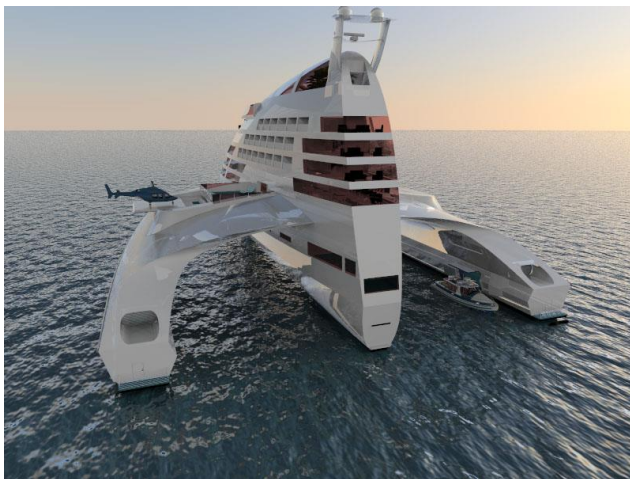
The larger design is a 155m long ship called the *Streets of Monaco*. The vessel reflects the sophistication and style of the principality and features a racing track for cars. It is made in majority of steel, with aluminum upper superstructure for better weight distribution. The vessel has diesel electric propulsion and has maximum speed of 15 kn, which is only 2.5 kn faster than *Radisson Diamond's* SWATH cruise ship from 1992. SWATH vessels are too slow for currently explored cruise ship routes. *Streets of Monaco* can accommodate 16 passengers and 70 crew.



Two SWATH concept design by Yacht Island Design

Other Futuristic Multihull Cruise Ships

An Australian designer BHnautika (2012) proposed an aesthetically-pleasing *Blade* - a new trimaran concept boutique cruise ship. It was designed for small number of passengers in mind, for an intimate luxury cruise. Spacious cabins are of apartment standard and vary in size. There are 7 passenger decks, and the height of the structure is estimated to be 30 m, and the length is estimated to be 50-60m.



Blade - the boutique trimaran cruise ship concept

Dylan (2009) Designed a Giant Catamaran Cruise Ship named *Edinburgh*. Even though this is just an simple sketch, certain features are worth noticing. The superstructure fully explores the greath width of the vessel, providing sufficient interior space for a new generation of onboard entertainment, including cinemas, theaters, casinos. It is felt however, that space in the bow region of this concept design is wasted and could be used safely for accommodation.



Dylan's Giant Catamaran Cruise Ship Edinburgh

Stromman (2012) revisited a forgotten design from 1989 by a Finnish designer Heikki Sorvali. The image was preserved on a postcard. This trimaran design offers a new arrangement of cabins, with many having a private terrace facing forward. The accommodation block has a square base and spans 18 decks if counted above bridgedeck clearance. 6 Life rafts are located symmetrically on each side of the ship.



Sorvali's Cruise Ship Of The Future

The last concept design presented in the critical review is an unnamed tower-style trimaran *Future Cruise Ship* revisited by Freakcruiser (2009). The tower has 20 decks alone, and the total height above water of the vessel is estimated to be 80-90 m, equivalent to a small skyscraper. A trimaran platform is believed by the concept designer to provide sufficient stability for this high centre of gravity structure.

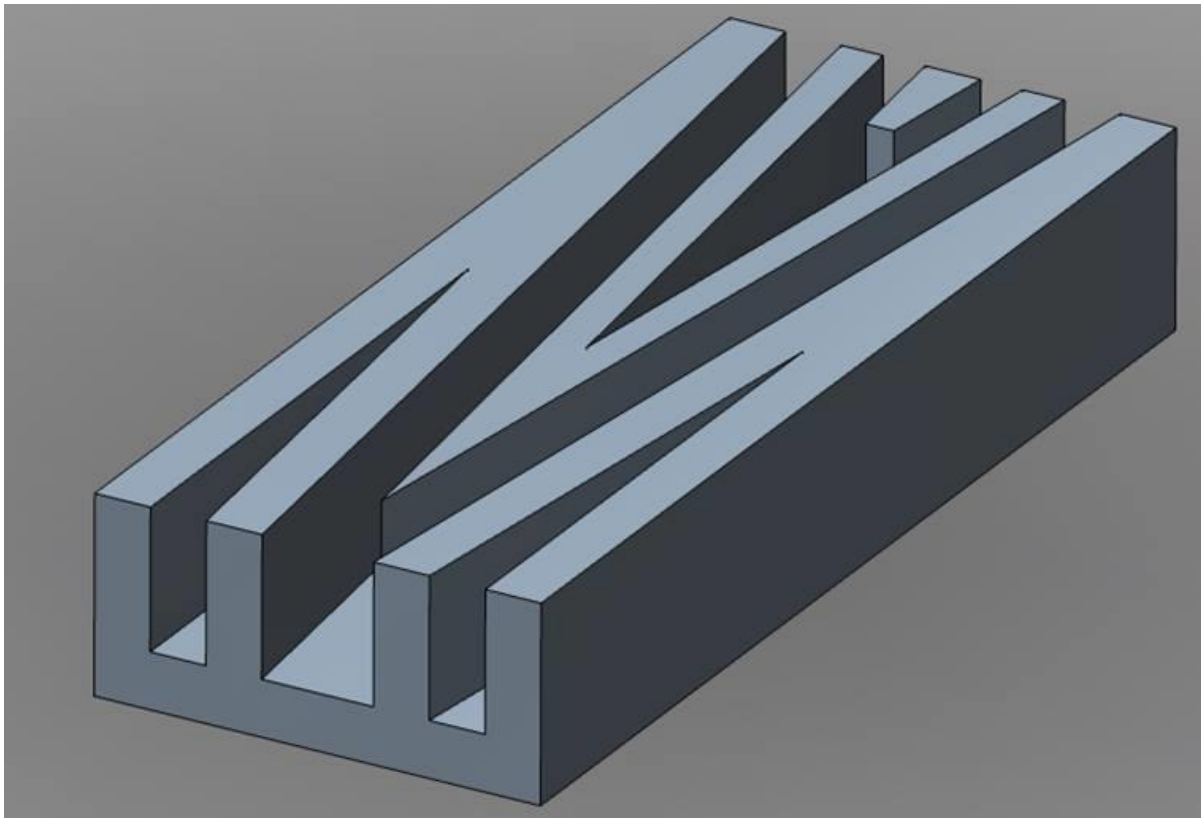


Trimaran tower cruise ship

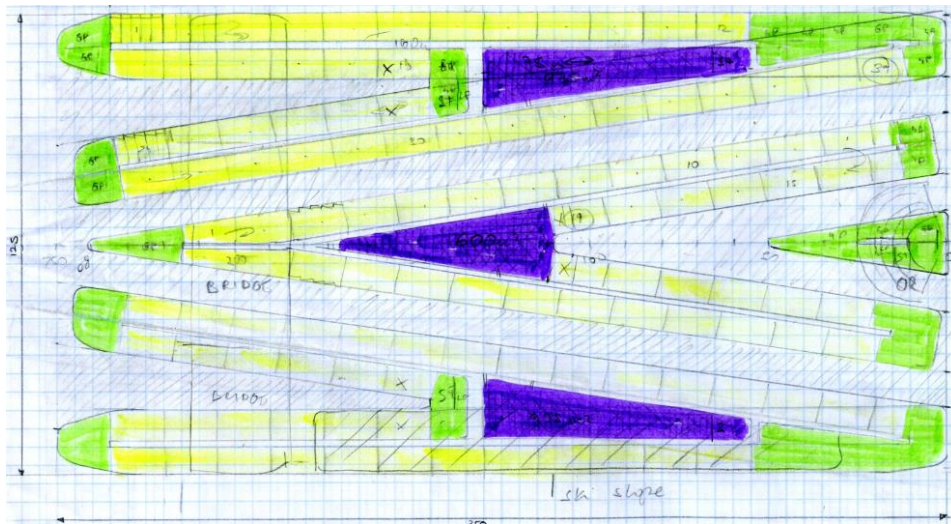
Detailed Design

Layout and General Arrangement

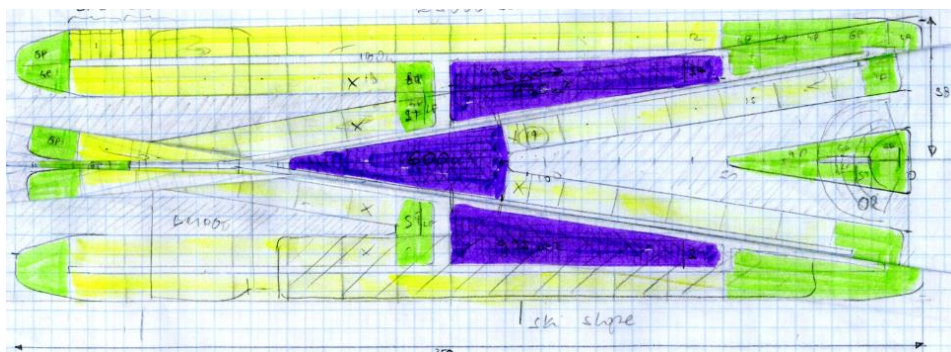
W-class layout



The initial concept idea included a large, triple-vee shaped accommodation block shown above. The idea came about as a solution to providing everyone with a seaview cabin. Its unique angled shape provides lines of sight. This means that passengers spending time on verandas, angles at 10 deg to centreline, have unobstructed vistas of the sea. Due to port restrictions and strength limitations, its width of 125 m could not be accepted. This design was named Iteration 1, and its layout is presented in the following drawings. The design was easily folded over into a double-vee concept. It's width reduced to a more manageable 78m.

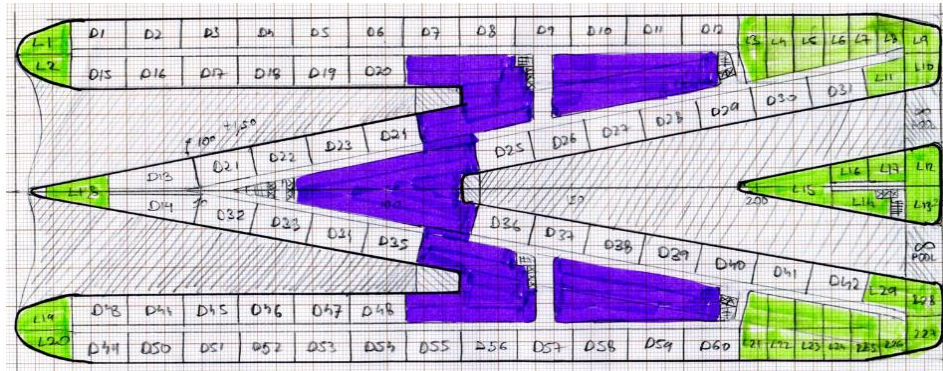


Iteration 1: Triple Vee-class, 250m LOA x 120m BOA



Iteration 2: M-class, 250m LOA x 78m BOA

The next step was to experiment with wider option. Iteration 3 has increased beam which resulted in only minor capacity increase. The only significant increase was in park deck area.



Iteration 3: Double Vee-class, 250m LOA x 90m BOA

To conclude the zigzagging design can be modified according to customer's requirements and can start a new class of cruise vessels.

Current Design

Iteration 4

- *Innovation of the Seas*
- 250m LOA x 80m BOA
- Deep-Vee Hull 24m max width
- replaces Iteration 1: Triple Vee-class, 250m LOA x 120m BOA
- replaces Iteration 2: M-class, 250m LOA x 78m BOA
- replaces Iteration 3: Double Vee-class, 250m LOA x 90m BOA

The reason for selecting iteration 4:

- Optimal capacity
- correct seaview lines of sight
- maximum use of available limited port space
- only slight loss of passenger capacity compared to Iteration 1&3
- good cost saving ratio compared to earlier iterations

Main data

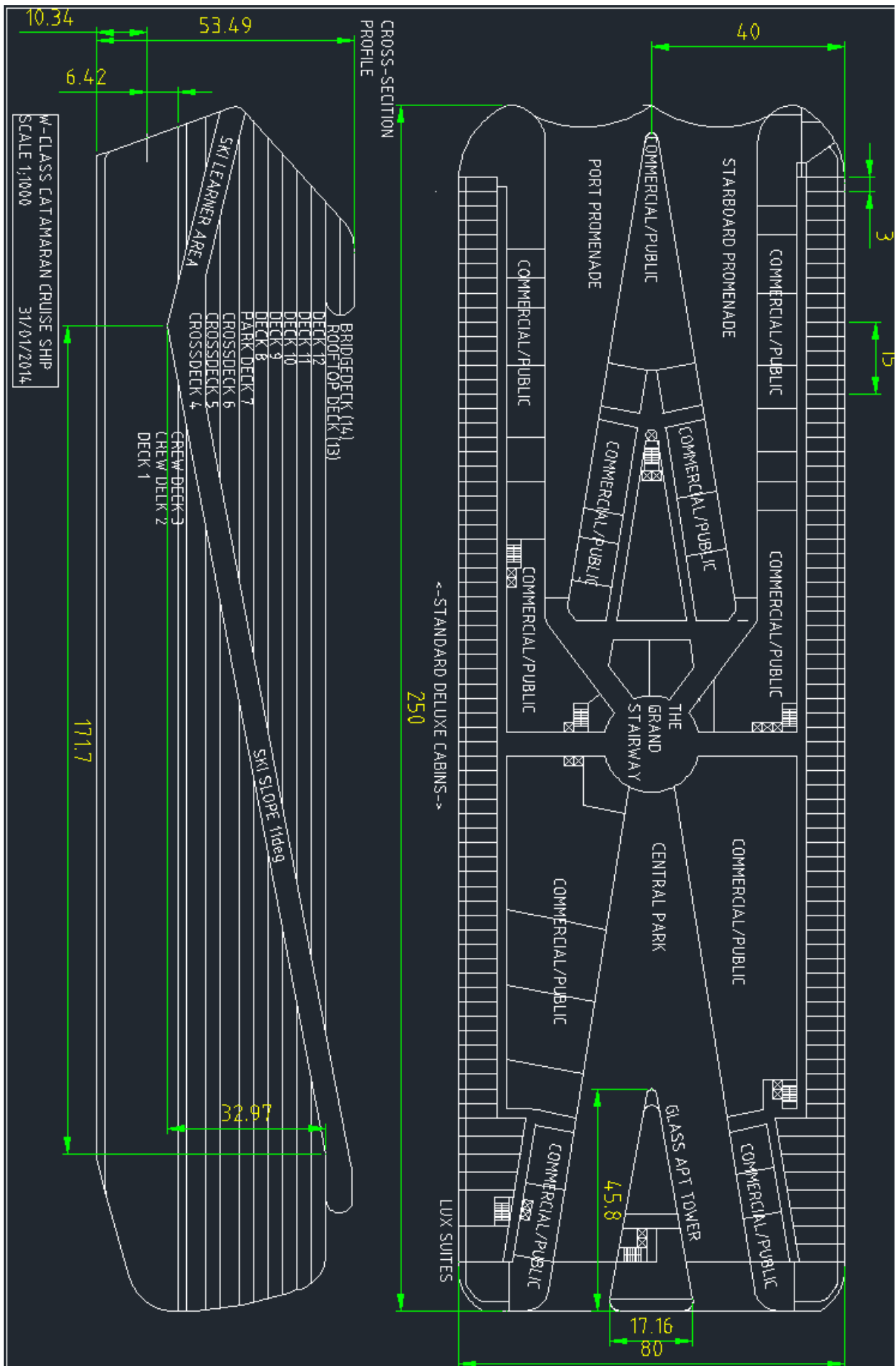
Passengers	3,828
- inc. Standard Deluxes	3,176

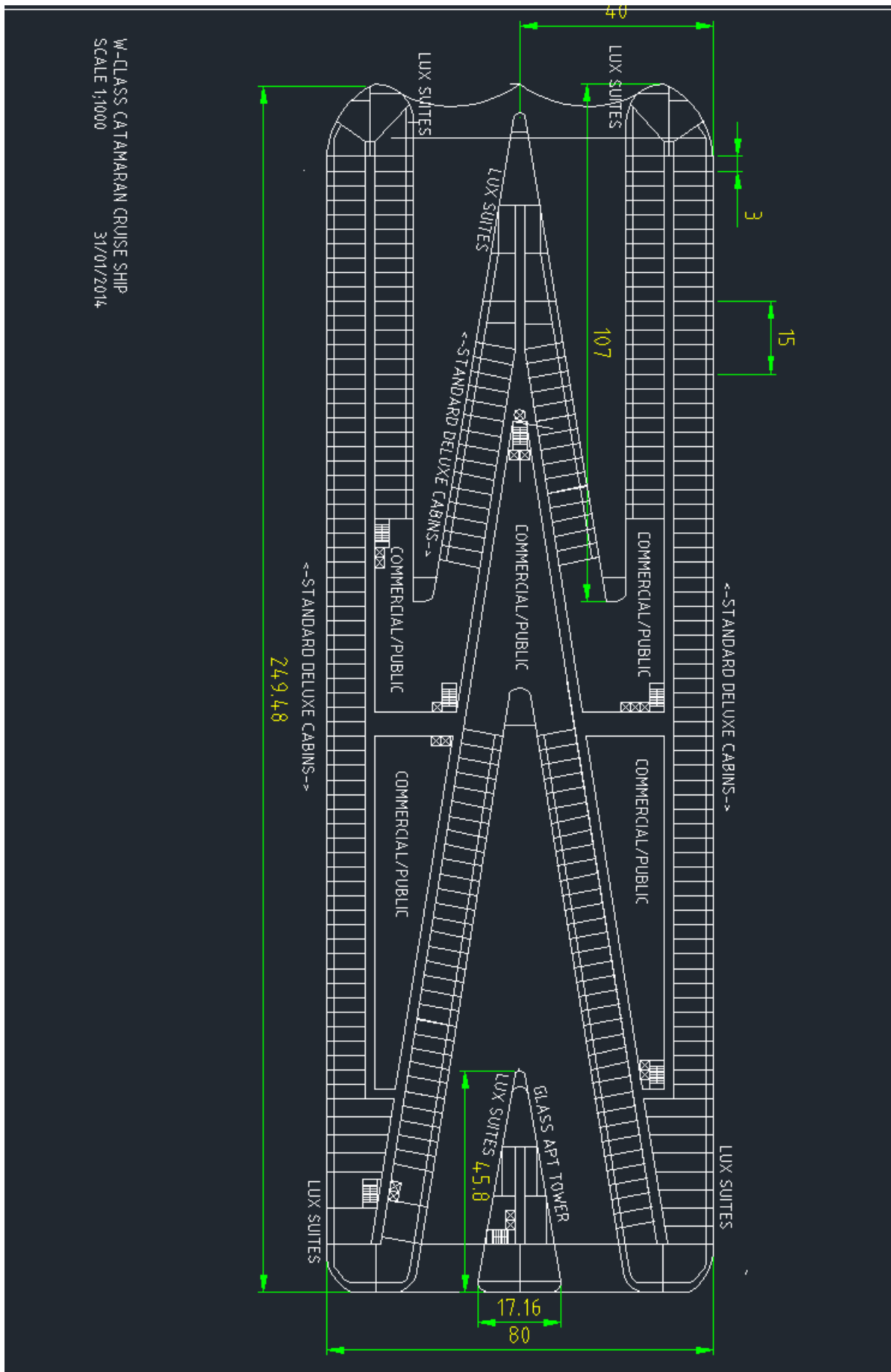
- inc. Lux Apartments	652
Crew	1,722
Total souls onboard	5,550
Gross Tonnage	115,000 t
Estimsated Cost	\$1.0 bn
Speed	18-25 kn
Apartment block inclination	10 deg
Ski slope	11 deg
Total cabin area	52,230 m2
Total crew cabin area	22,995 m2
Total comm./entertn area	70,630 m2
Total machinery/stores area	19,215 m2
Total deck area	200,235 m2
Total volume	600,697 m3

Main Features / Unique Selling Points:

- All-seaview standard 20m2 deluxe cabins
- 170m Ski Slope, height 37m, breath 25-30m; with bow learner's slope
- 2 stern Infinity pools
- 3 park outdoor malls
- 'Toblerone' Glass apartment tower
- Cross-deck glass-floor Shopping Mall
- A 600 people theater and cinema
- Ice rink and ice climbing wall
- Rooftop entertainment pod
- Observation Ship-Eye crane
- 4 rooftop pool areas
- wind-sheltered tennis and basketball courts, golf area, kids area
- Casinos, Bars, Climbing Walls, Surfing Simulators, Astronaut chair

The Following pages show the general arrangement of the *Innovation of the Seas*.

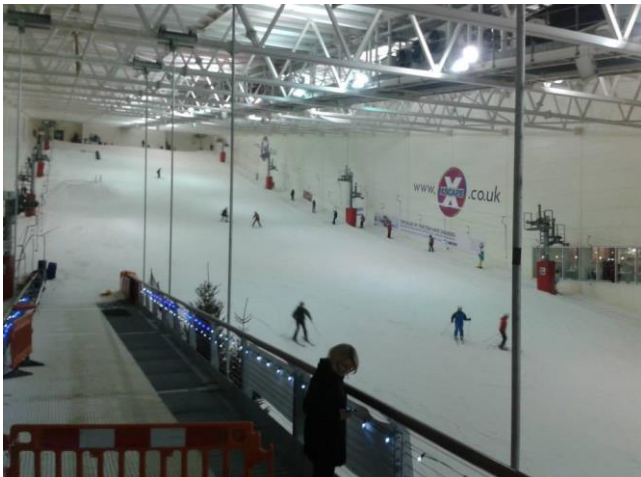




Passenger Experience and Economics

Ski Slope

One of the Unique Selling Point of the project is including a full size 170m long ski slope within port side of the vessel. This idea was inspired by a similar slope in Glasgow as shown by pictures above. The gentle slope of 11 degrees cuts through the port side of the ship creating more space for standard deluxe cabins. As a result, cabins in proximity of the slope's floor and ceiling will be equipped with more headroom and addition of mezzanine floor bedrooms.



Glasgow/s Xscape 200m indoor ski slope

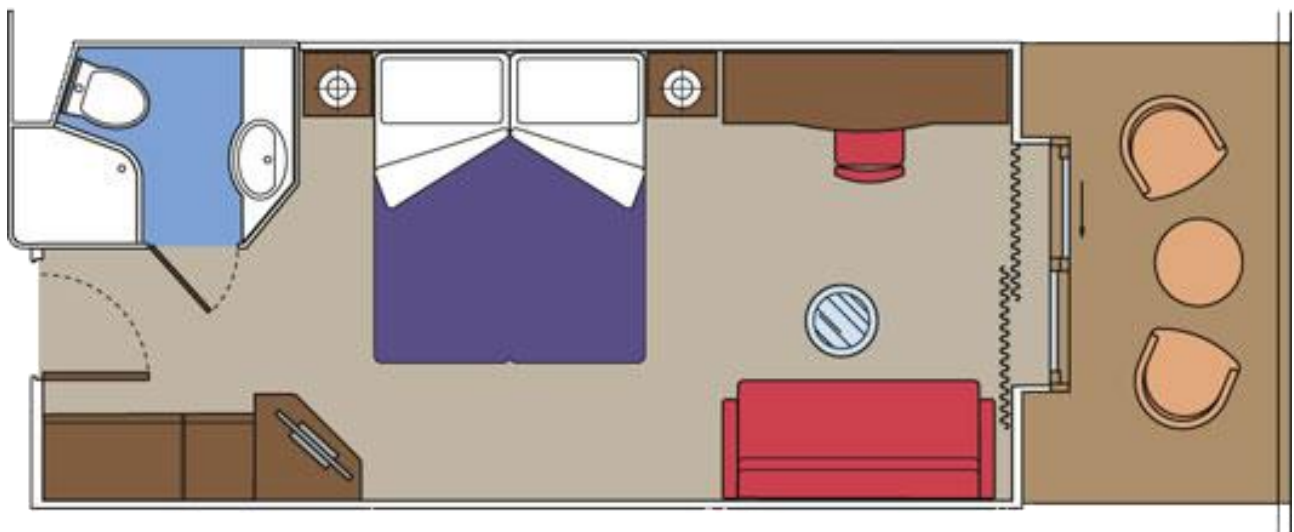
Cabins

The Standard Deluxe Cabin offers spacious accommodation for two. Its generous size (19.5m²) is 60% greater than industry's average of 13m². Moreover every cabin has its own veranda with seaview. Inner Cabins are placed at an angle of 10deg to the centerline to orientate passengers' cabins with lines of sight, providing every cabin onboard the ship with undisturbed vistas.

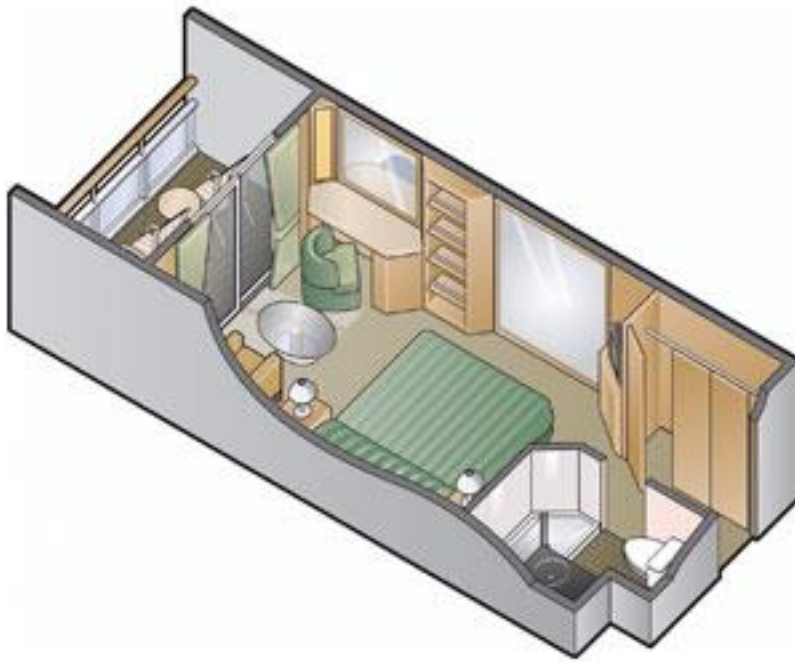
All Standard Deluxe cabins are manufactured in identical, modular 15m x 8m blocks, which comprise of 5 cabins 3m wide and 6.5m long (19.5m²). 1.5m is reserved for seaview verandas for all cabins.

Lux Apartments vary in shapes due to more desirable location, and average 100m² per 4-person cabin.

Crew cabins are 13m² and are created for double occupancy and occupy decks 2,3.



Layout of a Standard Deluxe Cabin: 3x6.5m + 3x1.5m veranda.



3D visualization of Standard Deluxe Cabin



Example of a cabin with mezzanine (Oasis of The Seas)

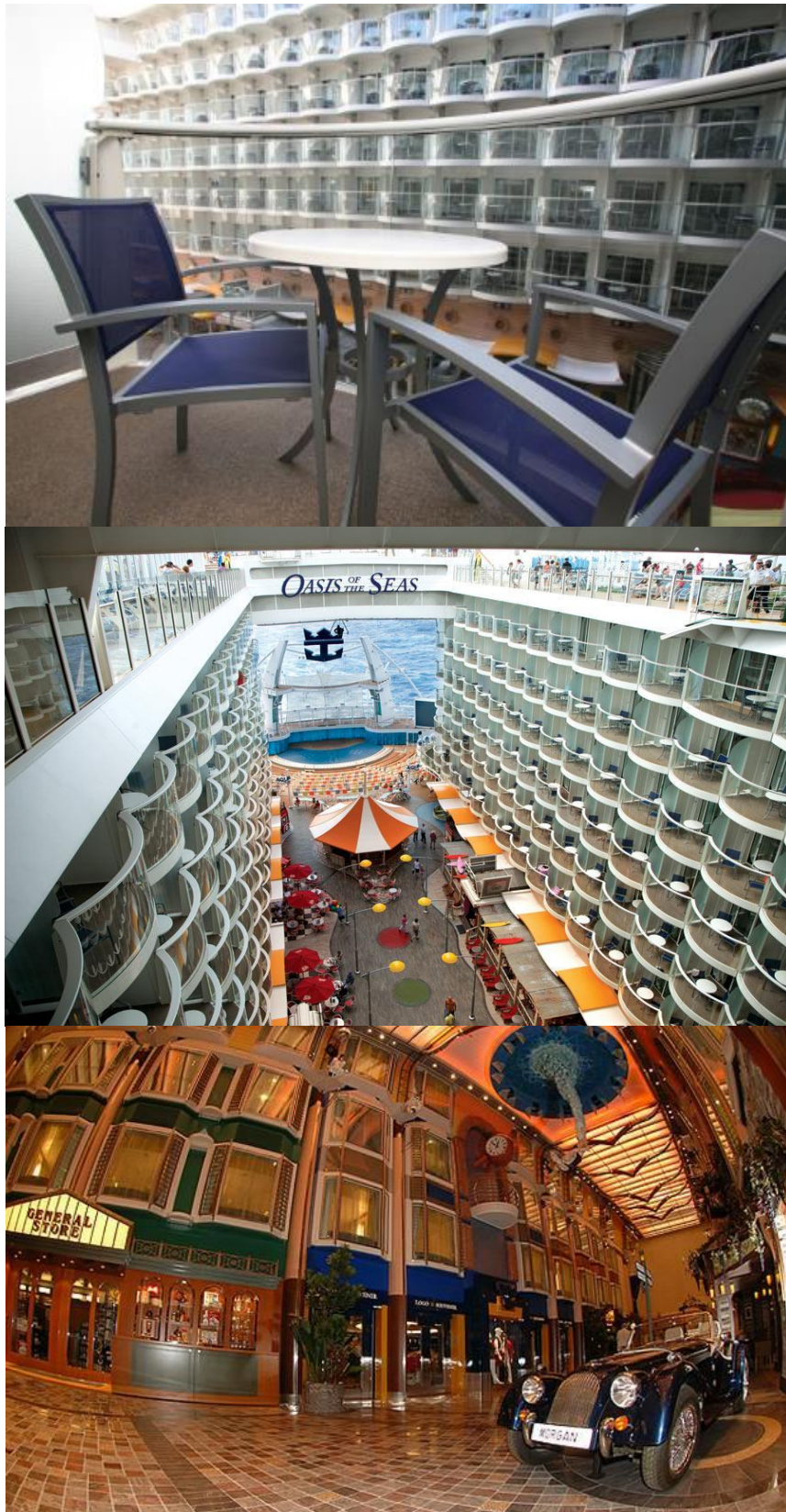
Most cruise lines like squeeze as many cabins into the space available as possible. Their standard staterooms line the hallways, and many are windowless and internal. Most cruise ships Standard Cabins have bad reputation due to small size and cramped bathrooms. On W-class all cabins are large and airy by default. Suites occupy most

desired spaces – the corners and ends of each deck. The new trend is to provide cabins on two floors. 10% of W-class cabins have mezzanine floors



Oasis of The Seas' Central Park

Royal Caribbean offers Central Park and Boardwalk inside the ship. This trend is expanded in our design by including three park decks and an indoor Shopping Mall. Another trend is to equip cabins with an indoor balcony. Unlike on oasis of the Seas, passengers using these cabins are not exposed to the public to the same extent, and benefit from seaview and unobstructed sunlight. An example the inner balcony and Malls is shown below. *Innovation of The Seas* will feature similar arrangements



Inner balconies and the mall of Oasis of the Seas

		STANDARD DELUX	LUX SUITES	COMMERCIAL/PU	CORRIDORS	VERANDAS	SUM				
No. cabins/deck max		290	50								
No. modules/deck max		58	28								
location:	deck n	area <m2>	area <m2>	area <m2>	area <m2>	area <m2>	area <m2>	volume <m3>	no. pax dlx	no. pax lux	
bridgedeck	16						3600	10800			
rooftop deck	15						11460	10800			
accom. block	14	5421	2800	2550	1332.5	1400	13503.5	40510.5	484	88	
accom. block	13	5460	2800	2550	1332.5	1400	13542.5	40627.5	504	96	
accom. block	12	5499	2800	2550	1332.5	1400	13581.5	40744.5	524	96	
accom. block	11	5538	2800	2550	1332.5	1400	13620.5	40861.5	544	100	
accom. block	10	5577	2800	2550	1332.5	1400	13659.5	40978.5	564	104	
accom. block	9	2175	2800	6030	1332.5	1400	13737.5	41212.5	292	96	No. pax
	Sum	29670	16800	24810	9327.5	9800	95382.5	266535	2912	580	3492

		<m2>	<m2>	<m2>	<m2>	<m2>	<m2>	<m2>	<m2>
		delux cabin module	lux apt modu	Communal/Entert.	Corridors	crew cabins	**deck area estimation:		
cross-deck	8	1680	600	13440	5760	0	19200	57600	136
cross-deck	7	1680	600	13440	5760	0	19200	57600	136
cross-deck	6	600	600	12880	5520	0	18400	55200	64
hull deck	5	N/A	N/A	N/A	N/A	8400	10500	31500	
hull deck	4	N/A	N/A	N/A	N/A	7980	9975	29925	
hull deck	3	N/A	N/A	N/A	N/A	6615	9450	28350	
hull deck	2	N/A	N/A	N/A	N/A	N/A	8925	26775	
hull deck	1	N/A	N/A	N/A	N/A	N/A	8400	25200	
		3960	1800	39760	17040	22995	104050	312150	336
SKI SLOPE				5500		no. crew capacity			

Capacity Calculation for W-class Cat Cruise Ship

The above calculations were conducted from measurements taken from detailed general arrangement presented before. Number of cabins was established, and surface areas calculated. The next step was to calculate the volume of the ship which was necessary to obtain a value for the Gross Tonnage.

Assumptions:

Cross-deck (decks 4,5,6) are developed conceptually to include a 500 people Theatre, Casino, Cinema, Shops, Restaurants, Kids Area, Clubs, and is estimated to cover 70% of cross deck area. Crew Cabin layout is not determined yet due to uncertainty about hull form. They will fill 70-80% of decks 3-5 area. For now, hulls are assumed to be 30m wide at the top and narrowing downwards, and their space is estimated with coefficient of 0.7 of a rectangular space enclosed by hull's length and beam.

Delux cabin area <m2>	29670				
Lux Sui. area <m2>	16800				
Extra cross-deck cabin area	5760				
Total cabin area <m2>:	29670				
Total crew cabin area <m2>:	22995				
tal communal/entert. area <m2>:	70070				
tal machinery/stores area <m2>:	19215		For GT	Hull Vol Sum	
Total no. passengers	3828	V	266526	100000	366526
Total no. crew	1450	$K = 0.2 + 0.02 \times \log_{10}(V)$			
Total souls	5278				
Space per pax <m2>	52	K	0.3112821		
Total Area	199432.5	GT=K*V	114092.981		
Total Volume	578685	GRT final	115,000		

Summary of Capacity Calculations and Gross Tonnage Calculations

The gross tonnage could be obtained from the general formula presented in the table above. The result of 115,000 gross tonnes positions the vessel well in its class. The vessels offer more accommodation per tonne, however, due to the fact that it is a multi-hull, the total cost to build per tonne is expected to be higher. The calculations below detail how to obtain a ship price estimate:

Cost to build per Gross Tonne						
		Present Worth	GT	\$/GT	LOA	
CAT	Stena Explorer HSC Ferry	1996	\$164,800,000	19638	\$8,392	126
CAT	Leonora Christina HSC Fe	2009	\$91,800,000	10371	\$8,852	113
MONO	Viking XPRS	2007	193050000	35918	5374.742469	185
MONO	MS Spirit of France	2012	257580000	49000	5256.734694	185
REFERENCE	Oasis of the Seas	2006	\$1,590,000,000	225000	\$7,067	366
REFERENCE	Literatutre value for Cruise Ships				\$5,500	N/A
	Difference Cat/Mono				162.19%	
	Assumed cost/GT				\$8,920.61	

The table above compares two catamarans and two monohull ferries. The cost of the vessels is adjusted to present worth including purchasing power, inflation and change in relative labour cost. The table clearly shows that the average cost to build a catamaran ferry is 62% larger than a monohull ferry. This has to do with additional hull construction, more steel and more complicated shapes and technology applied to the construction. The average monohull ferry cost per tonne of \$5,300 is close to average cruise ship cost of \$5500 quoted in literature by Cathwright (1999). 162% of \$5500 equals to \$8,920, which is an assumed cost per tonne for our vessel. This compares well with cost of mega cruise ship Oasis of The Seas, which averaged \$7,067 per tonne.

mean GRT-based ship price

Cost\$/tonne *p.190	5500
Cost\$/tonne **Oasis	5950
Cost\$ assumed	\$8,920.61
Cost to build \$ *	\$1,025,869,948.71
Cost to build \$ **	\$1,025,869,948.71
Cap Recov @*8%/ Yr	105626405.4
Cap Recov/wk/pax	579.0921347

Assumed 15 r repayment @6%

Based on above research, the total cost to build the ship in 2014 is estimated to be \$1,026 billion, 40% less than Oasis'. Cruise ships are built with 95% borrowed capital. Applying capital recovery factor with interest rate 6% for 15 years, a yearly instalment would be \$105,6 million corresponding to \$579 per passenger per 7-day cruise.

Total cost breakdown ^^

Total estim. Cost	100%	\$1,025,869,949
Design	9%	\$92,328,295
Management	4%	\$41,034,798
Steel	14.50%	\$148,751,143
Insulation & Paint	4.50%	\$46,164,148
Public Space Outfit	9%	\$92,328,295
Pass. Cabins	4.50%	\$46,164,148
Crew Cabins	2%	\$20,517,399
Galleys Offices	3%	\$30,776,098
Hull Piping	4.50%	\$46,164,148
Hull Equipment	7.50%	\$76,940,246
HVAC	7.50%	\$76,940,246
Cold rooms	1%	\$10,258,699
Electrical	9%	\$92,328,295
Machinery	11%	\$112,845,694
Spares	1%	\$10,258,699
Financing	2%	\$20,517,399
Insurance	2%	\$20,517,399
Warranty	1%	\$10,258,699
Sea Trials	0.50%	\$5,129,350
Profit	2%	\$20,517,399
Miscellaneous	1.50%	\$15,388,049

Furthermore, based on Douglas (2003) cost breakdown percentages for a typical cruise ship, various elements can be subdivided, and budges for them established. For

example \$46 will be needed to fit passenger's cabins, and \$92 million to fit public/commercial spaces.

Crew costs

	junior ave	senior ave
wk salary crew	315	1000
crew/pax ratio	0.274294671	0.105263158
	86.40282132	105.2631579
Total \$/wk/pax		191.6659792

assumed: 1000 junior 70h/wk @\$4.5, 400 senior @ \$1000/wk average

The next stage was to estimate fixed and variable costs. The Guardian (2013) published an article indicating that junior hotel crew have a contracted bay of \$2/h plus tips. The average working week is 70h. For the purpose of establishing the cashflow higher pay was assumed. 1050 junior staff receives \$315/wk and 400 senior staff, on average, \$1000. This adds up to \$191 per passenger per 7 day cruise which is line with Cruise Market Watch (2012) research which equates \$189. The next step was to calculate cruise cashflow based on Cruise Market Watch (2012) investigation into data from Royal Caribbean Cruises, Ltd., Carnival Corporation and plc, NCL Corporation Ltd., Cruise Lines International Association (CLIA), The Florida-Caribbean Cruise Association (FCCA) and DVB Bank. Also Cathwright's (1999) data was used.

Coashflow per 7 day cruise - very optimisic

100% occupancy, 100% onboard spending

Income		per pax	per wk	
Standard Fare	\$/wk/pax	\$1,536	\$4,878,336	54%
Premium Fare	\$/wk/pax	\$3,072	\$2,002,944	22%
Shopping	\$/wk/pax *	\$240	\$918,720	10%
Shore excursions	\$/wk/pax ^	\$81	\$310,068	3%
Onboard Activities	\$/wk/pax **	\$100	\$382,800	4%
Alcohol/drinks	\$/wk/pax **	\$150	\$574,200	6%
			\$9,067,068	100%
Cost		per pax	per wk	
Food & Drink Costs	\$/wk/p	\$108	\$413,424	6%
Fuel Cost	\$/wk/p	\$235	\$900,345.60	13%
Agent Commission^	\$/wk/p	\$108	\$413,424	6%
Corporate Op Costs^	\$/wk/p	\$199	\$761,772	11%
Other Op Costs^	\$/wk/p	\$249	\$953,172	14%
Onboard&Transport	\$/wk/p	\$129	\$493,812	7%
Crew payroll^	\$/wk/p ****	\$192	\$733,697	11%
Capital Recovery	\$/wk/pax	\$579	\$2,216,765	32%
			\$6,886,412	100%
Profit before tax		\$570	\$2,180,656	

large profit

Coashflow per 7 day cruise - conservative A

75% occupancy, 80% onboard spending

Income		per pax	per wk	
Standard Fare	\$/wk/pax	\$1,536	\$3,658,752	57%
Premium Fare	\$/wk/pax	\$3,072	\$1,502,208	23%
Shopping	\$/wk/pax *	\$192	\$551,232	9%
Shore excursions	\$/wk/pax ^	\$65	\$186,041	3%
Onboard Activities	\$/wk/pax **	\$80	\$229,680	4%
Alcohol/drinks	\$/wk/pax **	\$120	\$344,520	5%
			\$6,472,433	100%
Cost		per pax	per wk	
Food & Drink costs	\$/wk/p *218	\$108	\$310,068	5%
Fuel Cost	\$/wk/p	\$235	\$900,346	14%
Agent Commission^	\$/wk/p	\$108	\$310,068	5%
Corporate Op Costs^	\$/wk/p	\$199	\$761,772	12%
Other Op Costs^	\$/wk/p	\$249	\$953,172	15%
Onboard&Transport	\$/wk/p	\$129	\$493,812	8%
Crew payroll	\$/wk/p ****	\$172	\$495,246	8%
Capital Recovery	\$/wk/pax	\$579	\$2,216,765	34%
			\$6,441,248	100%
Profit before tax		\$8	\$31,185	

small profit

The first prediction is the most optimistic, assuming competitive cruise price of \$950/pax/wk for Standard Deluxe and \$1526 per Lux Suites per passenger per week on average. Full occupancy is assumed and full spending is taken into account. Figures used to calculate onboard spending are in agreement with researched data. The most optimistic prediction results in a large profit of \$2.2 M per 7-day cruise.

The Second cashflow shown still a small profit when things go wrong. In this scenario only 75% of cabins are occupied and people spend 80% of the usual spending. Costs are adjusted accordingly to correspond with decline in pax. The sheer size and volume of a catamaran helps avoid a loss in such a unfortunate scenario.

The third cashflow is a normal prediction – neither optimistic nor pessimistic. A healthy profit of \$650k is a result of 85% occupancy and 80% onboard spending.

Finally, the last forecast assumes only 70% occupancy, but regular onboard spending. Even in this situation, the operator is not subjected to a loss.

Any further decline in occupancy has to be compensated by increase in ticket price. A small, 50% increase can greatly limit the risk to the operator.

Coashflow per 7 day cruise - normal prediction

85% occupancy, 80% onboard spending

Income		per pax	per wk	
Standard Fare	\$/wk/pax	\$1,536	\$4,146,586	57%
Premium Fare	\$/wk/pax	\$3,072	\$1,702,502	23%
Shopping	\$/wk/pax *	\$192	\$624,730	9%
Shore excursions	\$/wk/pax ^	\$65	\$210,846	3%
Onboard Activities	\$/wk/pax **	\$80	\$260,304	4%
Alcohol/drinks	\$/wk/pax **	\$120	\$390,456	5%
			\$7,335,424	100%
Cost		per pax	per wk	
Food & Drink Costs	\$/wk/p	\$108	\$351,410	5%
Fuel Cost	\$/wk/p	\$235	\$900,345.60	13%
Agent Commission^	\$/wk/p	\$108	\$351,410	5%
Corporate Op Costs'	\$/wk/p	\$199	\$761,772	11%
Other Op Costs^	\$/wk/p	\$249	\$953,172	14%
Onboard&Transport	\$/wk/p	\$129	\$493,812	7%
Crew payroll^	\$/wk/p ****	\$192	\$660,328	10%
Capital Recovery	\$/wk/pax	\$579	\$2,216,765	33%
			\$6,689,015	100%
Profit before tax		\$169	\$646,409	

healthy profit

Coashflow per 7 day cruise - conservative B

70% occupancy, 100% onboard spending

Income		per pax	per wk	
Standard Fare	\$/wk/pax	\$1,536	\$3,414,835	54%
Premium Fare	\$/wk/pax	\$3,072	\$1,402,061	22%
Shopping	\$/wk/pax *	\$248	\$664,541	10%
Shore excursions	\$/wk/pax ^	\$81	\$217,048	3%
Onboard Activities	\$/wk/pax **	\$100	\$267,960	4%
Alcohol/drinks	\$/wk/pax **	\$150	\$401,940	6%
			\$6,368,384	100%
Cost		per pax	per wk	
Food & Drink costs	\$/wk/p *218	\$108	\$289,397	5%
Fuel Cost	\$/wk/p	\$235	\$900,346	14%
Agent Commission^	\$/wk/p	\$108	\$289,397	5%
Corporate Op Costs'	\$/wk/p	\$199	\$761,772	12%
Other Op Costs^	\$/wk/p	\$249	\$953,172	15%
Onboard&Transport	\$/wk/p	\$129	\$493,812	8%
Crew payroll	\$/wk/p ****	\$172	\$462,229.34	7%
Capital Recovery	\$/wk/pax	\$579	\$2,216,765	35%
			\$6,366,889	100%
Profit before tax		\$0	\$1,495	

just break even

Resistance and Powering

Estimated Power consumption per passenger per day

According to the Hamburg University of Technology, a modern cruise ship consumes between **10 and 12 kWh per passenger every day** for propulsion, air-conditioning, lighting, and the other amenities.

[http://www.siemens.com/innovation/apps/pof_microsite/_pof-fall-2010/_html_en/destination-energy-savings.html]

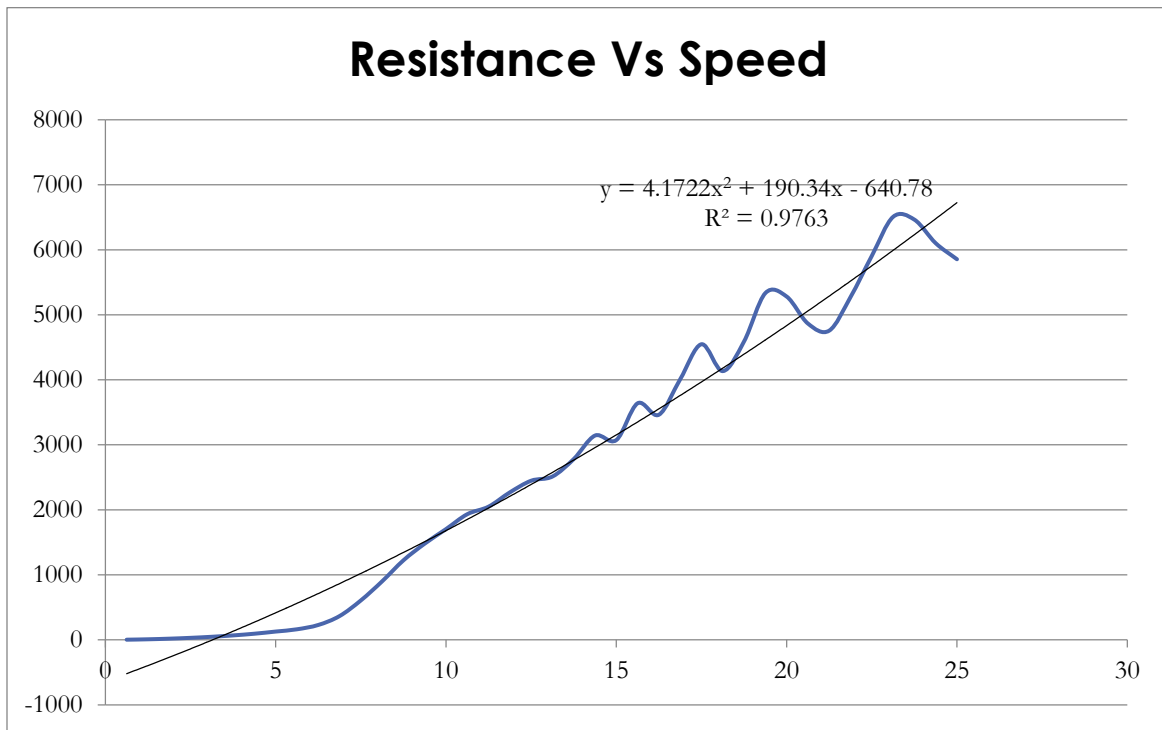
- 12 kWh/24=0.5 kW /passenger
- 0.5kW*5000 peoples = 2,500 kW = 2.5MW per day

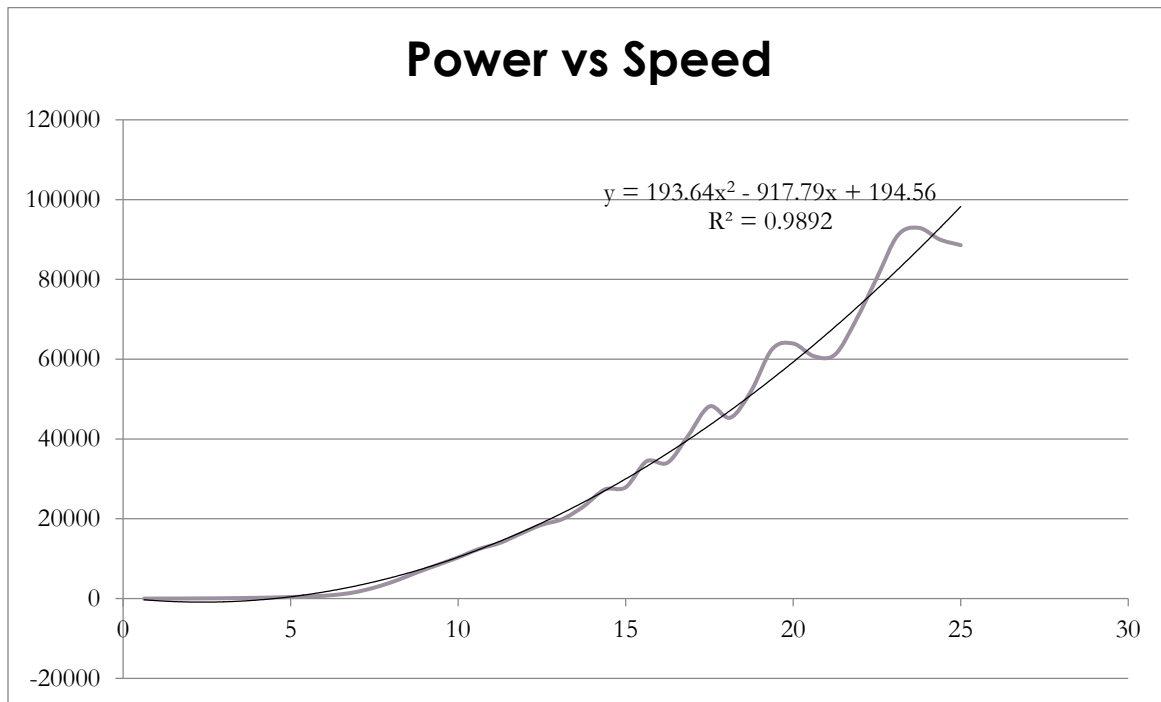
Resistance & Power Estimation

An initial resistance calculation for our deep-v catamaran hull form was made, using Maxsurf Resistance Software. The methods were selected in order to deal with resistance calculations were Molland and ITTC'57. The results obtained for speeds from 0 to 25 knots presented in the table below.

Speed (kts)	Resistance (kN)	Speed (kts)	Resistance (kN)
0	--	13.125	2512.6
0.625	2.2	13.75	2781.1
1.25	8.2	14.375	3142.6
1.875	17.7	15	3073.3
2.5	30.6	15.625	3638.9
3.125	47.1	16.25	3463.2
3.75	68.1	16.875	4009.2
4.375	94.1	17.5	4547.4
5	127.2	18.125	4134.4
5.625	162.2	18.75	4590.7
6.25	228.5	19.375	5334.2
6.875	365.6	20	5281.1
7.5	606.1	20.625	4865.9
8.125	899.8	21.25	4756.9
8.75	1223.3	21.875	5273.1
9.375	1479.9	22.5	5906.3
10	1703.7	23.125	6507.2
10.625	1932.9	23.75	6464.6
11.25	2048.9	24.375	6102
11.875	2268.9	25	5854.9
12.5	2447.9		

Efficiency of the ship was used by the basis ship (85% efficiency). Table and diagram in the next pages, gives the required power to overcome ship resistance in trial speed.





In order to calculate the appropriate power for the resistance of the ship, the average value of the powers predicted from Molland and ITTC'57 was calculated. Also by considering sea condition increase of 25%, SMCR at 85%, and efficiency of system η equal to 0.99, as it can be seen from the below calculations the actual value of power is equal to 98.55 MW.

Pe	75294.01	kW
Pt	71708.58	kW
Pd	97562.70	kW
Pb	98548.18	kW
Pb	98.55	MW

Weight Estimation

Preliminary weight estimation is attempted through the method presented by Karayannis et al (1999), which adapt a method previously used in Watson (1976), whilst utilising a rough guess of the vessel surface area, derived from known vessel parameters. This method is typically applied to fast ferries, so some adaptation is required to make an approximation of the design of a catamaran cruise ship.

$$E_c = L * (b + T) + 0.85 * L * (D - T) + 1.6 * L * (B - 2 * b)$$

where:

E_c = Equipment Numeral, catamarans

L = vessel length, overall = 250 meters

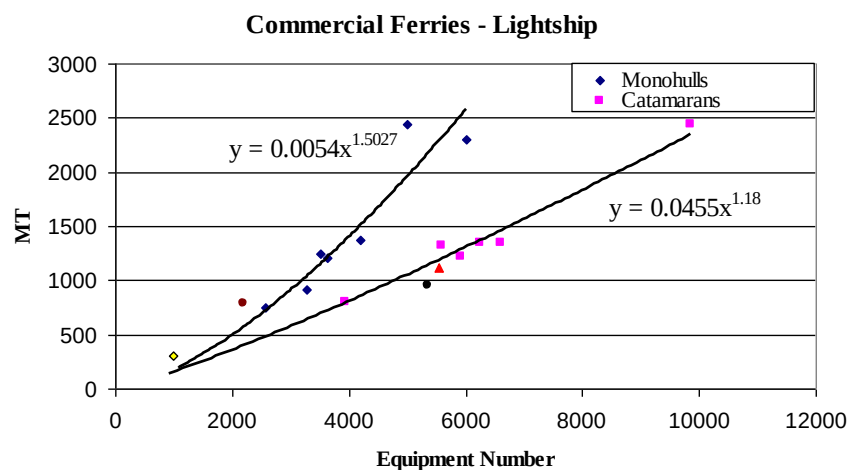
B = vessel beam, overall = 80 meters

T = vessel draft = 10 meters

D = vessel depth including superstructure = 50 meters

b = demihull beam = 24 meters

Using the derived equipment numeral (**29800**), we can estimate the weight of the hull (the most significant value in lightship calculations) through the following graph.



Using the data shown for catamarans, we can estimate that the metric tonnage will be equal to $0.0455 \times (\text{Equipment Number}^{1.18})$, which turns out to be **8661.37 tonnes**. This is very low, which is due to the trend line being based on aluminium ships. Since the vessel will be built from steel, it seemed reasonable to scale up this value by the same factor between the relative densities aluminium and mild steel, which is 2.91. Therefore, our new value for hull weight is **25182.13 tonnes**. Lightship is also made from interior and exterior outfit weight, machinery weight, auxiliary systems, electric systems and various

liquids in pipes. These values have been estimated using reference ships of similar scale and function (Royal Caribbean Freedom, Voyager and Oasis Class Cruise Ships).

Estimations:

Hull Weight:	25182.13 tonnes
Outfit Weight:	5500 tonnes
Machinery Weight:	Azipods 600 tonnes, remainder 900 tonnes
Auxillary Weight:	500 tonnes
Total Lightship:	32682.13 tonnes

Deadweight, or the total payload mass capacity plus the consumables on-board, was also estimated from the Royal Caribbean vessels, which ranged from **11,000 to 15,000 tonnes**. Due to the projected passenger capacity of the catamaran cruise ship, it seemed sensible to use the upper deadweight value, equal to that of Oasis of the Seas. This has a similar passenger capacity and it was assumed that the deadweight from passengers, crew and facilities will be within a very similar range.

Lightship:	32682.13 tonnes
Deadweight:	15000 tonnes
Displacement:	47682.13 tonnes

This derivation was checked for accuracy by subjecting the Celebrity cruise ship “Millennium” to the same calculations. Having known her displacement to be around 40,000 tonnes, the parameters were entered and altered to represent a monohull. The end result was within 2000 tonnes of the actual answer, which lends credibility to the results attained for the Catamaran Cruise Ship. An added benefit of this check was the revelation of the deadweight attributed by passengers and their luggage, which made only minor changes to the overall displacement.

Load Capacity Analysis

One of the most crucial elements of the catamaran cruise ship design is the enhanced provision of capacity. This is exemplified in the general arrangement, as the increased cabin space (from conventional cruise ship rooms) is a clear feature of the design. However, all cruise ships provide the potential passenger with a range of cabins, suites and luxury apartments to suit their standard of extravagance and taste. Fortunately, the deck plan and prices for the many rooms on-board any Royal Caribbean cruise liner is clearly detailed on their website; this data was used to initiate an analysis of the capacity of these rooms, along with predictions on pricing and total income for a specific trip.

Generally, the range of cabins are sold under the title 'stateroom', and vary from the most basic and cheap Interior Stateroom to the ultra-luxurious Presidential Family Suite. Spreadsheets were created for both the "Voyager of the Seas" and "Freedom of the Seas" liners to provide some resources for comparison to on another, and secondly to affirm and guide our own design.

To begin, each deck was analysed separately; the number of each type of cabin was detailed and the total cubic meter value for every type was totalled. From this it was assumed that the average number of passengers in each room would be 2. This analysis was detailed for each deck on board both ships. The deck arrangement of both was strikingly similar, however the main differences lied with the increased number of cabins in "Freedom of the Seas", which allowed for many more passengers on decks 6, 7 and 8.

This capacity information was used with the value for ship volume to determine the percentage of the ship's internal volume dedicated to cabin space. An approximation of this value is a good indicator for the catamaran cruise ships internal arrangement.

To get a rough overview of the cost of a typical trip on board these two vessels, two separate sample trips were planned to determine the income generated from the cabin sales alone. This was straightforward, as the RCCL website once more allowed for extraction of prices for each room type for available trips. For the Voyager class, a

fourteen-night trip in the Mediterranean was planned, whereas a seven day trip was planned with the Freedom class ship.

	Voyager Class	Freedom Class	
Cabins	1557	1766	
GRT	137276	154407	
Volume	388765.632	437280.624	m ³
Capacity	3214	3538	passengers
Cabin Area Capacity	33137.109	35852.895	m ²
Cabin Volumetric Capacity	96097.6161	103973.3955	m ³
Accommodation Volume Usage	24.72	23.78	%
14 night Mediterr. Income	5385972	-	GBP
7 Night Mediterr. Income	-	4405333.63	GBP

These figures are clear and encouraging for our project, as they show our general arrangement is feasible (with regards to cabin capacity) and there is a profit to be made from the provision of more space. This being said, our analysis can be taken further by detailing the most common types of cabin on board these cruise ships. This will allow our team to construct the most effective weighted range of cabins for the same market.

Voyager of the Seas	% of volume
Superior Ocean View Stateroom	6.886283
Interior Stateroom	5.078134
Deluxe Ocean View Stateroom	4.994886
Junior Suite	2.2785
Ocean View Stateroom	1.78692
Promenade Stateroom	1.531765
Grand Suite	0.775317
Owners Suite	0.44399
Royal suite	0.353735

Family Ocean View Stateroom	0.325223
Large Ocean View Stateroom	0.218526
Promenade Family Stateroom	0.04537
 Total %	 24.71865

Freedom of the Seas	% of volume
Superior Ocean View Stateroom	6.285096
Interior Stateroom	5.054277
Deluxe Ocean View Stateroom	4.702844
Ocean View Stateroom	2.03977
Junior Suite	2.025708
Promenade Stateroom	1.648
Grand Suite	0.689298
Owners Suite	0.394731
Royal suite	0.314489
Family Ocean View Stateroom	0.180713
Large Ocean View Stateroom	0.172695
Presidential Suite	0.124217
Promenade Family Stateroom	0.080673
 Total %	 23.71251

This data reveals that the mid-range cabins, or the ocean view staterooms, are the most common on board both these ships. The lowest-priced interior cabins are second most provided with the remaining luxury cabins in the minority. This is an excellent guideline to provide the basis of a service tailored to the cruise market.

Stability Analysis

The most straightforward way to design a ship with speed and comfort is with a long and thin hull. However with this comes reduced stability, something which is of extreme

importance to passenger vessels. Catamarans could be seen as the perfect solution to this as they consist of two thin hulls side by side which still produce less drag than an equivalent monohull (Armstrong, n.d.). Passenger vessel safety is at the forefront of discussion and is especially important now with the number of passengers on a ship increasing and ever changing designs through innovation and technology. All vessels are at risk of being lost if the hull is damaged in any way, whether this is due to collision with another ship, grounding, or even damage which originates internally e.g. explosions. Ships are expected to be able to survive certain amounts of damage and remain stable in moderate environmental conditions, allowing passengers and crew to safely evacuate and possibly even return the ship to port. One aim of this design is a cruise ship design with increased stability compared with an equivalent monohull.

Here an initial intact stability analysis of the hullform was carried out, this analysis will give an indication of the stability characteristics of the hullform based on the displacements calculated so far.

Displacements and draughts:

Lightship: 32682.13 t, Draught 7.201 m.

Full Load: 47682.13 t, Draught: 8.752 m.

Centres of area/volume:

LCG: 125 m.

VCG: 11.274 m.

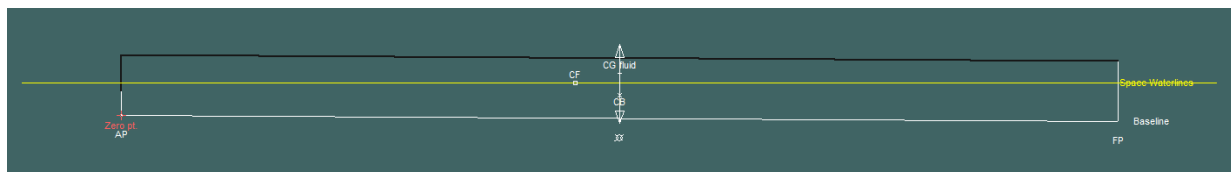
TCG: 0 m.

Hydrostatics:

Hydrostatics	
Displacement	47682 t
Volume (displaced)	46518.92 m ³
Draft Amidships	8.752 m
Immersed depth	10.009 m
WL Length	245.18 m
Beam max extents on WL	79.224 m
Wetted Area	12914.7 m ²
Max sect. area	248.727 m ²
Waterpl. Area	9597.442 m ²
Prismatic coeff. (Cp)	0.763
Block coeff. (Cb)	0.408
Max Sect. area coeff. (Cm)	0.627
Waterpl. area coeff. (Cwp)	0.843
LCB length	120.411 from zero pt. (+ve fwd) m
LCF length	113.345 from zero pt. (+ve fwd) m
LCB %	49.111 from zero pt. (+ve fwd) % Lwl
LCF %	46.229 from zero pt. (+ve fwd) % Lwl
KB	5.869 m
KG fluid	0 m
BMt	169.649 m
BML	800.255 m
GMt corrected	175.518 m
GML	806.125 m
KMt	175.518 m
KML	806.125 m
Immersion (TPc)	98.374 tonne/cm
MTc	1537.502 tonne.m
RM at 1deg = GMt.Disp.sin(1)	146059.6 tonne.m

Equilibrium analysis:

Equilibrium analysis is carried out to make sure the vessel does not sink or have excessive trim before further stability analysis is carried out. As shown in the following figure, analysis shows there is no significant trim in the initial stage.



Intact and damage stability of a Catamaran

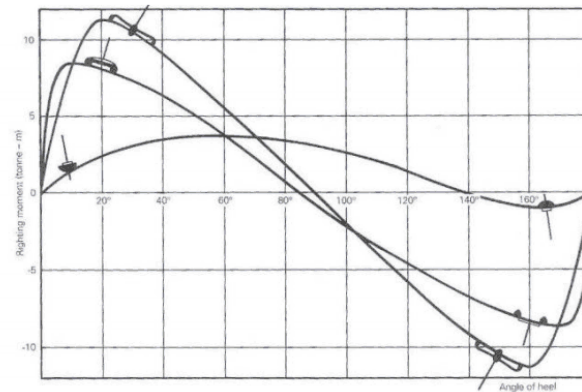
Passenger vessel

The most straightforward way to design a ship with speed and comfort is with a long and thin hull. However with this comes reduced stability, something which is of extreme importance to passenger vessels. Catamarans could be seen as the perfect solution to this as they consist of two thin hulls side by side which still produce less drag than an equivalent monohull. (Armstrong).

Passenger vessel safety is at the forefront of discussion and is especially important now with the number of passengers on a ship increasing and the change in designs through innovation and technology. All vessels are a risk of being lost if the hull is damaged in any way, whether this is due to collision with another ship, grounding, or even damage which originates internally e.g. explosions. Ships are expected to be able to survive certain amounts of damage and remain stable in moderate environmental conditions, allowing passengers and crew to safely evacuate and possibly even return the ship to port.

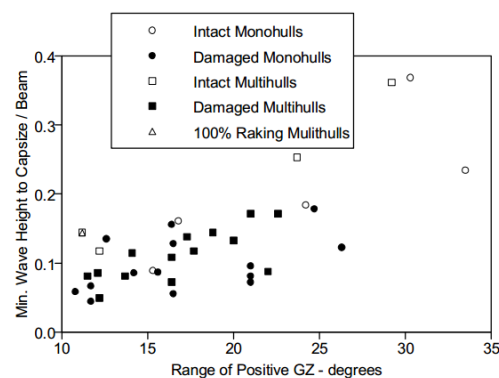
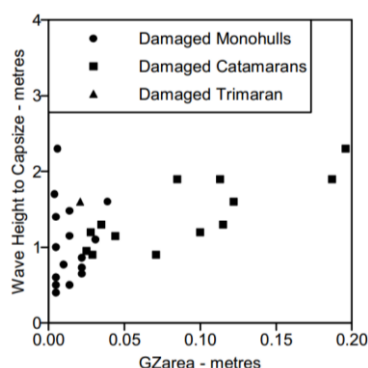
Designing a safe ship is the fundamental aim of this project and for any project of this kind. Safety is regulated by the International Maritime Organisation (IMO) where intact and damage stability regulations are implemented through SOLAS. Stability regulations have evolved greatly in the last few years with the implementation of SOLAS 2009, a probabilistic framework to replace the previous deterministic method for analysing ship stability. Multi-hull vessels bring additional stability at low angles of heel through a larger metacentric height than that of mono-hulls. Many multi-hull vessels are also subject to the HSC (High Speed Craft) Code which is used to take into account the special features of the catamaran in terms of intact and damage stability. However, application of the code is limited as follows, "The HSC Code applies to high-speed craft engaged on international voyages, including passenger craft which do not proceed for more than four hours at operational speed from a place of refuge when fully laden and cargo craft of 500 gross tonnage and above which do not go more than eight hours from a port of refuge. The Code requires that all passengers are provided with a seat and that no enclosed sleeping berths are provided for passengers." (IMO, 2001)

The following figures display some of the differences in characteristics shown between monohull and multihull vessels after damage.



Typical GZ curve for a monohull, catamaran and trimaran. (De Marco Muscar-Fenech & Grech La Rosa, 2012)

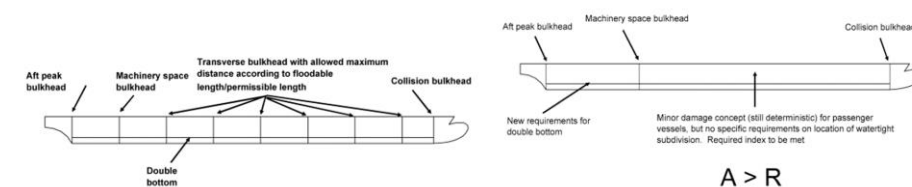
Figure 1 shows the GZ curves for a monohull, catamaran and trimaran. The GZ curve is plotted over a range of angles in order to obtain the point of maximum stability and corresponding righting lever. From this it can be seen that the maximum GZ occurs at smaller angles of heel for the multihull vessels compared with the monohull. The righting lever at these angles is also noticeably larger than that for the monohull. This shows that the multihull vessels only have positive stability for angles of heel up to around 90 degrees however the maximum GZ is significantly greater. Since the maximum righting moment is the maximum moment that could be applied to the vessel without causing it capsize, and is $GZ \times \text{Displacement}$, the multihull vessels indicate better stability.



Left Figure. Variation of wave height to capsize with GZ curve area. **Right Figure**
Variation of wave height to capsize with range of stability (Deakin, 2005)

Figure 2 shows the minimum wave heights required to capsize various models against the area under the GZ curve. Figure 3 shows there is a strong trend of increasing safety with GZ range. The study which evaluated the criteria applied to monohulls and multihulls concluded that multihulls were shown to have a higher level of safety than monohulls due to greater margins over the code requirements.

The transverse distance of the hulls plays the primary role in the damaged stability of multi-hull vessels; the larger the transverse distance, the better the damage stability characteristics. (Qiang, 2008). In general with multi-hull vessels, the passenger areas will be above deck with the hulls used for void spaces and only containing the engine room. One of the main problems in mono-hull design is the balance between subdivision and maximising space. With this free space, there are a variety of options for the subdivision arrangement of the hull so as to meet and surpass the damage stability requirements. As well as this, with two separate hulls, damage to both is unlikely meaning one will always remain intact providing buoyancy and increasing survivability (Armstrong). In saying this, with the new probabilistic regulations there is a new found freedom of design which was not allowed according to the previous rules for which most currently operating ships were designed and built. With the removal of the 2 compartment standards there is greater flexibility in the design to produce a more cost effective and innovative ship. As shown in Figure 4, there is no specific requirement on the placement of watertight subdivision as long as the required indices are met.



Deterministic and probabilistic subdivision requirements. (Vassalos, York, Jasionowski, Kanerva, & Scott, 2007)

SOLAS 2009 Regulations

Passenger ships built after the 1st Jan 2009 are required to comply with the new SOLAS 2009 probabilistic regulations. The SOLAS 2009 regulations are based on the probability of accidents occurring based on statistical evidence from previous accidents. This data is based on sea-state, weather conditions, extent and location of damage, speed and course of the ship and whether it survived the damage or sank. In theory this should improve the design of ships as the criteria can be focused on areas which statistically prove the most problematic. An example of this is the improved sub-division requirement at the bow and bottom of the ship due to the statistical data collected showing that most damages occur at these positions. This makes sense as damages usually occur when colliding or grounding. The probabilistic regulations require the same level of safety, regardless of area of operation with carrying traffic, ship type, all of which might cause different levels of actual risk. However other aspects such as size of ship and number of people on board are accounted for by the use of the required Index R. (IMO)

To carry out damage stability analysis, 2 main probabilities are looked at, the Attained Subdivision Index A and the Required Subdivision Index R. These parameters are based on probabilities of accidents occurring based on statistical evidence gathered from previous accidents. The probability of the vessel surviving collision damage is given by index A and this must be greater than index R to pass the criteria.

$$R = \frac{5000}{L_s + 2.5N + 15225} \quad N = N_1 + 2N_2$$

$$A = 0.4A_s + 0.4A_p + 0.2A_l$$

A_s , A_p , A_l are the partial indices calculated for the deepest subdivision draught, partial subdivision draught and light service draught. These draughts are further explained when used in the methodology. Each partial index is calculated as a summation of all the damage cases taken into consideration using the following formula:

$$A = \sum (p_i \cdot s_i)$$

i is the compartment or group of compartments under consideration

p_i is the probability that the compartment or group of compartments under consideration may be flooded.

s_i is the probability of survival following the flooding of the compartment or group of compartments under consideration. This factor is taken as the minimum of $S_{intermediate,i}$, $S_{final,i}$ and $S_{mom,i}$. $S_{intermediate,i}$ is the probability of survival of all intermediate flooding stages until the final equilibrium. $S_{final,i}$ is the probability of survival of the final stage of flooding. $S_{mom,i}$ is the probability to survive external heeling moments.

These probabilities are calculated as

$$S_{final,i} = K \cdot \left[\frac{GZ_{max}}{0.12} \cdot \frac{Range}{16} \right]^{0.4}$$

$$S_{intermediate,i} = \left[\frac{GZ_{max}}{0.05} \cdot \frac{Range}{7} \right]^{1/4}$$

$$S_{mom,i} = \frac{(GZ_{max} - 0.04) \cdot Displacement}{M_{heel}}$$

M_{heel} is the maximum assumed external heeling moment and is taken as the maximum of moment due to movement of passengers $M_{passenger}$, maximum assumed wind force M_{wind} and maximum assumed heeling moment due to launching of all fully loaded survival craft on one side of the ship $M_{survivalcraft}$. The principle behind the probabilistic method is that two ships with the same attained index A should be of equal safety. (Hildingsson, 2006)

Mechanism for loss

The two main mechanisms for loss of ship are progressive flooding and capsizing. The complexity in the geometry of passenger/cruise vessels can make them dangerous in terms of damage stability (Tsakalakis, 2012). Accumulation of water in high decks,

creating free surfaces can lead to transient capsize. This happens when capsize occurs before the equilibrium of the ship is reached, meaning rapid loss. Progressive flooding is caused by insufficient protection of openings, leading to flooding of adjacent spaces and gradual deteriorating stability until the vessel capsizes. Cruise ships are vulnerable to this after large damages as central corridors on higher decks become flooding through their unprotected openings. Progressive flooding is much less dangerous than transient capsize as it generally takes longer and allows time for intervention.

Passenger vessels are designed not just for transport but for passenger entertainment and comfort. The common problems that occur in all different types of cruise ship associated with accommodating a large number of people on board with factors such as evacuation as well as water accumulation.

Grounding has been identified as the main hazard to passenger vessels and is 4 times more likely than collision. Flooding and fire-related incidents contribute to 90% of the risk for loss of life and 100% of the events which lead to abandon ship. (Tsakalakis, 2012).

A study which looked into the parameters affecting the survivability of passenger vessels in collisions, compared the behaviours of a monohull vessel, similar wider monohull and a catamaran after collisions with a larger vessel. As a measure of the resistance to capsize, critical capsize was looked at which is the minimum speed at which a colliding vessel may cause capsize. The model used was a 33 metre round bilged hull ferry, although smaller than a typical cruise ship, should give insight into the characteristics when compared with a similar size monohull. Results showed a minimum critical capsize speed of 5.4 knots compared with 4 for both monohull vessels. (MCA, 2004)

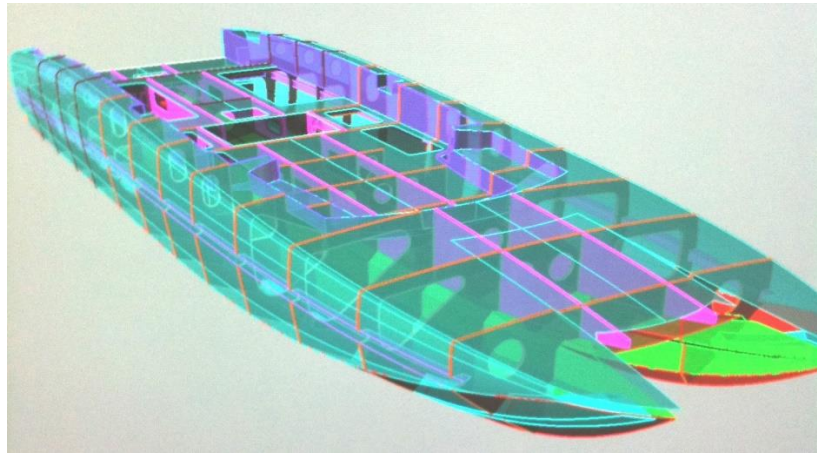
Catamaran Structural Analysis

Overview

For catamarans, longitudinal strength is less important than transverse strength. The structure connecting the two hulls needs to be analysed for class-specified minimum moments and other forces. For a project such as this, it would be ideal to analyse the structure with data taken from the areas in which the final design may operate. These will have to be modified to allow for the long-term distribution of responses that the vessel may undergo throughout its life. Also key to this investigation is the prediction of limitation on structures of large catamarans. Features that limit catamaran size are said to be differential wave loads on the hulls, primarily. Also the material used for the hull will greatly impact the feasibility of the design. For such a large structure, it has been advised that steel be considered in the place of aluminium (Maniar & Chiang, 1971). Limits will also be imposed by the economic benefit of such a large ship along with the current capacity of shipyards, dry-docks and piers of desired route destinations.

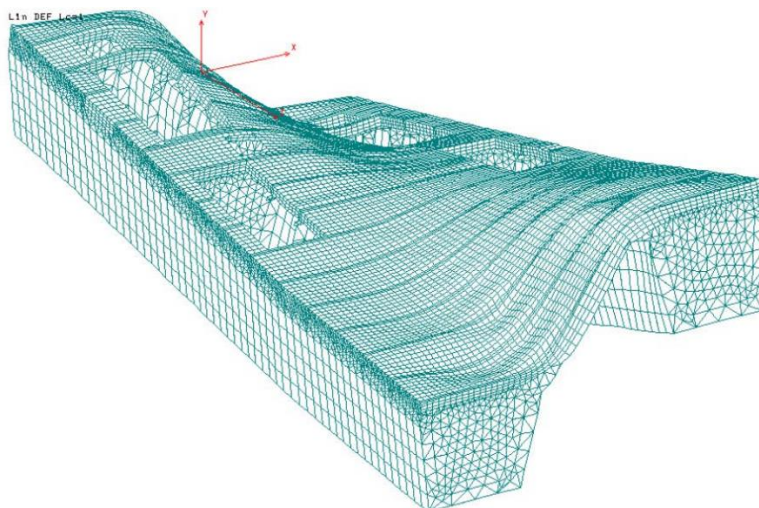
Generally, key loads on catamarans include, firstly, calm water loads caused by the weight of the cross structure, and wave-induced loads which can be summarised by transverse vertical bending moments, vertical shear force and the pitch-correcting moment. Torsional moments occur throughout the scantling structure and are also of significance. The focus for these loads is usually found in the transverse cross section. Other longitudinal loads are present but are not seen as significant in force calculations.

Structural design needs to achieve low life cycle costs within the constraints of serviceability and safety requirements. Conventional transverse strength analysis will involve the creation of finite element models of particular parts of the structure, typically this is the intended mid-ship section. The relationship between this section and the surrounding structure can either be determined by including a coarse global model or surrounding the section with a series of springs or nodal forces using simple calculations. This initial estimation involves the composition of the structural scantlings. It is intended that through this process the scantling configuration will be optimised.



Larger catamarans can be roughly structurally characterised by an aft and a fore bridging structure connecting the two hulls, along with multiple bridging structures in between them. Above we observe these bridging structures spanning the entire beam of the ship.

Catamarans are acutely susceptible to transverse stresses, common between the transverse girders and the hulls. This is a significant issue that does not arise in the typical structural considerations for monohulls. By considering the nature of the vessel's operation, it may not possess the same risk as it may to high speed craft that will encounter waves at a much higher frequency.



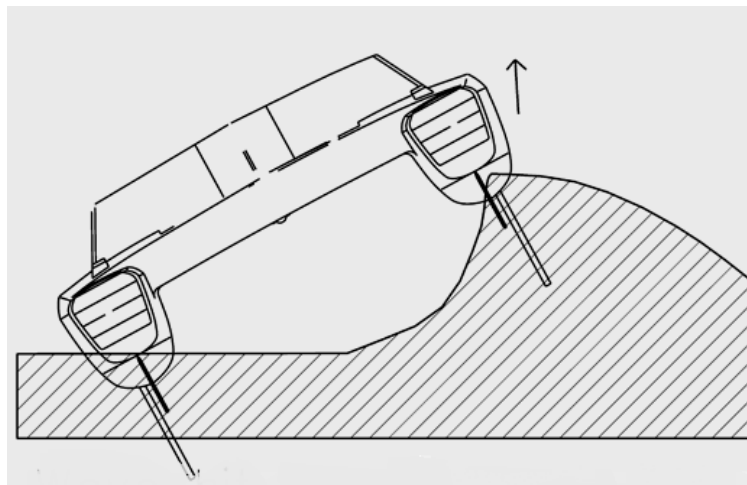
The dynamic behaviour of catamarans in beam seas will be largely determined by the beam stiffness (between the hulls) and this will directly affect the roll motions experienced by the vessel. Above is an exaggerated example of the ways in which

wave loads may cause the structure to react. It is clear that close attention must be paid to ensuring the stiffness is determined with the operating environment in mind.

Simulation

The operating environment may simulated with the main intention to accommodate for a fatigue analyses; this can be based on an investigation into spectral development, called the JONSWAP (Joint North Sea Wave Project), which provides insight into the interactions between waves at various frequencies. It demonstrated how wind loads on waves transferred energy at the high frequency end which is transferred, non-linearly, to the low frequency end of the waves.

The loading from a wave is dependent on the dimensions of the structure relative to the wavelength. When the width of a structure is large enough to distort the original form of the wave, then we must take diffraction and the resultant wave scattering into account. A typical catamaran hull reaction to a high amplitude wave is shown below in an exaggerated diagram. The ramifications of beam waves will be the cause of slamming to the underside of the crossbeams in very heavy weather. So it is not assumed that diffraction will be of importance in our forthcoming simulations.



The sustained wind speed is measured as the mean wind speed over one minute whilst gust speeds are measured as the average speed over an interval of three seconds at 10m from the waterline. Gust speeds are important for cruise vessels, and are considered to be constant values of wind speed rather than short-term occurrences.

This is a conservative method of ensuring the vessel does not adversely respond to extreme gust conditions. A dynamic analysis of wind gusts are computed as follows;

- Discrete gust: Select a wind speed by measuring the maximum transient response of the system.
- Random gust: Random series determined by probabilistic methods.
- Spectral Frequency/Time Domain: Apply a wind spectrum to the vessel to determine response

Steady wind loads are calculated by the “building block” method where the structure that is exposed to the wind is divided into sub-elements that inhabit drag coefficients. These elements are summed to give a profile of wave loading. Wind profiles of ships greatly affect this parameter, and the design of the superstructure of our cruise ship will need to bear this effect in mind.

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Appendices

The following are Concept designs for the vessel which were developed over the course of the project. They include the modelling of the vessel as a whole, as well as the modelling of individual elements of the catamaran cruise ship.

