Chapter 11
Design Features and Construction Enlightenments of Oasis-Class Luxury Cruise Ships

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Abstract The rapid development of cruise economy and the eastward shift of cruise industry have put forward urgent demand for the development of cruise manufacturing industry in China. In recent years, China's shipbuilding industry has developed rapidly, but China has no experience in luxury cruise ship design and building. To develop the luxury cruise shipbuilding industry is of great significance for China to be the world shipbuilding power and for the transformation and upgrade of the shipbuilding industry chain. At present, the trend of large-scale cruise shipbuilding becomes more and more obvious in the world. The world's largest cruise ship has reached 228,000 t. The characteristics of ship type and in-ship facilities not only impose strict requirements for the building technology of functional equipment on ships, but also pose great challenges to the design of the overall speed, safety and comfort, and personalized configuration and building of cruise ships. In this paper, the features, building difficulties and core building technology of the world's operating Oasis-class luxury cruise ships are sorted with the hope to bring enlightenment on the development of China's luxury cruise shipbuilding industry.

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1 Introduction

In recent years, the world's cruise industry shows a high-speed development trend. The rapid rise of cruise economy brings great opportunities for the development of China's cruise industry. In spite of the large downturn pressure of global economy, China is still the most promising emerging economy in the world's cruise industry with a growing market size and huge market demand, attracting wide attention. The cruise industry is featured by multi-layers and multi-links in its structure group, with a relatively long industry chain. With very obvious disadvantages, China's cruise industry mostly stays at the midstream and downstream of the industry chain, such as undertaking port services for foreign cruise ships, However, China is blank in the cruise shipbuilding industry which is highly technical, additional and economically beneficial. Under this background, it is of great significance to vigorously develop the cruise shipbuilding industry and break through the core technical difficulties in cruise shipbuilding to promote China's cruise industry into the whole industry chain as soon as possible.

According to the data of global cruise shipbuilding, the building of luxury cruise ships shows a trend of large scale. In Table 1, the tonnages and passenger capacities of built global cruise ships are sorted out. The average tonnage of a cruise ship was 26,000 t in 1980s, 46,000 t in 1990s (Cui 2011; Li and Yang 2017), 76,600 t after 2000, and 98,000 t in 2010–2017, which is 3.7 times of that in 1980s. Especially the appearance of the cruise ship "Oasis of the Seas" in 2009 makes the development of global cruise ships enter the Oasis-class era, and the trend of large-scale becomes more and more obvious. In April this year, Symphony of the Seas, the world's largest cruise ship, has reached 228,000 t. Moreover, experts forecast that a super-large cruise ship of 250,000 t will appear in the near future. The building of large luxury cruise ships is a systematic project integrating modern industry and urban construction. The building difficulty is even greater than that of aircraft carriers, so it is called the typical representative of high-end equipment manufacturing industry. The development of luxury cruise shipbuilding capability and technology is very powerful to drive relevant industries and it is of great significance in practical application. At present, the luxury cruise ships in the world are mostly built in Europe. With the rise of China as an emerging shipbuilding economy in Asia in recent years, China is steadily the largest shipbuilding country in the world with the three shipbuilding indexes of shipbuilding completions, new orders and handheld orders in the whole year. However, most ships built by China are mainly bulk carriers, oil tankers and container ships, and the independent design and building of luxury cruise ships is still at the exploration stage. Affected by the external factors such as the worlds' sagging economy and stagnant demand in the ship market, the global shipbuilding industry is deeply depressed, the handheld orders of China's shipbuilding industry also show a

Table 1 Parameters of Oasis-class luxury cruise ships

Parameters	Oasis of the Seas	Allure of the Seas	Harmony of the Seas	Symphony of the Seas
GT (10,000 t)	22.5	22.5	22.7	22.8
Length (m)	361.8	362	362.1	362.1
Width (m)	65.5	65.5	65.7	65.7
Passenger capacity (person)	5400	5400	5479	5518
Crew (person)	2165 (maiden voyage)	2165 (maiden voyage)	2300 (maiden voyage)	2300 (maiden voyage)
Guest rooms	2742	2742	2747	2759
Passenger deck	16	16	16	16
Average speed (km)	22	22	23	22
Time of maiden voyage	2009.12	2010.12	2016.05	2018.04
Operation regions	Caribbean and North America	Caribbean and North America	Caribbean, Mediterranean and North America	Caribbean, Mediterranean and North America

Source Official Website of Royal Caribbean International www.royalcaribbean.com

decline trend, and the shipbuilding industry's overcapacity is prominent, driving the demand for the upgrade of the shipbuilding industry. In 2016, the cruise ship owner operated JV company established by CSSC and Carnival Corporation and plc placed orders to the cruise shipbuilding company established by CSSC and Fincantieri for two Vista-class large cruise ships, and the option for four large cruise ships. The newly ordered two cruise ships were jointly designed by the experts from CSSC Cruise Technology Development Co., Ltd. (CCTD) and Fincantieri and they will be built in Shanghai Waigaoqiao Shipbuilding Co., Ltd., a company under CSSC. In June 2018, CSSC formally approved *Overall Scheme and Next Work Plan for Cruise Industry Development of CSSC*, and the process of China's luxury cruise shipbuilding projects and industrial construction were formally started. The development of the large-scale luxury cruise shipbuilding industry meets the needs of China's ship industry transformation, which is of positive significance for China to overcome the technical difficulties of cruise shipbuilding as soon as possible and to solve the capacity problem of the ship industry.

2 Concept and Features of Oasis-Class Luxury Cruise Ships

2.1 Concept of Oasis-Class Cruise Ships

The concept of Oasis-class luxury cruise originates from the Oasis of the Seas, the first luxury cruise ship with GT above 200,000 t under Royal Caribbean International. In 2009, the Oasis of the Seas formally started its voyage from Port Everglades, Fort Lauderdale, United States. The building cost and luxury level of Oasis of the Seas, once the largest super cruise ship in the world, started a new era of huge luxury cruise lines. Since then, the luxury cruise ships above 225,000 t are collectively called Oasis-class luxury cruise ships in the industry. There are four Oasis-class luxury cruise ships in operation, namely Oasis of the Seas, Allure of the Seas, Harmony of the Seas and Symphony of the Seas. All four super cruise ships are owned by Royal Caribbean International. Among them, the Symphony of the Seas with its maiden voyage in April 2018 is the largest cruise ship in the world at present. See Table 1 for details.

2.2 Features of Oasis-Class Luxury Cruise Ships

2.2.1 Large Size

The size of Oasis-class cruise ship is far larger than that of the common ships, with larger length, width and height. Four Oasis-class cruise ships in operation have an average hull length about 361.9 m, an average width about 65.6 m, and average height above the water surface about 72 m. The ship sizes are unified, with small changes.

2.2.2 Large Gross Tonnage

Gross Tonnage (GT) refers to the total volume of all enclosed spaces determined according to *Convention on Tonnage Measurement of Ships*, which is one of the core indexes reflecting the transport capacity of a cruise ship. As a series of cruise ships that have continuously broken the world's cruise tonnage records, GT of Oasis-class cruises has been kept above 225,000 t. The GT of symphony of the Seas delivered recently even exceeds 228,000 t, with the building cost up to USD 1.4 billion.

2.2.3 Large Passenger Capacity

Passenger capacity refers to the standard number of passengers on board, which is another key index of the transport capacity of a cruise ship. There is an inseparable relationship between the passenger capacity and GT of the cruise ship, both of which

jointly determine the scale of the cruise ship. With the increase in GT of cruise ships, the passenger capacity of Oasis-class cruise ship is improved continuously. The standard passenger capacity is improved from 5400 persons of Oasis of the Seas to 5518 persons of Symphony of the Seas. The maximum passenger capacity is improved from 6296 persons of Oasis of the Seas to 6780 persons of Symphony of the Seas. The standard crew is improved from 2165 persons of Oasis of the Seas to 2300 persons of Symphony of the Seas. The smallest Oasis of the Seas can carry 8461 persons, and the Symphony of the Seas can carry as many as 9080 persons, far more than the passenger capacities of ordinary cruise ships.

2.2.4 Complete Functional Facilities

Great importance is attached to the high-quality experience of passengers in Oasis-class cruise ships. The ship facilities are complete with various functions, which can meet the demands of passengers for leisure and vacation to the greatest extent. The superstructure of any Oasis series cruise ship has more spectacular open-air Central Park and Royal Avenue than any previous cruise ship, the concept of land "community" is applied to cruise ships, creating seven theme areas, namely Central Park, City of Joy, Royal Avenue, swimming pool and sports area, marine spa and fitness center, entertainment world and youth activity area, and providing living and entertainment facilities such as restaurant, hotel and special guest room, shopping center, bar, amusement park, theater and golf course etc. as shown in Table 2. The unique and innovative concept of community, rich and exciting entertainment facilities, and the extremely luxurious guest room layout etc., highlight the "Oasis" series cruise ships in facility service innovation, which can meet the demands of tourists at different ages and of different types during holiday.

2.2.5 Large Energy Consumption and Emission

The huge size and tonnage as well as complex and diverse on-board facilities mean that the Oasis-class cruise ships will inevitably result in the problems of large energy consumption and excessive waste emission when sailing. An Oasis-class cruise ship has six engines. In order to support the normal operation of the on-board equipment and systems, its main engine ship consumes 5210 L diesel oil per hour under full power, and the daily fuel consumption is up to 110,000 L. In addition, a large number of wastes, such as black water, grey water, air pollutants and solid wastes, will be discharged when the cruise ship anchors, stops or moves. If they are not properly treated, a series of negative effects will be produced on the marine ecology (Carić 2016).

Table 2 Facilities on Oasis-class cruise ships

	Oasis of the Seas	Allure of the Seas	Harmony of the Seas	Symphony of the Seas
Restaurant	17	16	18	20
Special guest room	Balcony room Ocean view room Inside room Landscape room Room for the disabled	Balcony room Ocean view room Inside room Landscape room Room for the disabled	Balcony room Ocean view room Inside room Landscape room Room for the disabled Inside room with virtual balcony	Balcony room Ocean view room Inside room Landscape room Room for the disabled Inside room with virtual balcony
Shopping center	Shopping street Royal avenue	Shopping street Britto gallery	Shopping street Britto gallery	Shopping street Britto gallery
Bar	11	8	8	8
Standard facilities	Green plant area, outdoor entertainment area for families, swimming area, sea spa, fitness center, theater, indoor/outdoor sports areas, activity center for children and youth, recreation room, video game room and internet bar etc.			
Special entertainment facilities	Merry-go-round Zip line Water theater		Merry-go-round Zip line Water theater Water slide Sea slide Robot bar	Merry-go-round Zip line Water theater Water slide Sea slide Robot bar

Source Royal Caribbean Press Center

2.2.6 Unique Superstructure Design

The Oasis-class cruise ships are of a unique superstructure design. Their superstructure is actually divided into two parts. Both the left shipboard and right shipboard are independent. The middle is an open structure. The atrium is the Central Park Community the "Oasis" series cruise ship is proud of, from which unique Central Park landscape cabins are designed. This unique superstructure design benefits from the cruise ships' large width, providing tourists with a richer and more diversified experience on board.

3 Requirements and Difficulties for the Building of Oasis-Class Cruise Ships

The building of cruise ships is more complex and comprehensive compared with ordinary ships. The characteristics of Oasis-class cruise ships in ship type and in-ship facilities pose great challenges to the overall speed, safety, comfort and personalized configuration of the cruise ships. Therefore, the Oasis-class cruise ships have stricter and more precise requirements for building than ordinary ships in such aspects as power system, steering, maneuverability and hull stability, which needs the shipyards to concentrate on solving such problems and constantly seek technical innovation and breakthrough in such aspects.

3.1 Power System to Be Enhanced

Oasis-class cruise ships are characterized by larger size and tonnage, which require the shipboard power system to provide strong propulsion to overcome the enormous resistance of cruise ships when they set sail or sail. In addition, the vehicle attributes of cruise ships require that the entire voyage must be completed on schedule, which requires the cruise ships' power system to maintain a certain speed on the basis of sufficient range ability, not only to promote the normal operation of cruise ships, but also to adjust the speed under special circumstances, so as to complete the expected range.

3.2 Steering and Maneuverability

The cruise ship types gradually become wider and larger to ensure the stability of ship draft under the trend of large-scale cruise ships. The entry channels of some traditional ports are too narrow for such behemoths, and a little bit of course deviation may cause a port entry incident. The larger the size of the cruise ship is, the more difficult it is to control over the fine adjustment of heading and speed. In order to enter the port safely and smoothly, a cruise ship must be equipped with a precise and flexible steering system to adjust the direction when entering a port.

3.3 Hull Stability to Be Maintained

The vehicle and travel attributes of a cruise ship require that the safety and comfort of the cruise ship must be taken into account when building the cruise ship. The cruise ship is tall. The bad sea conditions that probably encounter in actual sailing are easy

to cause hull jolt, and the cruise ship itself contains complicated equipment and facilities, it will produce self-sway even under the sea conditions with small wind and waves. In addition, the International Maritime Organization (IMO) has strict requirements for the stability of passenger ships, so maintaining the hull stability is an issue that must be considered when building a cruise ship.

3.4 Modularization Technology to Be Utilized

The building of a cruise ship is a huge project which is time-consuming and energy-consuming. The complexity of the internal layout of a cruise ship and the high cost for the building of a cruise ship require the shipbuilding enterprise to make a perfect building plan before starting. In order to simplify the building process of a cruise ship, shorten the use period of the dock and reduce the building cost, all major shipyards in the world generally adopt modular building technology, which divides a cruise ship into modules to be completed at the same time by a number of professional supporting manufacturers, which can greatly improve the building efficiency.

3.5 Green Development Requirements to Be Met

When a cruise ship anchors, stops or moves, it will produce a large amount of waste water, exhaust gas and solid wastes, which will affect the marine and atmospheric environment. In order to reduce the negative externality of a cruise ship and promote the sustainable development of cruise tourism, the requirements for environmental protection should be fully considered when a ship is built, advanced waste treatment technology should be adopted and the waste treatment system should be optimized. In addition, the consumption of a large quantity of sulfur-containing fuel oil is the main cause for air pollution caused by cruise ships; it prefers to develop clean energy and nuclear power to power the cruise ships in the future.

3.6 No Venture Capital Investment

Large luxury cruise ships require a lot of money during their design and building. The minimum cost of Oasis-class cruise ship is USD 1.2 billion (Allure of the Seas); two ships cost USD 1.35 billion (Harmony of the Seas and Symphony of the Seas), and the maximum cost is USD 1.4 billion (Oasis of the Seas). The new shipbuilding enterprises in the cruise shipbuilding industry are required to have great working capital due to high standards for design and building technology. In addition, the uncertainty of the risks and benefits of the later management and operation of cruise ships also makes some domestic venture capital investors shrink back. To break through the

problems of less investment and difficult financing in independent luxury cruise shipbuilding in China, it's not enough to strengthen guidance from government policies. If we fail to fundamentally solve the technical problems in cruise shipbuilding to assure the successful delivery of independently built cruise ships on schedule, it is difficult to make substantive breakthrough.

4 Key Technologies for Building of Oasis-Class Cruise Ships

In terms of intuitive feeling, the biggest feature of Oasis-class cruise ships is "big". Therefore, there are new requirements and challenges for cruise ship design, building and management. Some specific technical problems during cruise ship design can be correctly judged and properly solved in China, but it is difficult to put forward new design ideas with creative thinking (Zhang et al. 2016a). In order to improve the building quality of cruise ships and build high-quality cruise ships, international shipyards generally implement precision management in the building process of cruise ships to improve their market competitiveness (Mao 2017). But currently, there is no self-built cruise ship in China. It is even more important for China's major shipbuilding enterprises to be able to build cruise ships and accumulate experience in cruise shipbuilding. On the basis of basic capability of building cruise ships, the shipbuilding enterprises will carry out comprehensive precision management, improve the building quality of cruise ships, and strive to establish "Chinese cruise ship" brands in the word. Through detailed analysis on the building process of Oasis series cruise ships, it is found that engineers often spend a lot of time and energy focusing on solving power, steering, stability, module assembly and environmental protection problems by adopting the methods and means such as computer simulation analysis, building model and comparative experiment. Therefore, the technologies in the following five aspects should be specifically analyzed from the perspective of building.

4.1 Propulsion Technology

Due to the large displacement and heavy tonnage of Oasis-class cruise ships, it requires powerful engines to provide powerful and sustainable propulsion. Currently, the Oasis-class cruise ships adopt an electric propulsion system, its operation principle is a way of propulsion by converting the mechanical energy generated from the prime mover into electric energy and driving the propeller with a motor (Wang 2010). The prime mover is the power source of the whole propulsion system, usually diesel or gas turbine. But the Oasis-class cruise ships also apply turbocharging technology in the engine. The turbocharger can improve the diesel engine power, perfect eco-

nomic performance and provide stronger power than ordinary engines, which will be favored by cruise lines. As revealed in 2017 by Royal Caribbean Sustainability Report, the Company has equipped eight ships with gas-turbine engines that burn clean fuel and reduce air pollution.

The Oasis-class cruise ships adopt ABB podded electric propulsion system, including three ABB Azipod propulsion units, three ACS6000 medium-voltage frequency converters, six main generators, 11 kV main switchboards, six propulsion transformers, four propeller motors, distribution and propulsion excitation transformers and substation switching equipment. The motive power comes from six medium-speed generating units, with total output about 97,020 kW (130,110 hp), far higher than non-Oasis cruise ships (Table 3). Such energy is converted into electric power, the main purpose is to drive the three Azipod pod boosters that can realize ship propulsion and steering in a space-saving device in addition to the supply of power to the ship's electrical facilities. Compared with the conventional axial propeller, the power from the generator set enables the Azipod pod propeller to transport more payloads at a higher speed and operate more efficiently with less energy. Azipod pod propeller has excellent maneuverability (full thrust all-around), steady cruising speed, undetectable noise and vibration, and significantly reduced fuel consumption and greenhouse gas emission. The prow of Oasis-class cruise ships is equipped with four sets of side thrusters. The main system with auxiliary propulsion system makes the Oasis-class cruise ships with the most powerful propulsion in the history, which makes the Oasis-class cruise ships more operational. The cruise ships can also easily dock in the absence of tugboat help. In addition, the pod electric propulsion system has greatly reduced fuel consumption and exhaust emission, enabling ships to operate with unparalleled fuel efficiency, ship maneuverability and passenger comfort, saving energy costs and meeting the requirements for environmental protection.

4.2 Steering Control Technology

For ordinary cruise ships, pod propellers are not only driving devices of cruise ships, their advantage in 360° horizontal rotation and drive-force generated all around can also help cruise ships to change their courses (Nie et al. 2003), meeting the demand for the direction adjustment during the daily sea voyage of cruise ships. However, when entering and leaving a port, due to the high requirements for the accuracy of the cruise terminal, in the past, a cruise ship could only rely on large tugs to provide side thrust for steering control when berthing and leaving. For giant cruise ships like Oasis-class, their unusual mass makes it difficult to maneuver, and steering with only a pod propeller is barely adequate for most steering needs. When an Oasis-class cruise ship enters or leaves from a port, the slower the ship sails, the worse the rudder effect is, and the more difficult the cruise ship operation is. In order to meet the requirements of Oasis-class cruise ships above 200,000 tons for steering mobility on the sea, it is extremely important to equip with steering control devices when entering or leaving a narrow fairway and arriving at a port.

Table 3 Performance comparison between the power propulsion systems of Oasis-class and non-Oasis-class cruise ships

Class	Representative cruise ship	Tonnage	Motive power	Side thrust	Propeller
Oasis-class	Oasis of the Seas	225,282	3 × 13,860 kW (18,590 hp) Wärtsilä 12V46D 3 × 18,480 kW (24,780 hp) Wärtsilä 16V46D	4 × 5500 kW (7400 hp) Wärtsilä CT3500, Bow thrusters	3 × 20,000 kW (27,000 hp) ABB Azipod, All Azimuthing
	The Allure of the Seas	225,282			
	Harmony of the Seas	227,000	4 × 14,400 kW (19,300 hp) Wärtsilä 12V46F 2 × 19,200 kW (25,700 hp) Wärtsilä 16V46F	4 × 5500 kW (7400 hp) Wärtsilä CT3500, Bow thrusters	3 × 20,000 kW (27,000 hp) ABB Azipod, All Azimuthing
	MS Symphony of the Seas	228,081			
Non-Oasis class	Quantum of the Seas	167,800	2 × 14,400 kW (19,300 hp) 2 × 19,200 kW (25,700 hp) 2 × 2500 kW (3300 hp)	4 × 3500 kW (4694 hp)	2 × 20,500 kW (27,500 hp)
	Ovation of the Seas	167,800			
	MSC Meraviglia	171,600	4 × 38,400 kW (51,500 hp)	–	2 × 19,200 kW (25,700 hp)
	Norwegian Joy	167,400	2 × 16,800 kW (22,520 hp) 3 × 14,400 kW (19,300 hp)	–	2 × 40,000 kW (53,600 hp)

Source CruiseMapper, ABB official website and Wärtsilä official website, etc.

With the development of side thrust technology, at present Oasis-class cruise ship relies on the pod propeller as well as the bow thrust technology to complete the steering control. The side thruster is a propeller driven by motor in the transverse pipe at the bow of the cruise ship. This flexible propeller can push the water from one side to the other side and drive the ship to change the direction by means of the reaction force of sea water. Compared with the ordinary marine ships, cruise ships arrive at ports more frequently, and the requirements for the safety and comfort of tourists are higher. Therefore, the steering control technology of cruise ships is very critical. For ordinary marine ships, if there is no requirement for DP positioning, they have only one bow thruster. Moreover, cargo ships with large tonnage are fitted with only one axial flow side thruster at the bow. At present, all the Oasis-class luxury cruise ships adopt 5.5 kW side thrusters produced by Wärtsilä Corporation (Table 3), with four ones set at the bow of Oasis-class cruise ships (Table 1). The bow thrusters not only provide the cruise ships with unparalleled steering control and accuracy, but also greatly enhance the overall maneuverability of the cruise ships (Fig. 1).

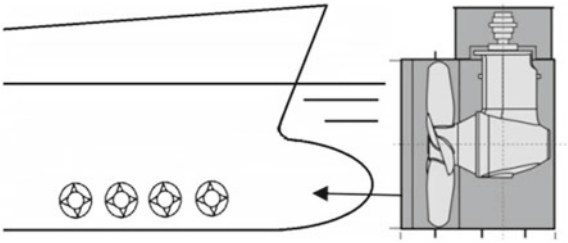

Fig. 1 Schematic diagram of the side thruster on Oasis-class cruise ships

4.3 Hull Stabilization Technology

Compared with regular cruise ships, the wind profile of an Oasis-class cruise ship is large when it is sailing. Severe sea conditions, random waves, various activities on board and acceleration will significantly affect the ship's stability, which will not only reduce the comfort satisfaction of tourists, but also affect the safety. Therefore, it is particularly important to install stabilizing devices on board. Ships may produce six kinds of motion when sailing at the sea: Swaying, surging, floating, rolling, pitching and yawing, in which rolling is most harmful to the sailing ship, so the ship stabilizing devices often refer to the rolling stabilizers. The Oasis-class cruise ships mainly adopt fin stabilizers to keep the ship stable. The principle is to use the lifting force moment generated by the fins in the process of sailing to offset the ship rolling moment, so as to resist the disturbance caused by waves and other factors. The fin stabilizing system consists of a control subsystem, a hydraulic subsystem and a mechanical subsystem, taking micro-gyroscope as the sensor to control the mechanical stabilizer through a computer. In case an Oasis-class cruise ship is in rolling motion when sailing under wind and waves conditions, the fin stabilizer can make corresponding rotation according to the disturbance law of waves under the action of the control system, so as to resist the wave disturbance by the lift force generated by the fin stabilizer, and to reduce the rolling of the ship (Zhu 2012).

Although the fin stabilizer technology has been applied in marine ships and engineering ships etc., the cruise ships are different from other ships. Its passenger transport and tourism attributes require extremely high safety and comfort during the voyage. In this case, the anti-rolling fin technology for ordinary ships cannot meet the requirements for the stability of large cruise ships. It is particularly critical how to customize the fin stabilizer according to the specific parameters of the cruise ships, and to avoid the excessively high resistance of the fin stabilizers onto the cruise ship when stretching while maximizing the rolling stabilization. Generally, the passenger capacity of an Oasis-class cruise ship is above 5000 people. The fin stabilizer technology can effectively maintain the stability of the cruise ship in complex sea conditions, provide security guarantee for cruise voyage, and provide tourists with high-quality travel experience.

4.4 Modularization Technology

Modularization technology was first applied in the building of military vessels. During the second world war, United States built a large number of military vessels, and the modularization technology gradually attracted attention, and other countries also researched and applied modularization technology in succession. Modularized shipbuilding concept was introduced in China in the mid-1980s and began to apply the modularization technology in military shipbuilding in the 1990s. Currently, the total number of 052C destroyers is up to 6, and the number of 052D destroyers is expected to be up to 12. In addition, a large quantity of 054A and 056 frigates has been built to achieve the goal of building a ship with multiple models. In civil shipbuilding, modularization technology has also been widely used, such as engine room module, health unit module and some superstructure modules. Apparently, modularization technology has been widely used in China, but the actual situation shows that the existing understanding and application of modularization technology are insufficient for the building of luxury cruise ships, especially Oasis-class cruise ships, which is determined by the building characteristics of the cruise ships themselves. For the hull structure, it can be divided into the main body and the superstructure. The main body refers to the part below the upper deck, which is surrounded by upper plywood, ship bottom and ship side, and used for power equipment, cargo, fuel, fresh water and other functional compartments. It is the main part of other ships. In addition to the main body of the cruise ship, the superstructure is more important. The visible area above the deck of the cruise ship belongs to the superstructure, including thousands of cabins, such as guest rooms, bars, restaurants, casinos and opera houses. Each cabin module is laid with piping and cable in advance in the professional supporting factory. With an outfitting rate of nearly 100%, and its building complexity and accuracy are much higher than those of other ships. Therefore, a breakthrough can be realized in cruise shipbuilding only when existing modularization technology has been further researched and innovated in.

The building engineering of an Oasis-class cruise ship is huge, and the building of a cruise ship usually needs tens of thousands of tons of high-strength and high-elasticity high quality steel. These steel materials will be cut into tens of thousands of individual components, including steel sheets, steel beams and other smaller components through numerous production lines and automation equipment. The assembly process is as shown in Fig. 2. On the single deck, the steel sheets, main beams and small members are welded to form the basic hull frame, and then welded to the bulkhead, column and ceiling to form a section module containing multiple cabin unit spaces. Generally, the section module is only as high as a single deck. At present, all major international shipyards adopt the prefabricated module building method to process the section modules, i.e., the circuit system and pipeline system are laid ahead of time at the section module stage, and reserved interfaces with the same sizes and shapes. After the installation of the outfitting equipment, the sections are stacked and welded into a block, and the outer surface of the block is coated. For example, the building of the “Harmony of the Seas” is divided into 90 blocks, the largest of

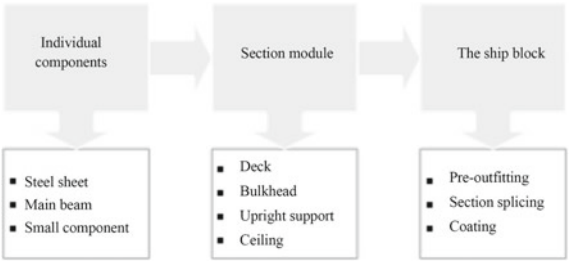

Fig. 2 Schematic diagram of modularized assembly process

which has the height of five decks and has 10 sections. Following the principle of building blocks, the blocks are spliced together to form a complete cruise ship hull building.

Modern shipyards generally separate hull construction and cabin construction. Cabin construction and interior decoration are completed by professional matching manufacturers, and finally, they will be hoisted aboard for assembly. Therefore, modularization technology is not only a building technology, but also the comprehensive embodiment of design and management technology (Wang and Chi 2003). For the current situation of the cruise shipbuilding in China, the establishment of an efficient system integration network is the premise and guarantee for the application of modularization technology. The nature of system integration is to optimize the comprehensive and overall layout and integrate various resources, so that each independent module unit can work after having been connected together, and the whole system has the lowest cost and highest efficiency. A mature industry is necessarily a highly integrated industry of equipment, technology and functions. Using advanced computer technology to perfect and optimize the design process is helpful to control the overall layout at the macro level and better guide the building process. Adopting advanced management modes and strengthening the close coordination and tacit cooperation between shipyards and supporting manufacturers are also very important for cruise shipbuilding (Pero et al. 2015).

4.5 Environmental Protection Technology

Oasis-class cruise ships are praised as “a moving city on the sea”. Thousands of tourists produce a large amount of domestic wastes in the course of their living, relaxation, sports and entertainment, which are generally treated by means of incinerator equipment (Wang and Chen 2010). A cruise ship requires large consumption of energy fuels every day. Insufficient burning of fuels not only leads to increase in operating cost, but also produces hazardous exhaust gas severely polluting atmospheric environment. On an Oasis-class cruise ship, engineers try to maximize fuel efficiency by reducing resistance. On one hand, according to principle of fluid dynamics, the hull of a cruise ship is usually designed to be a shape with wide rear and narrow front.

This design enables minimum level of undulation while the ship is cruising along and minimizes the resistance. On the other hand, while the cruise ship is sailing, there will be a great number of bubbles at the bottom of the spherical prow, flowing backwards along the hull, which can effectively reduce resistance to the hull. With the design of spherical prow and air lubrication technology, fuel efficiency can be increased by 5% approximately, thus fundamentally reducing emission of hazardous exhaust gas (Zhang et al. 2016b). Moreover, the cruise ship is equipped with the largest exhaust gas scrubber for marine applications- Wärtsilä integrated cleaning system which eliminates detrimental impurity by means of seawater in open and closed loop system, relying on state-of-the-art exhaust gas cleaning technology, thus effectively reducing emission of sulfur oxide and nitric oxide.

In addition to technologies of power, steering gear, stability, module assembly and environmental protection, the Oasis-class cruise ship utilizes a lot of high and new technologies, for example, global automatic positioning system capable of satellite navigation and automatic collision prevention, meteorological monitoring system comparable to prefecture-level city monitoring system, internet technology developed by a scientific and technological company, condition monitoring software, as well as fully automatic robot bartender and virtual staterooms. These high and new technologies not only improve information level, safety and operability of the cruise ship, but also provide tourists with intelligent, convenient, comfortable and luxurious touring experience. The Oasis-class cruise ship is a modern "castle on the sea" integrating various advanced technologies, which will shine more radiantly as a pearl on the crown of shipping industry.

5 Conclusion and Inspiration

With rapid growth of cruise tourism market development and cruise industry, cruise ships tend to be larger and larger. Arising of the Oasis-class cruise ship leads and reinforces such a trend. To be specific, inspiration includes the following.

5.1 Mastering Key Technological Requirements for Large and Luxurious Cruise Ships

An Oasis-class cruise ship has large tonnage and volume, and requires strong power system and operable steering gear system to enable fast speed and convenience of controlling direction. Furthermore, given that such a giant cruise ship has a complete variety of facilities and functions, and carries numerous passengers, it needs well-designed stabilization and shock absorption systems, so as to ensure stable operation and provide tourists with comfortable touring environment. Currently, low-carbon has become a globally agreed environmental protection concept. An Oasis-class

cruise ship also incorporates this concept into its design and building. Its pod electric propulsion system enables the effect of energy saving and emission reduction. On the whole, building an Oasis-class cruise ship often requires cooperation of supply chains on the basis of module assembly, which not only greatly improves building efficiency, but also meets personal needs of cruise lines. The Oasis-class cruise ship has been more successful than those cruises formerly built in terms of tonnage, passenger capacity, internal structure, standard of relaxation and entertainment, or in terms of advanced power, stabilization, steering gear and assembly technologies, ushering cruise industry in a new chapter.

5.2 Improving Engineering Management Level of Large Shipbuilding Projects

Organization and management of building of luxurious cruise ships, particularly Oasis-class cruise ships, is complicated systems engineering. Its specialized ancillary construction covers a far wider scope than that of ship industry, as it relates to hotel, culture, entertainment and arts.

The following issues will come out in connection to production management, safety management and cost control: management of over ten thousands of mountainous conduits, air ducts and cables; control of equipment suppliers and their fitting-out in order to ensure hundreds of contractors to deliver quality goods on schedule according to shipyard's intent; management of production and fitting-out process of thousands of accommodation quarters, deformation prevention in the course of sheet steel cutting, welding and segmental hoisting, control of shipbuilding precision, construction of propelling plant with high power, coordination of interior decoration; segmental arrangement to facilitate mechanical equipment installation; noise elimination and vibration reduction in cabin area, correct measurement of ship stability; understanding of specific requirements for luxurious cruise ships from classification society, the flag state of ship, International Labor Organization and the United States Coast Guard, understanding of requirements for installation of barrier-free access in the entire passenger cabin under Americans with Disabilities Act, understanding of the latest requirements for luxurious cruise ships from international ports; construction of quiet air conditioning for multistory application, construction of fire protection facilities, and construction of escape and lifesaving appliances on large population background; authentication of furniture and interior flammability test results, guarantee of food and health safety, and western high standard for staterooms for passengers and crew; understanding of how to read complicated technical specifications, and difference between signing a commercial contract for a luxurious cruise ship and a commercial contract for a cargo ship. Foreign practice of cruise ship interior decoration test is to specify the identity with cruise ship XX in the contract. If mother ship cannot be found, model room is generally taken as the standard for test in order to avoid needless disputes with ship-owner.

Building process should be strictly controlled. A ship-owner requires delivering the ship on the exact date specified in the contract, failing which the cruise lines will suffer tremendous losses. Therefore, shipyard take quite strict measures to control building process of luxurious cruise ships, and its production schedule is difficult to be changed. To prevent delay in delivery, the shipyard will refuse a change in order if such a change may result in extension of dock cycle. The ship-owner will also control quantity and form of changing an order. All changes have to be verified and approved by the owner's senior management. Cabin installation begins in the mid-term of dock and ends after trial trip. Clearly, cabin building accounts for the most proportion of entire shipbuilding process, and therefore control of its building schedule is more critical.

5.3 Studying the Latest Update of Cruise Shipbuilding Technologies in Advance

Cruise shipbuilding technologies represent advanced technological level of shipbuilding. Arising of the giant Oasis-class cruise ships lifts these technologies to a new height. International shipyards and cruise enterprises never stop pursuing technological innovation of cruise shipbuilding. With continuous improvement of technological level in ship industry, more and more new technologies will also be applied to giant cruise ships. For example, hybrid-power cruise ships driven by LNG are being built; with the development of nuclear energy technology for civil applications, nuclear-powered cruise ships will be not just a dream in the future. All these technologies can provide Oasis-class cruise ships with stronger and cleaner impetus, thus increasing ship speed and extending voyage. Additionally, now artificial intelligence (AI) has been developed rapidly and applied to diversified sectors. To use AI controlling system in an Oasis-class cruise ship is also a great innovation, not only improving operability of this "jumbo" cruise ship, but also improving intelligent level of the entire cruise ship. The arising of Oasis-class cruise ships maybe is only a beginning. There may be larger and more advanced cruise ships which will make amazing appearance in the future. To Chinese dockyards, each stage, from design, building to trial trip, requires strict and prudent management and control. To make breakthrough in terms of giant and luxurious cruise shipbuilding as soon as possible, Chinese dockyards must refer to successful experience of international dockyards, and learn lessons from failed building or severe accidents, so as to take precautions, in addition to careful analysis on technological difficulties in shipbuilding and tackle them one by one.

At present, China is still incapable of building luxurious cruise ships, and lacks related technologies and experience. However, China is actively preparing to build local cruise ships. In 2017, CSSC signed a Memorandum of Agreement with Carnival Cruise Lines and Fincantieri regarding the first large cruise ship made in China, declaring the beginning of building local cruise ship in China. As a great power

of shipbuilding in the world, China also has abundant experience of building large ships. China Shipbuilding Industry Corporation (CSIC) and CSSC have considerable technological foundation for stabilization technology that maintains ship hull stable and side thruster technology that helps ship to turn. However, overall design and building of luxurious cruises are still shortage of Chinese shipbuilding industry, and propulsion technology and module assembly technology applied to cruises have long been monopolized by foreign companies. Therefore, China should be active in learning building experience of Oasis-class cruise ships, on one hand learning technical practices regarding advanced engines, stabilization and shock absorption, low-carbon and environmental protection, informatization, as well as security and stability, on the other hand using the experience of module assembly technology by foreign dockyards for reference, so as to improve management level of cruise shipbuilding projects, particularly fine management level. Furthermore, we need to seek breakthrough in disciplinary study and core technology on our own, building local cruises from a high starting point, according to a high standard and with a high technological level.

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