THE NAVAL ARCHITECT

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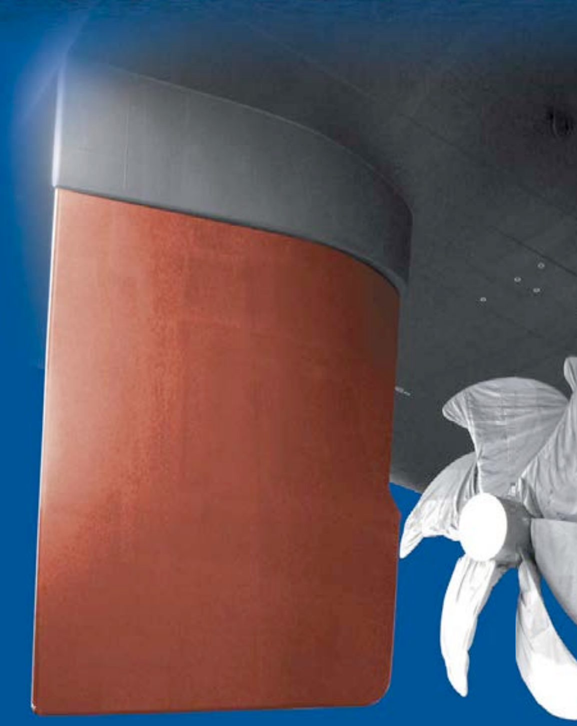

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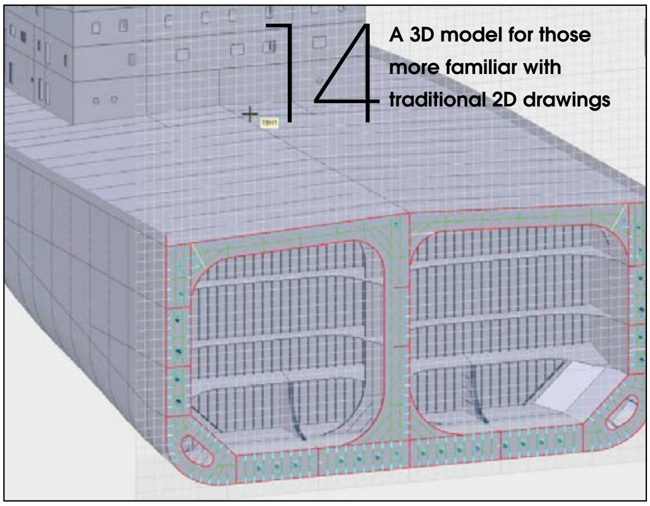

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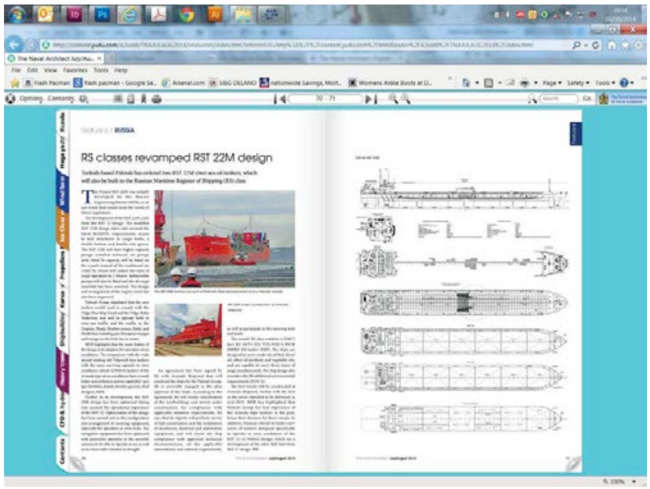

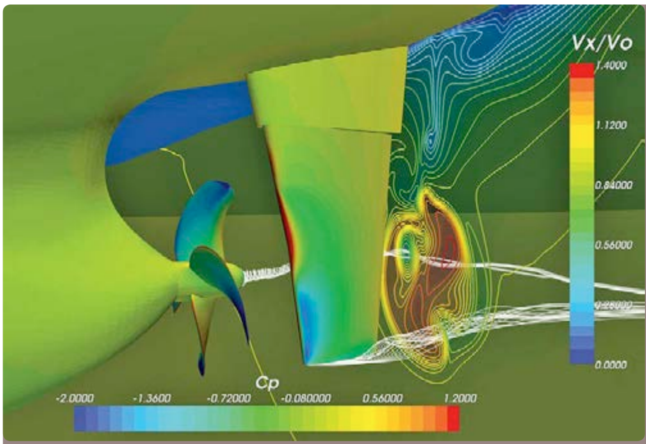

Is there an upside?

CFD could be a saving grace for the maritime industry's emission challenge

It is clear that 2017 will be a year to remember. For the maritime industry, attempts to combat climate change are being taken to new lengths; new regulations are coming into effect to prevent the transfer of invasive species, to protect passengers, and to permit safe polar cruises (to name but a few); and the transformative powers of CFD and 3D modelling may unleash new ways to save the planet, redefining the 'optimum' design of a vessel.

This issue takes heed of the changes currently taking place, outlining various challenges that designers face or may come to face as a result of new regulatory paradigms or new technologies.

The In-depth section of the magazine demonstrates the presence of these forces in the industry. On the part of technology, NAPA's work on software development illustrates the progress of a wider industry trend, the user experience (UX). Its UX development builds a new, iterative approach that centralises the user in the way software is created and aims to increase the speed of change, leading to better functioning design tools that meet the interface expectations of the 'iPhone generation'. On the part of regulation, Foreship's head of ferry design, Ari Huttunen, reflects on MSC 97 and how proposals on damage stability and survivability in the event of a collision, which stand to increase damages stability requirements, will force fresh trade-offs between various design criteria.

In a similarly user-centric approach to NAPA, Nicolas Bialystocki of Antares Shipping presents ways to incorporate crew feedback in the design process of a vessel with the aim of improving their living and working environment. His article, "From theory to practice: centring human factors and ergonomics in ships design", demonstrates how such an approach can be achieved, highlighting a PCTC case study and the changes made to improve workability and other human factors onboard. The key point here was the constant communication between crew, designers, shipyard and shipowner, bringing all stakeholders together to build the most efficient and most easy-to-live/work-with vessel possible.

> "The transformative powers of CFD and 3D modelling may unleash new ways to save the planet, redefining the 'optimum' design of a vessel"

This month's CFD & Hydrodynamics feature picks up on two contrasting uses of CFD technology, to simulate environmental effects and to monitor performance. Volker Bertram of Stellenbosch University and DNV GL summarises the current capabilities and limits of CFD for performance monitoring, evaluating the most important techniques in its use and where developments may follow. The second article, "Giant FLNG unit simulated in waves", brings the Australian CFD scene into view, focusing on AMC Services' analysis of how the world's largest offshore facility will be affected by different wave scenarios. Dr Max Haase of AMD Services believes: "CFD has not yet unfolded its considerable potential for the maritime industry in Australia."

The cruise industry finds itself under the lens of reporter Sandra Speares as she delves into the changing seascape of 2017. LNG's increasing presence onboard cruiseships is top of the agenda, but other developments including cybersecurity and the move of smaller yards that previously specialised in offshore ships into cruise shipbuilding feature. Wang Sun, reporter for *Ship Economy & Trade* builds on this feature, investigating the new joint venture design company formed by Shanghai Waigaoqiao Shipyard, China, and European cruise specialist Fincantieri.

This month's feature on propellers and thrusters also engages with changes in the cruise industry, but with an underwater perspective. Clive Woodbridge reports on ABB's target of the polar cruise market, how, according to the company, its Azipod units are well-equipped to handle the demands of polar duties safely and efficiently, and moves on to discuss new offerings from Rolls-Royce and Wärtsilä. *NA*

Deliveries

"World's largest hybrid" on the horizon

Color Line and Ulstein Verft have signed a letter of intent for the construction of a 160m-long 'plug-in' hybrid ferry, claimed to be the largest hybrid vessel in the world.

The vessel, provisionally named *Color Hybrid*, will operate the Sandefjord-Strömstad service between Norway and Sweden with a capacity of 2,000 passengers and 500 cars – almost doubling the capacity of the current ferry, *Bohus*, according to Ulstein Verft.

The vessel will be battery-powered, using electricity from onshore facilities or onboard generators to recharge. Its power arrangement allows the vessel to be solely run by battery power when travelling into and out of the fjord to Sandefjord, preventing the environmentally damaging emission of greenhouse gases, NOx and SOx.

Color Line has increasingly invested in shore-based power facilities, installing them in Oslo, Larvik, Kristiansand, and now Sandefjord, in an effort to become a "leader in European short sea shipping".

Trond Kleivdal, president, Color Line, says: "The focus on a new vessel with new green technology happens partly because the company, through the Government's maritime strategy, has received approximately identical conditions as their competitors in the Nordic region".

The vessel will be designed by Fosen Yard and is scheduled to begin operations in 2019.

Deliveries

First hybrid ferry for Canadian west coast

A new low-emission ferry has been delivered to Canadian shipowner Seaspan Ferries Corporation to operate between Vancouver Island and the British Columbia mainland.

Seaspan Swift is capable of running on diesel, LNG and battery power and is the first of its kind to enter service on the west coast of Canada.

Class society Bureau Veritas played an important part in the vessel's development, leveraging its considerable experience with LNG. Steve Roth, vice president of Seaspan Ferries says: "We are happy to be working with Bureau Veritas on this technical LNG/Hybrid project. Their partnership with Seaspan Ferries has helped make the design, approval, production and delivery of the vessels a success."

The ferry was designed by VARD marine and measures 148.9m in length. A sister vessel, *Seaspan Reliant*, is set to be delivered from Sedef Shipbuilding, Turkey, in early 2017.

Deliveries

LNG ferry for Tallink Grupp

The 212m LNG ferry *Megastar* was delivered by Meyer Turku Shipyard to the Tallink Grupp to start operations on the 29 January 2017, travelling between Helsinki, Finland and Tallin, Estonia. *Megastar* is claimed to be the most advanced fast ferry in the Baltic Sea. Using several energy saving technologies and burning a clean fuel LNG, *Megastar* is designed to be both fuel efficient and to comply with the current and future northern Europe's Emissions Control Area regulation.

Dual-fuel engines in gas mode produce 25% less CO_2, 85% less NOx and practically zero SOx and particles, compared to traditional diesel or heavy-fuel burning engines. The ferry also benefits from an advanced hull form developed by Meyer Turku Yard's naval architects who evaluated 35 different hull forms using CFD tools before selecting the final one.

The ferry has a capacity for 2,800 passengers and a service speed of 27knots. *Megastar* has three travel classes; Standard, Comfort and Business. There are separate business, standard, sitting and drivers lounges, seven different restaurants and cafés also pubs and bars, and a 2,800m^2 shopping retail area.

The ferry has double level loading and wider car deck access, which improves loading and unloading time. Passengers can also access the parking garage during the voyage.

Alternative propulsion

Potential for Wind Propulsion

Study on the analysis of market potentials and market barriers for wind propulsion technologies for ships has recently been released and can be downloaded from www.cedelft.eu under their list of 2016 publications.

The study, commissioned by European Commission, DG Climate Action, and undertaken by CE Delft, Tyndall Centre, Fraunhofer ISI and Chalmers University, analyses the barriers to the development and uptake of wind propulsion, it considers possible actions to overcome these barriers and estimates their potential emission saving, including associated economic and social effects.

One of its main conclusions was that "In 2030, the market potential could amount to around 3,700–10,700 installed systems on bulkers and tankers, associated with approximately 3.5–7.5tonnes CO_2 savings and 6,500–8,000 direct and 8,500–10,000 indirect jobs." *NA*

Bloc tension continues

Emissions and how to tackle them have continued to ruffle feathers among interested parties since the turn of the year, as the long running saga of bloc regulation versus international regulation continues, writes *Sandra Speares*.

1 January 2017 saw the introduction of new rules on operating in Polar waters, and the new mandatory IGF code for ships using gases or other low-flashpoint fuels.

If some industry analysts believe the IMO's strategy on CO_2 is sufficiently aggressive, European authorities, not to mention environmental groups, do not agree. The European Parliament's environmental committee sought to put the pressure on in December when it agreed to include emissions from shipping in the EU emissions trading system from 2023 if the IMO did not produce a further global measure to curb greenhouse gas emissions by 2021.

The International Chamber of Shipping (ICS) says the decision will polarise and impede current discussions on additional CO_2 reduction measures at the UN International Maritime Organization (IMO). ICS believes emissions-trading is inappropriate for international shipping, which mostly comprises SMEs typically operating less than 10 ships.

"The EU ETS has been an abject failure. Its unilateral application to global shipping would create market distortion while generating trade disputes with China and other Asian nations, as happened when the EU tried unsuccessfully to impose its ETS on international aviation," said Simon Bennett, ICS director of policy and external relations. The plenary of the European Parliament is expected to vote on the Committee's report in early 2017.

IMO secretary general Kitack Lim intervened in the debate, warning that "a final decision to extend the EU-ETS to shipping emissions would not only be premature but would seriously impact on the work of IMO to address GHG emissions from international shipping. Inclusion of emissions from ships in the EU-ETS significantly risks undermining efforts on a global level."

This prompted a response from environmental NGOs at IMO. Faig Abbasov, clean shipping officer of Transport & Environment (T&E), a member of the Clean Shipping Coalition, said: "It is wrong for the head of the IMO to condemn the European Parliament's actions, when it has the direct legitimacy of European citizens, and is working hard to protect those citizens from the impact of shipping's ever-increasing contribution to climate change. We are not aware of Mr Lim writing to those countries and industry bodies that have consistently been blocking progress on ship GHG emissions at IMO for years; it appears as if he is siding with them now."

The issue of CO_2 emissions has always been controversial and Tom Strang senior vice president, maritime affairs at Carnival says the general industry position is clear in that it makes more sense for the IMO to take the lead on the issue. "It would be challenging," he says, "to see how you could get regional CO_2 regulations for what is a global problem to align with a global system that the IMO is developing. While there is an understanding that pressure will continue to be brought to bear by green interests, we would prefer to see a solution that is global in its nature. The IMO is taking action and has an aggressive campaign to do that."

The Monitoring, Reporting and Verification (MRV) process is starting and emissions are being recorded. By 2023 there should be a mechanism to regulate greenhouse gas emissions within the IMO framework. "The industry is looking closely at the potential shape of the mechanism and the costs involved as well as the impact involved," says Strang. "Clearly all the emphasis that has gone into technical solutions to save fuel and look at cleaner fuels is going to be important in that discussion and the challenge will be: does the solution you choose increase or decrease greenhouse gas emissions? There is a lot of debate around that."

Meanwhile, the mandatory Polar Code for ships operating in Arctic and Antarctic waters, entered into force on 1 January 2017, and its requirements, which were specifically tailored for the polar environments, go above and beyond those of existing IMO conventions such as MARPOL and SOLAS, which are applicable globally and will still apply to shipping in polar waters.

Both the Arctic and Antarctic are becoming increasingly popular tourist destinations. These challenges need to be met without compromising either safety of life at sea or the sustainability of the polar environments.

The Polar Code sets out mandatory standards that cover the full range of design, construction, equipment, operational, training and environmental protection matters that apply to ships operating in the inhospitable waters surrounding the two poles.

Protective thermal clothing, ice removal equipment, enclosed lifeboats and the ability to ensure visibility in ice, freezing rain and snow conditions are among the Code's mandatory safety requirements. The regulations extend to the materials used to build ships intended for polar operation, and all tankers under the Code will have to have double hulls. From an environmental perspective, the code prohibits or strictly limits discharges of oil, chemicals, sewage, garbage, food wastes and many other substances. *NA*

Shipbuilding

Romanian yard upgrades for specialist vessels

Vard Tulcea Shipyard, Romania, has signed an agreement with Pemamek for the delivery of a 12m thin plate panel line, advancing the yard's production of special cruiseships and other vessels requiring thin plate panels.

Delivery includes a thin plate panel line with a web mounting and welding solution; a hydraulic one-sided welding station; a panel cutting, blasting and marking station; and an integrated stiffener mounting and welding system.

Vard Tulcea Shipyard, Romania, is set for a new thin plate panel line

In addition, the panel line will be accompanied by a PEMA robotised welding station. This station has been specifically designed to weld pre-assembled T-beams but also other secondary structures onto the panels, according to Pemamek. Each robot is equipped with Lincoln PowerWave power sources and is programmed with Pemamek's own weld software, WeldControl 200 Create.

Mr. Marcel Băleanu, VP Commercial from Vard Tulcea says: "Vard Tulcea selected the advanced PEMA panel line to support our future needs to produce thin materials. The delivery enables us to manufacture high-quality thin panels that are particularly needed for special ships like cruisers."

Pemamek will construct the shipyard's solution at its new development and production premises in Finland. It is due to be installed at the yard in the summer of 2017.

www.pemamek.com

CFD & hydrodynamics

Dassault purchases CFD specialist

Dassault Systèmes has acquired a company specialising in dynamic fluid flow simulation to enhance its multiphysics simulation offering.

Next Limit Dynamics' technology is used to predict and enhance the performance of complex designs exposed to fluid flow, and will be added to Dassault's 3DEXPERIENCE platform.

"For nearly a decade, we've developed our Lattice Boltzmann simulation technology, XFlow, to extend the applicability of CFD across multiple industries for challenging applications," says David Holman, general manager, Next Limit Dynamics. This, when coupled with the company's "disruptive methods", continues Holman, avoids time-consuming preparation tasks that may otherwise have to occur for traditional CFD approaches, leaving more time for design evaluation and optimisation.

Alain Houard, vice president marine & offshore industry, Dassault Systèmes, touches on the impact this purchase will have on the marine segment of Dassault's business. He states that "acquiring Next Limit Dynamics provides the opportunity to integrate XFlow into the 3DEXPERIENCE platform where it can be coupled with other cutting-edge Dassault Systèmes technologies to provide industry-leading experiences for designers and engineers in the marine industry."

Next Limit Dynamics is a young, Madrid-based company. Its 2015 revenue was approximately €1.6 million (US$1.7 million).

www.3ds.com

Scrubbers

First for Chinese scrubber manufacturer

Shanghai Bluesoul Environmental Technology has received approval in principle (AiP) from DNV GL for its BlueSulf scrubber system.

This AiP is the first received by a scrubber in accordance with the new DNV GL rule set and is also the first for a Chinese scrubber manufacturer, demonstrating its technical feasibility to the class society.

The system is a hybrid, capable of running in open loop or closed loop modes. It consequently offers operators more flexibility when adjustments need to be made to meet differing port requirements or changes in water salinity.

According to DNV GL, the system can operate on sea water and fresh water, reducing the sulphur content of exhaust gas to 0.1%. This capability ensures compliance, both with current Chinese Emission Control Areas, which already stipulate that sulphur emissions should be capped at 0.5% in 11 ports, and with the approaching global sulphur cap.

"We are very pleased to be the first Chinese supplier to receive this AiP and it demonstrates


Illustration of *Viking Grace* with with a 24 x 4m Norsepower Rotor Sail

BlueSulf's design in compliance with DNV GL class rules requirements, by using the sodium alkali method to clean exhaust gases. We have signed three scrubber projects with Chinese and European owners and we are also in negotiations for several potential retrofit and new building projects," says Jacky Chow, chief operating officer, Shanghai Bluesoul.

DNV GL will continue to work with Bluesoul, providing advisory services such as hardware-in-the-loop testing, simulations using the DNV GL Complex Ship Systems Modeling and Simulation (COSMOSS) tool, and CFD analyses.
www.shanghaibluesoul.com

Wind power

Rotor Sail for Viking ferry

Norsepower Oy Ltd., has signed an agreement with Finnish Viking Line to install its Rotor Sail design on the 218m *Viking Grace* LNG cruise ferry currently sailing on the Turku–Mariehamn–Stockholm route.

The cruise ferry will be fitted with one medium-size 24m high and 4m diameter Rotor Sail unit. It is hoped that this technology will reduce the ferry's carbon emissions by about 900tonnes per year: equivalent to a saving of 300tonnes of LNG fuel per year.

This project has received just over €1.5 million (US$1.6 Million) funding from the European Union's Horizon research programme.

Norsepower Rotor Sails are currently available in three sizes with sail heights of 18, 24 or 30m. They are delivered as a full-service solution that includes both delivery and maintenance of the hardware and software components.
www.norsepower.com

March of the digital native

3D modelling and demands for improved user experiences (UX) are changing the way shipbuilding software is developed. Joonas Kuusela, product owner, team leader, hull team, and Elina Uusimäki, director of customer experience, share how NAPA is developing tools for digital natives and a changing design paradigm

In 2013, NAPA set out to develop technology that met the needs of modern ship designers. The goal was to create 3D modelling technology that delivered a more streamlined and user-friendly design process, and which could easily store data and share it with other systems; software up to this time had required architects to design ships section by section in 2D.

The aim of the new software was to create a single 3D model for designers to collaborate on that could then be easily checked by class society software. At the time, new rules from class societies were increasingly requiring 3D models, so it was clear that a great deal of value could be added with the creation of a fully 3D system.

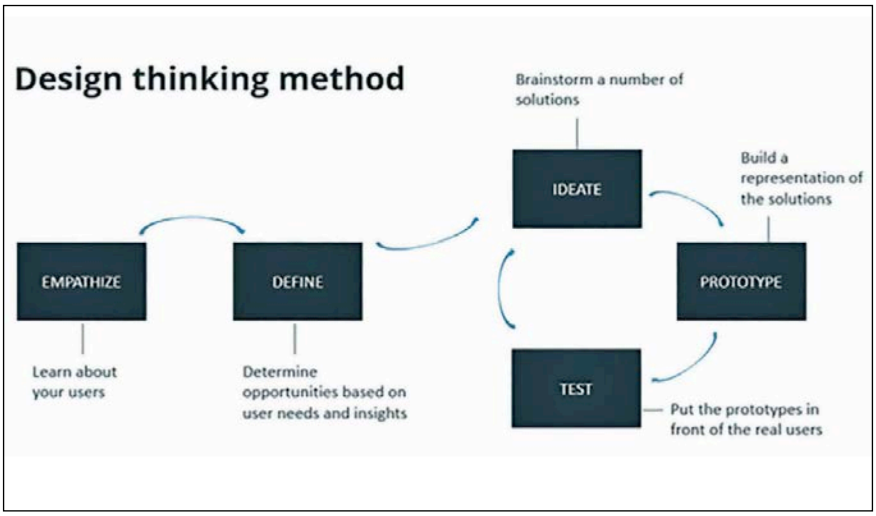

Figure 1: A design thinking method puts the user at the centre of developments

This 3D move came in response to the increasingly challenging environment in which designers operate. As market, legislative, and owner-driven requirements change, ship designers are on the front-line, responding and making sure that their designs are up to scratch. To keep pace, the tools they use needed to enable quick design changes, and so a significant re-tooling was becoming necessary.

At the same time, developers at NAPA were aware of a paradigm shift within the world of enterprise software. Previously clunky interfaces were becoming friendlier and faster to use, echoing the pioneering user experience (UX) design of the iPhone, which was blazing a new trail in consumer UX design. There was a growing realisation that the enterprise tools that professionals would spend nearly half their waking hours using needed to offer the same quality of user experience. In other words, users were beginning to appreciate and demand a better experience.

The challenge that followed was finding the right level of efficiency (high) and ease of learning (much higher than before) to balance the ship design tool for design requirements and user requirements. It had to be powerful, efficient and flexible, but also more comprehensible, perhaps even enjoyable; why couldn't it be pleasant, even fun to use?

However, while the world of 3D design was dawning, its relative 'newness' posed an additional challenge when helping users to adapt to its use. While many other sectors had adapted to 3D design long ago, many in shipping were used to starting with 2D drawings, often using pen and paper. This meant there was a need to demonstrate the speed and flexibility of 3D design without losing personnel to the confusion of a more high-tech approach.

NAPA wanted to take advantage of the new technological user interface capabilities to provide a better 3D modelling experience for its system's users. Given that 95% of newbuilds are designed at shipyards that use NAPA software, the software needed to meet the demands of a hugely diverse user base with a huge variation in terms of tasks performed, working environments, and cultural contexts.

A new approach

NAPA adopted a development process that put users at its centre, aiming to ensure that the end product met the needs of the modern maritime industry and its new digital native designers. This process is called 'design thinking', and is a guiding philosophy used by many businesses, such as IBM, to solve problems by maintaining focus on user experience, and iterating accordingly.

Taking cues from Agile methodology (an ongoing and iterative approach to project management), NAPA began a process that focused on breaking the stages of software development into small, fully functional chunks – known as minimum viable products or MVPs. This was combined with the creation of early prototype mock-ups that could validate whether assumptions about usability were correct without having to wait for a final product. Such an approach contrasts traditional 'waterfall' methods of development where a product is designed to a brief and user feedback is only available once it is finished.

This style of development consequently requires an intensive research phase with users at the centre, followed by rapid, iterative prototyping that generates user feedback as quickly and frequently as possible.

This built on previous work that had gone on before to examine how to reduce errors in using software. The principle remained the

same – to study how humans interact with electronic systems (a field of study known as cognitive ergonomics) and try to address the mistakes made when using the software. What was different here was the scale of the focus, and the breakthroughs being made. This went from an exercise in reducing errors to thinking about the overall experience.

The design thinking method dovetails with the scrum model of software development, with phases of rapid prototyping and user development.

Consumer software in general can tolerate more errors than professional software. In providing software for professional naval architects, it is vital to avoid errors while making sure that users are absolutely in control. These kinds of errors relate to people clicking in the wrong place or being unable to use a certain feature, but different errors can occur in different places.

In practice, reducing errors goes hand in hand with creating a pleasant user experience. This is where it connects to Lean manufacturing, making the process aligned, error free, and transparent, so that one individual cannot make errors.

NAPA has the unique focus of only developing software for maritime industry. This gives us a clearer focus than many other software developers for whom the needs of ship designers might be secondary to other groups of users.

Stages of user involvement in NAPA UX

1) Empathise

When there is demand for a new powerful and user-friendly product or feature, NAPA starts by gathering understanding and inspiration from existing products and benchmarks.

The overall idea is to understand the objectives, usage context, user pain points, and cognitive task flow of users before jumping into building a solution for how a new feature is implemented, for example. It is then recognised that the reality of the demand is still too complex to get all details right without iteration. Therefore, the intention is to get to the feedback loop quickly.

In order to help users talk about details of software interactions (which is not something users typically are very conscious of) the team uses demos and screenshots to make discussions tangible. They then compare and analyse benchmark user interfaces (UIs) together with end-users.

All phases apply a suite of methods, selected by applicability, priority questions to answer, and availability. There are qualitative, quantitative, behavioural, and attitudinal methods available.

For example, methods used at NAPA in the understanding and inspiration phase are:

- Studying feedback from users over the years about the existing product and user interface
- Analytics of queries to Customer Service
- Observing and interviewing users while they are using the current solutions – being in the room with users is the method that NAPA finds most valuable
- Benchmarking and comparing other solutions, both from within the domain but also gaining inspiration from interactions and standards from other domains. Similar interactions might be needed, for example, when comparing insurance options, online stores, and in other modelling and engineering software
- Sketching ideas of new solutions using wire-frame models, and putting those early ideas in front of end-users to test comprehension and help provoke a detailed discussion

The challenge in this phase is that people are not naturally aware of their needs and biases on a detailed level, which can make it difficult for them to recall and articulate their exact thoughts and feelings about using a product.

Henry Ford's 'faster horses' dilemma springs to mind, as how do you come to the conclusion that customers need a car when all they're asking for is a faster horse? For this reason, it is important to note this is an 'empathise' phase, and not an 'ask what the users want' phase.

2) Define, ideate, prototype

At this stage personal descriptions are created to summarise a user's surroundings, tasks and needs; a typical user journey is defined; design tenets and principles are defined; and a participatory design workshop including the whole team and internal stakeholders is organised (including sales, product management and developers). The NAPA team then continue with the final, workshopped ideas to define them in UI prototypes for the next stage: 'Prototype, test learn'.

There are two examples to put this stage into context. The first builds on customer interviews. NAPA identified some general 'pain points' about tracking the status of a NAPA project when designers open their database: i.e. is it the as-built version or maybe a database that has just been a working version for somebody in the team? These kinds of observations were then worked on in internal ideation and sketching workshops. By drawing quick paper sketches, or using prototyping tools, the team ideated several potential solutions to tackle the pain points including a log view, a status checklist and the potential to leave comments for colleagues? The

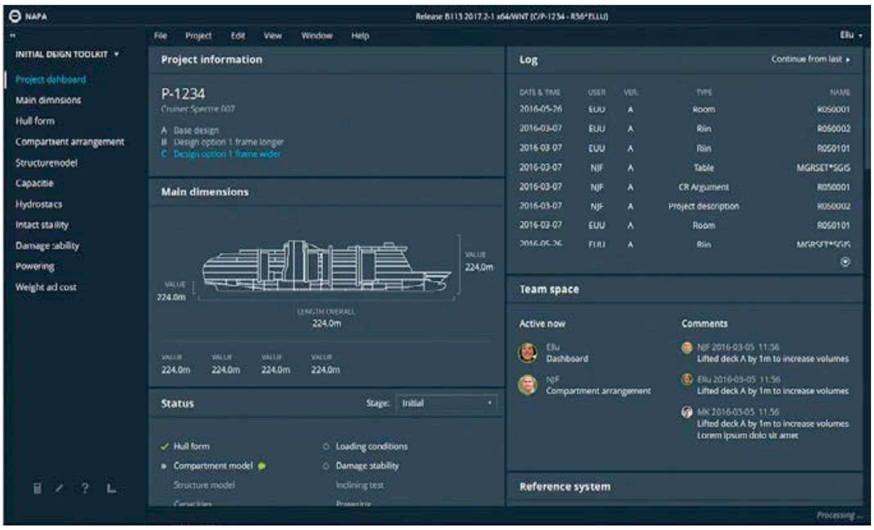

Figure 2: A to-do list or design log was added to the dashboard in response to people opening a document and thinking what version is this and what do I do next?

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process then continued with prototyping and feedback loops, both internally and with users, to find the most suitable candidates among these ideas. The end result was the inclusion of a progress log/to-do list that appears when the NAPA software is opened (Figure 2).

The second example illustrates the importance of individuating responses. So, in order to help people who are familiar with reading 2D paper drawings to use the 3D software, NAPA created a 3D model view that is as close as possible to a traditional drawing view while still being 3D. This can be seen in Figure 3.

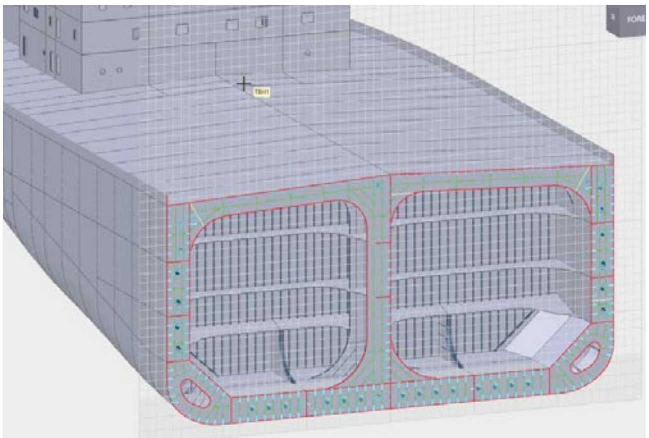


Figure 3: A 3D model for those more familiar with traditional 2D drawings

3) Prototype, test, learn (repeat)

The next stage is to continuously test prototypes to gain constant feedback and never lose sight of the user experience. This iterative loop continues in software development process settings all the time. However, occasionally there is need to take a more holistic view and get back to Empathise, Define and Ideate stages and begin the process once again.

Some methods used in this stage include:

- UX Lab with internal users: the internal UX Lab is occasionally more like a hallway test, where you just quickly get fresh eyes to look at the UI idea to see if it is intuitively understandable
- Releasing products and keeping constant feedback discussion open with end-users (team members frequently visit customers and participate in sales activities to gather feedback directly from the end users.)

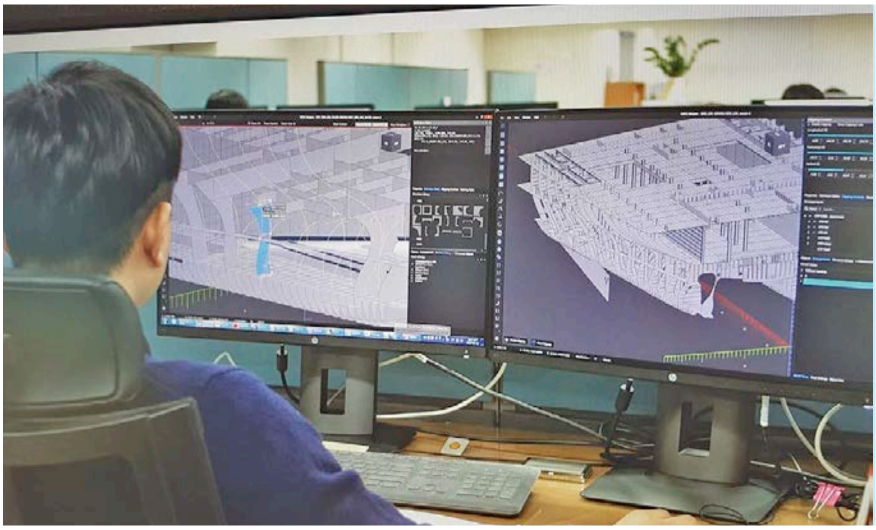


Figure 4: The user takes centre stage in NAPA's software development. A designer from Hyundai Heavy Industries, Korea, can be seen working with NAPA Designer and its interface

Most tests include some interview questions, test tasks, and scenarios, and closing interviews and open dialogue with the user to get their improvement proposals and involve them in ideation. But depending on the questions that need answering, different kinds of tasks and co-creation exercises are used.

The most efficient way to capture usability problems, and still have time and money to fix them, is to iterate often, qualitatively, with small samples. Although NAPA has a limited user base compared with the likes of Facebook and Google, it is able to leverage the great communication it has with users to gain valuable insights. Some teams have regular tests ongoing, every 1-2 months, involving a small number of users to test a feature, UI mock up, or whatever is being worked on at that moment. There are always several fixes made based on a test. These can range from little fixes, such as changing texts if they were confusing, to revising an entire feature if it did not serve its intended purpose.

Some mock-ups to describe design ideas are created and tested internally on a weekly basis. Almost every customer encounter will at some point help NAPA observe how users cope with some of our design ideas.

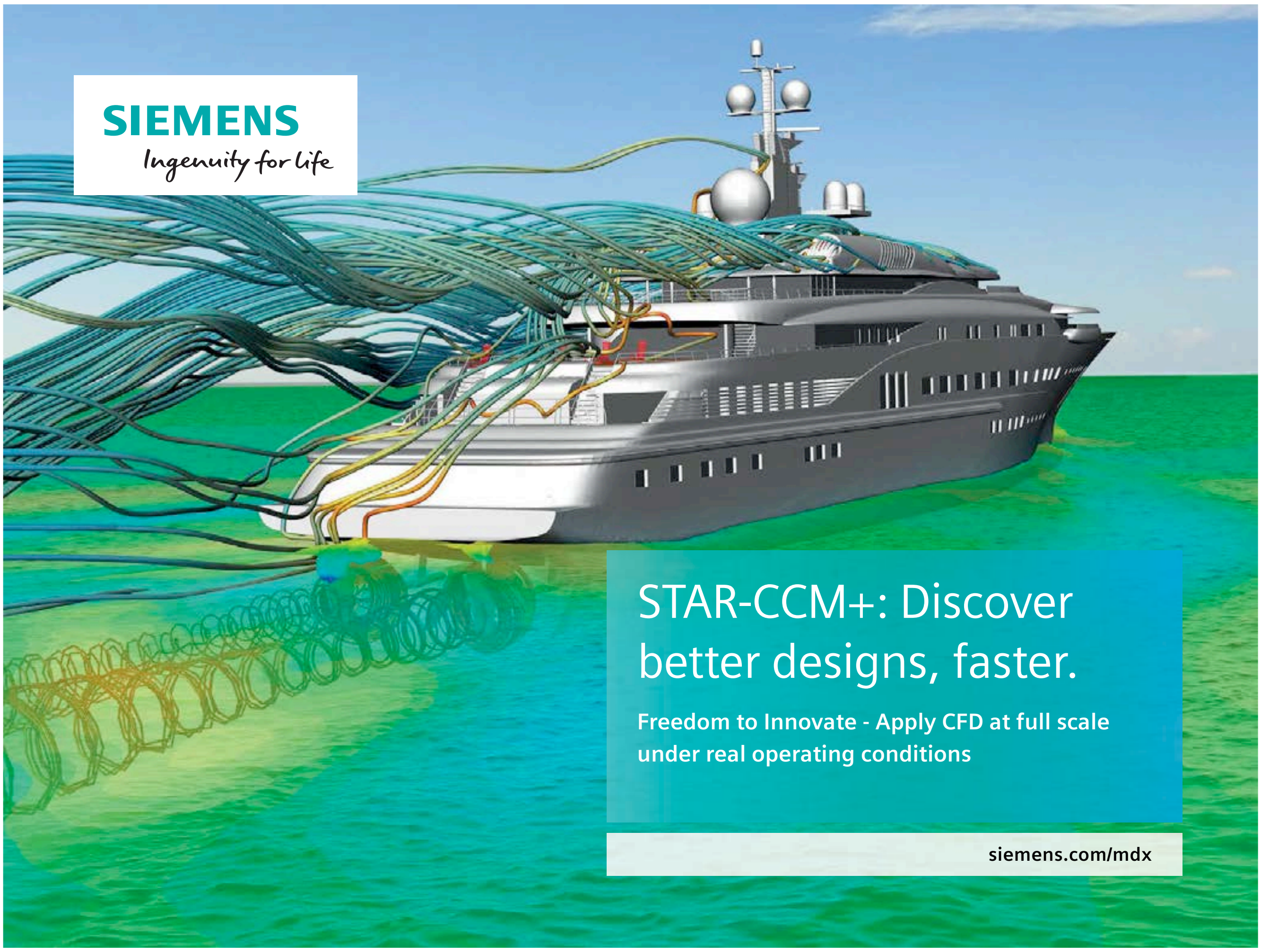
The developers who are experienced with user testing have learned to observe users spontaneously, paying attention to commands used, and examining whether, for example, they are aware of some more efficient shortcuts, or whether there are any ergonomics problems. It becomes second nature to pay attention to details users themselves would not be able to consciously give feedback about.

Most of the inspiration for NAPA user testing has been taken from Information Architect and author Steve Krug's lifework. For example, the book "Rocket Surgery Made Easy" is very tangible and gives a pragmatic guide to involving users in an iterative design process.

What happens next?

The design thinking method means that rapid prototyping - with user experience at the centre - is ongoing. The iterative process never really stops. And so, while NAPA Designer is being used today to enhance design processes around the world, the design thinking process ensures that user data is captured to continually enhance the software.

It is not just the software development teams and our graphical user interfaces that could make use of these methods and processes, but this is just the beginning. NAPA is starting to look systematically at the whole customer journey, and improving our customers' experience across all touchpoints. *NA*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New route to compliance for ferries

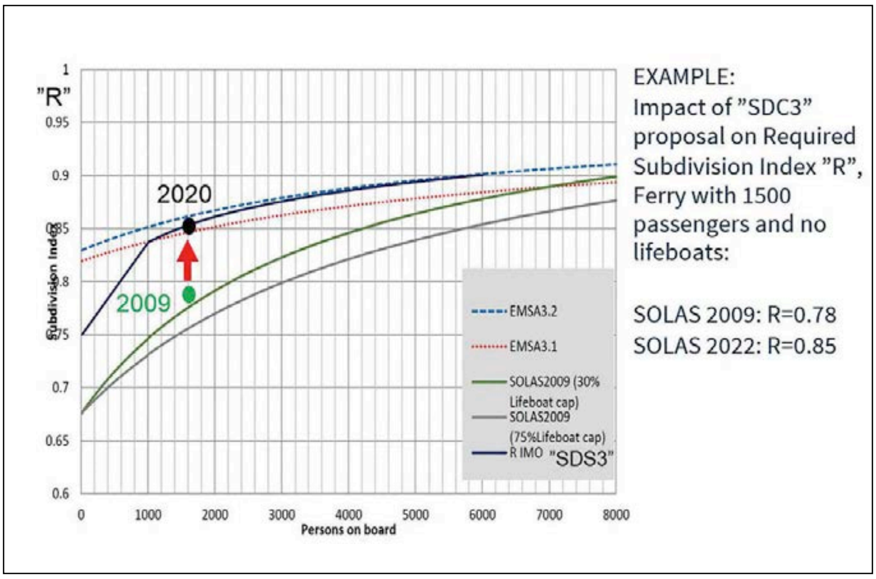
Emerging ferry safety regulations at the International Maritime Organization call for trade-offs between different design criteria. This leaves a sometimes tricky path to compliance for owners and operators, says naval architecture and engineering consultancy Foreship

Passenger ship safety was high on the agenda at the IMO's Maritime Safety Committee meeting MSC 97 in November as regulators pushed forward with new proposals on damage stability and "survivability" in the event of a collision. For the moment, changes to the rules must wait, with further work on the proposals deemed necessary before the MSC meets again in June next year.

As proposed, the new regulations will apply to all passenger ships contracted from 2020, or with keels laid from 2022, or delivered from 2024, and will supersede previous SOLAS (2009) provisions. The safety proposals, which have involved work by the European Maritime Safety Agency (EMSA), flag state representatives, ship operators, designers and builders, have focused on a ship's ability not to founder following a collision. The key objective has been to achieve a significant increase in the Required Subdivision Index 'R'.

"Damage stability is about ships not sinking in the event of a collision or grounding," explains Ari Huttunen, head of ferry design at Foreship. "The current legislation, embodied in SOLAS 2009, is based on probability and presented as an index – the Required Subdivision Index 'R'. It must be shown by calculations that a certain ship design exceeds the value of 'R'".

In the SOLAS 2009 regulations, the calculation of the 'R' depends on the number of persons onboard and the total lifeboat capacity. The formula penalises ships which have fewer lifeboat seats than the total number of persons onboard which, in practice is the case on every passenger ship, as a large proportion of the persons onboard will need to use life rafts. This, says Huttunen, places limits on designers, and especially on ferry design.



A comparison of requirements

"As proposed, the new regulations will raise damage stability requirements on new ferries," explains Huttunen, "but they will include a different way of calculating 'R', so that the number and capacity of lifeboats onboard is no longer a factor in the calculation."

Huttunen notes a recent surge in demand for passenger ship design consultancy services, as clients seek guidance on what the new regulations will mean from a practical point of view, not least because there are no easy options towards compliance. Huttunen explains that meeting the new regulations is likely to involve trade-offs between various design criteria, with a complex optimisation process necessary to offset gains made on one hand and drawbacks on the other.

Increasing the freeboard of a ferry, for example, should improve her damage stability because she would be able to take in more water before potentially capsizing or sinking. However, damage stability may also be improved by increasing the beam which increases initial stability, i.e. the metacentric height (GM), and reduces the risk of capsize.

However, the adverse result is a shorter roll period. This is uncomfortable for passengers, particularly on upper decks and in heavy seas, and also risks personal injury and damage to cargo, fixtures and fittings. Ferry designers, Huttunen explains, therefore aim for relatively low GMs to improve seakeeping, and an optimisation process is required to find the best compromise between freeboard and GM in the applicable seakeeping range.

A few weeks before the November MSC, Huttunen presented a paper at Interferry's Manila conference in which he revealed details of recent work completed on a theoretical ferry designed with colleagues at Foreship. The project had been set up specifically to see what design steps were required to ensure that a 1600-POB ferry would comply with the likely SOLAS 2020 regulations.

The ferry, with novel evacuation systems without lifeboats, was designed for 1,500 day-passengers and 100 crew. It had a length of 150m, a breadth of 25m, a depth to the vehicle deck of 9m, a draught of 6m (and therefore a freeboard of 3m), 700 trailer lane-metres, hoistable car decks and an electric dual-fuel propulsion system.

A key objective of the work was to optimise the design variables to achieve the required increase in 'R' from 78% to 85% as required by the proposed SOLAS 2020. However, it was also necessary to make sure that the vessel's "survivability" met extremely demanding water-on-deck requirements as set out in the Stockholm Agreement, 1996. This was where the design team started their optimising.

Foreship's naval architects confirmed that the Stockholm Agreement water-on-deck regulations were far more demanding than the existing rules set out in SOLAS 2009. The ferry design not only complied with both but was also found to be compliant with the forthcoming SOLAS 2020 rule proposal. This emphasises the significance of the Stockholm Agreement being phased out.

The ship designers also examined ways in which the ferry's main dimensions could be optimised in relation to other variables including beam, freeboard and subdivision. Based on a draught of 6m, the effect of increasing the beam by 50cm to 25.5m or raising the freeboard by 20cm each reduced the GM requirements by about 10cm.

Next, the team looked at the effect of installing two pairs of partial subdivision bulkheads on the vehicle deck. This resulted in a GM reduction of about 15cm, a significant effect considering the minor impact on tonnage or lightweight. The downside is the reduced extent of the cargo lanes along the ship's sides.

Overall, Huttunen and his colleagues reached a number of useful conclusions that will be important for ship design when working in compliance with the new SOLAS 2020 regulation. These include:

- Effective subdivision should not affect passenger capacity
- Too much initial stability could cause discomfort onboard, but this can be addressed by optimising various design criteria

Ferries in Europe, particularly those operating in northern waters, are very safe these days. However, further improvements can always be found, Huttunen observes. "For designers, owners and operators, the task at hand is to work within the trade-offs that the new regulations imply and optimise the overall safety and efficiency of passenger vessels." *NA*

SOLAS 2009 rules that the Required Subdivision Index 'R' depends on the number of persons onboard and the total lifeboat capacity of a ferry. This will no longer be the case according to proposals for the incoming SOLAS 2020 regulation

From theory to practice: centring human factors and ergonomics in ship design

Analysis of human factors and crew participation in the design process can improve onboard working environments, safety and efficiency. This can be seen in a real-life case study of a PCTC vessel, writes Nicolas Bialystocki, tech. department, Antares Shipping

The design and construction of *Harvest Leader*, a pure car truck carrier (PCTC) vessel delivered in October 2014, exemplifies the practical and successful consideration of human factors and ergonomics (HF&E) in ship design. Various changes relating to workability, habitability, maintainability, survivability, controllability, affordability, communication and user empowerment, as well as professional and psychosocial aspects were made throughout the build, incorporating crew-based feedback and design suggestions to deliver better working and living environments for those onboard.

Numerous rules and regulations exist in the shipping industry, and many of those are related to the human element. However, these regulations represent a minimum threshold for crew safety, efficient vessel operation and maintenance, comfort etc. This case study, contrastingly, presents examples which exceed the regulations provided.

Figure 1: Watertight door with slamming spring and one wheel for easy handling

The design process

The crew were encouraged to pass their feedback, both the good and the bad, to the ship's manager and subsequently to the shipowner with their proposals for any design improvements. In some cases the crew passed them directly to the shipowner's design team. Upon receiving a request for a design improvement, the shipowner's design team passed it to the shipyard with, on occasion, a proposed solution. Once a solution was agreed upon between the owner and the shipyard, the loop was closed by informing the crew.

Every modification to the PCTC vessel design was agreed upon and recorded between the shipyard and the owner, and during the detailed design stage (the most prolonged design phase) a total of 1,716 design modifications were applied, each of these related to the HF&E dimensions of ship design.

The design solutions that follow present an abbreviated list of the PCTC vessel's HF&E innovations and reflect solutions regular PCTC vessels are generally lacking.

Simplifying work

For improving teamwork, the vessel was packed with telephones in every cabin and working room, exceeding relevant rule requirements. Public address speakers were added in each cargo deck, with clocks throughout the accommodation public spaces.

For ease of use, weather and watertight doors and access hatches were designed with one operating turning wheel instead of multiple dog clips, and all of the doors were arranged with a slamming spring to catch what is a heavy steel door before tightening. This configuration acts to reduce the exertion needed to close the door, as the user is relieved of having to press the door and turn the wheel simultaneously (Figure 1). In addition, all doors and access hatch covers were designed so that they could only be opened away from the cargo space,

TECHNICAL PARTICULARS	
Harvest Leader	
Length overall:	199.95m
Breadth:	35.4m
Draught (design):	9m
Draught (scantling):	10.6m
Deadweight (design):	11,766tonnes
Deadweight (scantling):	20,941tonnes
No. of car decks:	13 (4 liftable)
Car deck area:	62,550m^2
Car capacity:	7,712CEU
Service speed:	about 20knots
Cruising range:	about 29,000nm
Complement:	32 + 6 persons
Flag:	Bahamas

preventing any person from hitting a car by mistake.

In a similar fashion, all hull piping systems were designed to pass through the ship's sides so not to disturb cargo loading and unloading. Where the cargo hold had a wall boundary, the fittings were recessed to prevent penetration and interference of the cargo space. Sounding pipes were also housed inside deck supporting pillars, protecting both the pipes and the surrounding cars.

Further design optimisations were made to the vessel's liftable decks. These decks were divided into panels, with each panel fixed on semi-auto stoppers at three different heights. Each of the stoppers was painted a different colour and colour-coordinated with the correct pulling ropes for the stoppers, limiting the risk of a crew member pulling the wrong rope.

Fixed ramps and corresponding deck openings inside the cargo hold were arranged with kick plates on each side of the ramp to avoid fittings such as cargo lashing material rolling and falling to a bottom deck, with possible damage to the crew and/or to the cargo (see Figure 2). However, despite various means to avoid cargo damage by human mistake, there are unavoidable structural members such as brackets that in some areas penetrate the cargo space. To mitigate this risk the obstacles were marked with zebra sponge reflecting tape, emphasising the hazard to crew.

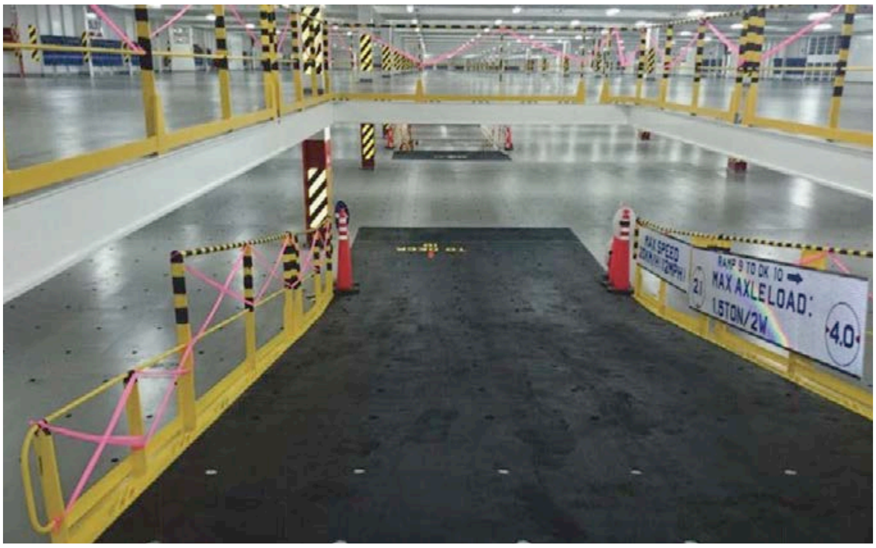


Figure 2: Kick plates (yellow painted) are fixed around the ramp and around the deck opening. Note also the yellow/black zebra markings that emphasise dangerous areas to stevedores

Habitability

Improvements were made to the vessel's facilities too. Refrigerators and laundry equipment onboard the subject PCTC vessel were arranged longitudinally in order to prevent their content from falling due to the ship's rolling motion, which is stronger than pitching. Drinking fountains were removed from the design as crew feedback stated they preferred drinking bottled water. And, in adaptation to this requirement, a plastic granulator was installed onboard to prevent the accumulation of plastic bottles.

The provision and design of cabins was also a focus point. Two extra cabins were proposed on top of the designed number of cabins for crew members by the yard, for Suez crew and for Pilot, but five extra cabins were actually added to the design from the Technical Specifications (TS) stage:

- 2 persons in owner's cabin
- 1 person in Superintendent cabin
- 1 person in Supercargo cabin
- 1 person in Pilot cabin
- 6 persons in Suez crew cabin

Those intended to be accommodated in these cabins are not normally onboard. However, they do occasionally stay onboard, and so in order to have comfortable and user-friendly accommodation, dedicated private cabins with private toilets were prepared.

Based on MLC 2006, a minimum of 7m^2 floor area should be designed for each single crew cabin in ships above 10,000gt. The design of the subject PCTC vessel was such that the area of cabins of ratings was between 11.6m^2 and 12.1m^2, with an average of 11.86m^2. The area of cabins for junior officers was between 13.5m^2 and 17.5m^2, with an average of 15.7m^2. The senior officers, chief engineer and the master cabins were designed with a dayroom and a bedroom for each person. It is therefore clear that in this case study, cabin areas surpassed the minimum requirement and were enlarged to improve habitability and comfort. This could be achieved without complication because the accommodation in a PCTC vessel is normally on the upper deck and has sufficient deck area to meet the accommodation design needs.

Other common spaces in the original design by the shipyard were enlarged based on the owner's understanding and insistence that habitability should be improved. An example is the Gym and Hobby room, which was enlarged from 31.7m^2 to 35.3m^2.

Crew movements were also addressed. The lift onboard PCTC vessels is usually arranged in the middle staircase, which goes from the engine room up to the accommodation deck. From the nature of this design, there is a need for a passageway in the upper deck from the lift to the accommodation entrance. An open-air walkway is used by many PCTC vessel owners. However, this is inconvenient and slippery in stormy weather. Several PCTC vessel owners have added a sheltered, steel-constructed passageway to their vessel designs, but this also has drawbacks; a steel construction is subject to timely maintenance, a lack of natural illumination, and a hot environmental condition.

A transparent passageway was consequently conceived for the subject PCTC vessel (see Figure 3), keeping the crew dry and comfortable when walking between the accommodation and the elevator. An elevator calling push button was also added in the accommodation lobby to save time spent waiting for the

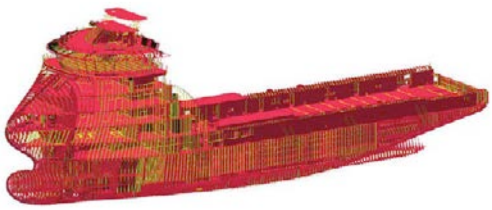


Figure 3: Transparent passageway from elevator to the accommodation lobby (left). Elevator push button in the lobby (right)

elevator to reach the accommodation deck (Figure 3).

Maintainability

Maintainability is partially examined by the degree of access to every part of the vessel. Hence, in the confined space of the engine room, it was made certain at the detailed design stage that each piece of machinery was arranged with 360deg access. This meant that equipment was not attached to walls or bulkheads and enough space was left for crew members to access and maintain it.

Unattended spaces are normally designed by the yard with insufficient accessibility. So, in order to enhance HF&E maintenance dimensions, the shipowner's designer decided to provide the crew with safe and comfortable means to access such spaces. For example, vertical ladders were arranged inside each cargo hold ventilation trunk with landing platforms between every couple of decks and bolted type anti-stowaway bars for enabling easy access from car deck to the trunk. In the elevator trunk, lighting fixtures were added (Figure 4) for maintenance and also for safety escape route purposes. Also, for the engine casing and funnel, gratings were fitted in every floor and all around each one of the exhaust pipes in order to be fully and safely accessed by the crew.

For light fixture replacement, the shipyard proposed hanging type lights in various locations. These are meant to counter the effects of ship vibration; however, the maintenance of hanging lights is more complicated because one seafarer needs to hold the fixture, and another must replace the bulb. As a result, fixed type lights were insisted by the shipowner's designer, and the agreed solution against vibration was rubber shock absorbers in the mounting bolts (Figure 5).

Noise that originates from the main engine and propeller is not usually an issue in the accommodation, because the accommodation is distanced from the engine room. However, cargo ventilation fans are arranged around the superstructure and air handling units and refrigeration machineries are normally arranged inside the accommodation space. These units can introduce local noise which might interfere with the social environmental condition, so cabins and spaces in the vicinity of machinery were designed with noise-reducing wall panels, and the machinery spaces were designed with perforated noise reduction plates.

Survivability

A fire that starts in accommodation can initiate from inside a cabin, therefore fire detectors were added in every cabin even though detection is only required in corridors to meet rule requirements. Fire retardant curtains and upholstery were selected for the accommodation, and fire hydrants with hoses were added inside the accommodation area.

Embarkation to the rescue boat onboard a PCTC vessel can be hazardous because the boat is on the upper deck, which is 31.023m above the lowest water line. As a result, a special embarkation procedure was designed from an outer shell door in cargo deck no.5. This means that the crew embark the rescue boat from 6.723m above the lowest water line, dramatically reducing the chance of accidents or injuries.

For reducing slips on working decks such as the mooring decks, steering gear deck, cargo deck (in some areas) and exposed decks, they were all painted with anti-slip coating. For reducing cargo slips in cargo spaces the ramps and the loading/unloading paths were coated with special rough anti-slip coating, which is efficient in preventing heavy cargo slips and reducing possible accidents, see Figure 2.

Figure 4: Illuminated elevator trunk for safety and for maintenance. The view is from the elevator top looking down

Figure 5: Lighting fixtures fitted with rubber shock absorbers against vibration

Handrails and storm rails were designed and arranged around the entire superstructure, in the engine room, and in staircases, where continuous handrails with round transitions were fitted to the benefit of crew safety. Vertical ladders above 2.5m were given back supports and a protection bar in a further effort to improve the safety of crew traffic onboard the vessel while it moves.

Finally, the control of the stern ramp was designed to be carried out from an enclosed room in the aft starboard side corner of the upper deck. The room was designed with windows all around, as well as a wiper and heater, in order to provide the operator with a smoother control of the stern ramp when it is lowered on the quay side and hoisted back home.

In conclusion

Directly involving the end user at any design stage of a new building is seen to be unusual for shipyards and shipowners, let alone encouraging crew participation from early design stages. However, the presented case study captures how HF&E can be implemented in a newbuilding by the successful collaboration of the shipowner's designers, crew, ship managers and the shipyard. I therefore suggest that HF&E should be an integral part of the plan approval and design of every new vessel, improving workability, habitability, maintainability, survivability, controllability, affordability, communication and user empowerment, as well as professional and psychosocial aspects. *NA*

Notes

This article is an abridged version of a paper delivered by Nicolas Bialystocki at RINA's International Conference on Human Factors in Ship Design & Operation in 2016.

The work carried out for the presented case study is indebted to a paper by Costa and Lützhöft (2014), "The Values of Ergonomics in Ship Design and Operation", which was presented at RINA's International Conference on Human Factors in Ship Design & Operation in 2014.

Stepping up

If the cruise industry is one of the sectors that has proved to be resilient in the downturn for shipping as a whole, cruise companies still have a number of challenges to face with the advent of new environmental legislation and threats from cybercrime to name but two, writes Sandra Speares

As Tom Strang senior vice president, maritime affairs at Carnival puts it, environmental issues are "not going to go away. Obviously with the 2020 changes that there are for fuel, companies will have to have a strategy now as to how they are going to handle the transition to a global ECA."

Last year saw the introduction of new cutting-edge vessels, as well as the decision to make 2020 the year for the introduction of the 0.5% sulphur cap, and 2017 has seen the entry into force of the ballast water convention.

Most cruise companies have decided that scrubbing technology is the way forward when dealing with the sulphur cap issue, while many have announced plans for LNG propulsion on their vessels going forward. The speed at which this fuel solution is taken up will depend on whether ports have the facilities and supplies for LNG bunkering by the larger cruiseships and what the costs will be when these ships come off the production line.

Marco Nardo, senior specialist, engineering systems at Lloyd's Register, explains that to install an LNG system on a ship, a risk analysis is required. The recently introduced IGF Code poses additional challenges when large numbers of people are onboard, as on a cruiseship or ro-pax.

The new mandatory code for ships using gases or other low-flashpoint fuels entered into force on 1 January 2017, along with new training requirements for seafarers working on those ships.

The code includes prescriptive requirements and parts of the design need to be assessed using a risk based analysis. For example, as far as the location of the tanks are concerned, there are requirements to prevent the possibility of the tanks being damaged in a collision, or to mitigate risks in an emergency. Tanks are normally located inboard and below the passenger decks, with the additional cosmetic advantage of not impeding visibility for passengers. That said, Nardo cites the example of *Viking Grace*, an LNG-powered ferry operating in Sweden, on which the tanks are visible and provide an environmentally friendly selling point.

Tom Strang, senior vice president, maritime affairs, Carnival Cruise Lines

There are some issues in relation to the installation that have to be considered, however. Whether the LNG-powered cruiseship order book expands in the future is something of a "chicken and egg" situation, he says. Much will depend on the availability of LNG as bunker fuel and whether cruise companies have access to sufficient supplies.

One of the benefits of LNG is compliance with environmental requirements. The economics seem to be positive but a key concern is whether it will be convenient for owners to use in view of availability. Another point is that cruise companies do not, like ferries, consistently operate on the same route, and this makes onshore investments more complex. A cruiseship could move its centre of operations because of political or economic considerations, for example, and this could potentially mean inefficient onshore expenditure.

Technology investment

One example of investment has been announced by Royal Caribbean, whose newest class of ships will be powered by LNG. The company also plans to introduce the use of fuel cell technology.

RCL signed a memorandum of understanding with shipbuilder Meyer Turku for the new class of vessel under the project name Icon. The vessels will be delivered in Q2 of 2022 and 2024. Royal Caribbean will also begin testing fuel cell technology on an existing Oasis class ship in 2017, and will run progressively larger fuel cell projects on the new Quantum class vessels being built.

Royal Caribbean is already known for making steady progress on energy efficiency and reduced emissions through such technologies as air lubrication, which sends billions of microscopic bubbles along the hull of a ship to reduce friction, and advanced emissions purification (AEP) scrubbers.

"Increasing the commitment to LNG makes it easier for suppliers to make their own infrastructure commitments," said Richard Fain, RCL chief executive in October. "As more ships are built for LNG, the number of ports that support it will grow." The Icon ships are expected to run primarily on LNG, but will also be able to run on distillate fuel to accommodate occasional itineraries that visit ports without LNG infrastructure.

The company believes fuel cells offer very interesting design possibilities. Harri Kulovaara, RCL's chief of ship design says that "As the technology becomes smaller and more efficient, fuel cells become more viable in a significant way to power the ship's hotel functions. We will begin testing those possibilities as soon as we can, and look to maximise their use when Icon class debuts."

Kulovaara said RCL had been eyeing fuel cells for nearly a decade, and believes the technology is now at a stage of development that justifies investment. "There is a long lead time for Icon class, and we will use that time to work with Meyer Turku to adapt fuel cell technology for maritime use." Kulovaara said that additional regulatory standards would also need to be developed for the technology.

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Because of the long lead time, Kulovaara said that many Icon design elements are in the early stages. The Icon ships would likely accommodate approximately 5,000 passengers, he said, but details are still being worked out.

Icon is the first new ship class announced by RCL since Celebrity Cruises' new Edge class, which debuts in 2018. The company is also expanding its fleet with new Oasis and Quantum class ships for Royal Caribbean International.

Meanwhile the installation of scrubbing technology has been a central feature of other cruise companies' investment recently, as the lines gear up for the introduction of the global sulphur cap.

In conjunction with its Eco-Smart Cruising programme, Norwegian Cruise Line recently completed the retrofitting of a new exhaust gas scrubber system on *Norwegian Jewel*, aimed at significantly reducing air emissions and the ship's environmental footprint.

NCL claims to be the first cruise line to retrofit a vessel while it is in service with an exhaust gas scrubber hybrid system. "*Norwegian Jewel*'s new lightweight in-line scrubbers are a hybrid technology developed by Yara Marine Technologies that are able to operate in dry mode, open loop and closed loop. Five scrubbers were installed, one per engine, covering the whole propulsion system. Collectively, they are capable of reducing the emission of sulphur to air [by] up to 99% and also reduce 85% particulate emission to the air," the company said.

NCL estimates that *Norwegian Jewel*'s new technology will reduce the equivalent of approximately 1,500tonnes of SOx in the years to come as a result of this new technology. A two-year project, *Norwegian Jewel*'s retrofitting began in spring 2014 with more than 100,000 man hours work involved.

NCL's scrubbers have a state-of-the-art water membranes filtration unit. This sophisticated water cleaning system uses Ultrafiltration technology to clean the recirculated water during the closed loop operation down to clear water. The by-product is collected and removed in drums.

Meeting and surpassing environmental requirements has also been a key target at Carnival Corporation, with the new *Carnival Vista* gaining Lloyd's Register's ECO notation.

Carnival Vista was engineered to reduce emissions and meets all current regulations for NOx and SOx discharges and particulate emissions through the use of low-sulphur fuel, particulate filters and exhaust-cleaning systems. The ship also has the first Intelligent Power Management System installed on a Carnival vessel. The system optimises diesel engine operational settings to reduce emissions and conserve fuel. In addition, *Carnival Vista* has a steam-turbine generator that recovers excess steam produced by the exhaust gas boilers while the ship is underway.

Other shipboard systems that contribute to *Carnival Vista*'s reduced environmental impacts include an advanced wastewater treatment system and energy-efficient LED lighting throughout the vessel. The ship has a ballast water treatment system that complies with Ballast Water Management Convention requirements before they take effect.

Norwegian Jewel has recently been retrofitted with five new lightweight in-line scrubbers, providing one scrubber per engine

Harri Kulovaara, chief of ship design, Royal Caribbean Cruise Line. Credit: Royal Caribbean Cruise Line

Carnival Vista is also ahead of regulatory requirements that are part of the Hong Kong Convention for Safe Recycling of Ships, which will render it safer and cleaner to recycle when it reaches the end of its service life.

With Carnival's orders for ships, plus those of other cruise companies like MSC and Royal Caribbean "you can clearly see a trend towards the utilisation of cleaner fuels in our sector. That is the first building block," says Tom Strang.

He does not believe "for a minute" that there will be a reduction in air emission standards and as market players increasingly look at alternatives, other solutions will develop, whether they are other fuel solutions or not. Carnival alone has fitted more than 100 scrubber systems on its vessels and that is where most investment has gone so far.

The big unknown is what is going to happen to the fuel price in 2020. A number of new low sulphur fuels have come onto the market from the major refiners and suppliers and the question will be their availability, what their stability is like and whether they meet all the requirements onboard for cleanliness and engine performance. "There is a lot of work to be done between now and then and I think we are seeing more interest in regional emission control areas, whether it is in China or Australia," says Strang. The other big unknown is going to be CO_2 and emissions.

LNG, for example, is not a retrofit solution he says and is very difficult to achieve on cruiseships because of the space requirements. It does, however, work for other ship types. There are also other areas to be addressed including ballast water treatment. "It seems there is a pathway to a solution," he says, with systems beginning to come on line. It has been a long and difficult pathway but solutions are now appearing, although the whole process of implementation has to be addressed. Strang says he has not always been optimistic about the ballast water issue because he feels the regulation was poorly written, but says that now there are at least systems that can meet all requirements.

Other environmental issues Strang points to include a renewed interest in shore power because of local emission requirements in different parts of the world; "we need to work together with the ports to see if that is something that makes sense both economically and environmentally". Carnival has been investing in expanding its use of cold ironing at the port of Long Beach, but the issue has yet to gain much traction because of the widespread installation of scrubbers on cruiseships.

As far as cruiseships are concerned there are about 10 ports that have facilities for this, and about 1,000 that they visit. In addition, cold ironing is only viable if the onshore source of power is more eco-friendly than the power supplied on the ship. Marco Nardo says that in the case of Venice cold ironing has been considered, but the power needed to supply cruiseships visiting the city would be more or less equal to the needs of the city itself. It would consequently require huge infrastructure investment whereas the ships themselves can already meet emissions requirements.

Interest is likely to increase in the future as emissions of nitrous oxide and particulate matter move further into the spotlight. "We haven't seen the end of air emissions issues," Strang believes. He agrees with other commentators that noise may well become a greater issue in the future. There are still noise issues as far as both air and water are concerned, but the question will be whether they become as big a talking point as emissions.

Waste disposal

Another issue on the agenda is sewage treatment and Annex IV amendments and the port reception facilities issue. The cruise industry has been holding discussions with the Baltic ports and working together with HELCOM and the Baltic states to ensure they have adequate facilities in place for 2021 when the rules come into force because that will mean a lot of investment, he says.

One issue to be addressed is whether there needs to be such facilities at every single port or whether ports should look to have a more regional approach operated on a cost sharing basis. Initially the issue was considered to have an onboard solution, whereas now it is looked at more as having a port based solution, he says. Strang says he is "cautiously optimistic" about the outcome of discussions between ports and the industry.

Carnival's Ocean Medallion smart device will connect with onboard systems to improve passenger experiences. Credit: Princess Cruises

Newbuilding challenge

Paul Nichols, lead specialist, Passenger Ship Support Centre at Lloyd's Register, says another challenge for designers and builders is that "we are seeing owners who have previously ordered with the larger cruiseship builders choosing to place orders with smaller yards. Some yards affected by the downturn in offshore business are looking to diversify into supplying the smaller cruise vessels, whilst the large builders concentrate upon the 100K+ market."

This then creates opportunities for builders, but also challenges as the requirements for passenger ships differ from those of cargo ships, he says. "There are some systems that passenger ships require which cargo ships don't have, there are systems which they both have, but the system details may be quite different, for example zonal smoke detection compared to fully addressable systems.

"These new cruise shipbuilders need to be careful not to simply order what they did before when they swap from cargo to passenger, if they do, that way lies madness! For regulations such as Safe Return to Port the new cruise builders are going through the process which the big yards went through about seven years ago." Experienced shipbuilders know the SOLAS requirements inside out and have in some cases been involved in writing the rules governing passenger ships.

Security & safety

Security, and in particular cyber-related issues, is another area that Nichols highlights. One area on the passenger side is the ability to monitor engine performance remotely for example. Aside from connectivity on the mechanical side on passenger ships there are obviously details of all the passengers including bank account information. Security here is a challenge.

"Any ship operator knows that a chain is only as strong as its weakest link and whilst many look to the large system aspects, care should be taken to control the smaller access points to the systems onboard. We've seen the system supplier for equipment look to grab a flash drive and open the files then look for another and another before installing an update. Practices such as these give opportunities for malware to be introduced into the ship, and with integrated systems becoming more prevalent the possibilities for problems increase."

Along with the cyber threat there is also an increased level of technology working to assist the passengers. A number of cruise lines recently brought out personal "gadgets" such as bracelets to improve the passenger experience. One example is the new Ocean Medallion initiative by Carnival.

Projects such as the EU-funded Lynceus take this further by allowing tracking of individuals in the emergency condition to assist crews and search and rescue teams to locate personnel onboard. It also tracks people overboard in an emergency situation. This is a project LR is involved with.

Tracking can be via lifejackets equipped with technology which activates when the lifejacket is opened up. "By piggybacking a detection system into the smoke detection system they can track lifejackets moving round the ship". If not by lifejacket, tracking can be done with bracelets. The bracelets also have a medical facility which identifies a pulse.

There are moves to develop man overboard systems and there is an ISO group developing this. US legislation stipulates that ships should have the ability to note if someone goes overboard as far as the technology allows, although the scope of this has not been published. The industry has set up the group to develop a standard so that when the US Coast Guard decides on the scope of the stipulation the industry will be able to show it has been developing a standard. The US legislation specifically applies to passenger vessels, but other classes of vessel will be covered by the ISO standard.

Alternative approach

Over the last few years more ships have been using alternative design arrangements (ADAs) where within SOLAS the cruise company proves that its proposed design is as good as the prescriptive approach. This might include the number of people allowed in a single lifeboat, or the length of fire zones. Where it can be shown that the proposed design offers an equivalent level of safety, it can be permitted.

Nichols says he can't think of any ships that have been proposed to LR that do not include ADAs, because they "let you build the ship that your owner wants rather than let you build [what] the regulations let you build". This can have savings for the owner. However, there are certain hurdles in the design that need to be jumped to justify that it is equally safe using ADAs. More use is being made of ADAs which offer more flexibility without infringing safety requirements.

There has been much discussion about the new ships to be built by Richard Branson's Virgin Group, which are understood to have hull dimensions that will be about six metres wider across the beam than similar vessels of the same length currently in service. The three new 110,00gt ships to be built are expected to be 278m in length and 38m across the beam. They are due to be delivered from Fincantieri's Sestre Ponente yard in 2020, 2021 and 2022 respectively.

The Virgin Voyages vessels will be the first cruise line to adopt the clean energy system, Climeon Ocean. Virgin Voyages is the first major cruise line to partner with Climeon, a world-renowned clean energy innovator. Virgin will install Climeon Ocean, a system that will transform low-grade energy into clean electricity on all three of its ships. The resulting environmental impact will be an estimated emissions saving of 5,400tonnes of carbon dioxide per ship per year – an amount that would take 180,000 trees 30 years to absorb. *NA*

ABB targets polar cruise vessels

Superior vessel manoeuvrability, better safety and comfort, and optimised power consumption are claimed to make ABB's Azipod units particularly suitable for expedition cruiseships operating in polar waters, writes Clive Woodbridge

ABB's Azipod propulsion technology is already highly popular within the ice-going vessel sector. The propulsors satisfy Polar Code (PC) requirements and are available with PC notations suitable for a range of ice conditions. Indeed, more than 60 Azipod-equipped vessels are either now in operation or ordered for working in icy waters.

Kimmo Kokkila, product manager, thruster products, ABB Marine and Ports Business Unit, says: "The interaction between pods and ice is well understood, which is perhaps why no pods have encountered structural damage due to ice loads. Several Azipod-equipped cargo vessels have also sailed the Northern Sea Route, some without icebreaker assistance."

Among the latest vessels to be fitted with Azipod units is *Polaris*, the Finnish Transport Authority icebreaker delivered in September 2016, which has been built to 'PC4' level under the Polar Code, covering year-round operation in thick first-year ice with old ice inclusions. This pioneering LNG-fuelled ship can break 1.8m thick ice at 4knots. Another icebreaker for the Polar Research Institute of China, also specified with Azipod propulsors, will be even tougher, ABB claims.

Meanwhile, the Azipod-equipped *Christophe de Margerie* will be the first LNG carrier delivered for the Yamal LNG project in the Russian Arctic. It is the most powerful vessel of its type, and is also the world's largest capable of navigating independently in ice more than 2m thick.

ABB believes that new opportunities are opening up for Azipods within the niche polar cruise sector. Today, around 60 cruiseships are fitted with Azipod propulsion, including the world's largest such vessels – Royal Caribbean's Oasis class. Building on this track record, ABB is now firmly targeting the growing market for new generation cruiseships designed for crossing polar and sub-polar waters, believing the technology has several specific advantages in this sector.

For example, ABB claims, Azipod units benefit safety by achieving far shorter crash-stop distances. Kokkila says: "Performing a crash-stop using podded propulsors involves a 180-degree rotation of the entire unit while keeping positive propeller rpm. This reduces the crash-stop distance by half, while pods retain their full thrust throughout, conferring greater heading control even in heavy weather or in ice-infested waters."

Azipod units allow the full thrust to be pointed in any direction, improving manoeuvrability in a way that is particularly welcome when navigating in proximity to icebergs and in icefields, while podded propulsion systems are also claimed to confer substantial benefits in collision avoidance scenarios. Furthermore, the manoeuvrability offered by pods is consistent across the full speed range and reduces the risk of getting stuck in compressed ice fields.

ABB also points out the benefits to cruiseships of the Azipod's relatively quiet performance. "Podded propulsion is the most straightforward way of

Highlighting the concepts potential in the niche polar cruise segment, Azipods will feature on *Scenic Eclipse*, now being built in Croatia satisfying this requirement," suggests Kokkila. "The arrangement eliminates the need for noisy gears and the pod motor and its shaft is located outside the ship's hull. Furthermore, because the pulling propeller of the Azipod unit receives a steady wake field, it is easier to optimise for silent operation compared to a conventional pushing propeller with rudder. The vibrations experienced in manoeuvres caused by tunnel thrusters also become a non-issue."

Furthermore, with Azipod propulsion, the electrical motor is installed directly on the propeller shaft, avoiding the need for mechanical gears, like those found in Z- or L-drive azimuthing thrusters. Consequently, the Azipod shaftline is more resilient to both bending and high torque peaks under ice loading. "If heavy ice interaction is expected, the Azipod unit's electric motor and ship's power plant can be configured to provide an over-torque capability, which prevents ice blocks impacting static propeller blades when the vessel is moving forward by inertia alone," Kokkila points out.

The gearless construction of Azipod units further reduces the risk of environmental contamination, because the amount of oil used is only a fraction of that found in geared mechanical azimuthing thruster or traditional shaftline propulsion arrangements. In addition, the shaft seal design does not have an oil-water interface, thus earning approval under the U.S. Vessel General Permit (VGP).

These benefits are cited as the reasons Azipod propulsion was selected for Scenic Cruises' *Scenic Eclipse*, the world's first passenger vessel to be constructed explicitly to Polar Code standards. With a PC6 notation, this 'discovery yacht' is currently under construction at the Uljanik Shipyard in Croatia and is set to launch in August 2018.

It has also been confirmed that ABB Azipods will feature on a series of five Polar cruise capable vessels ordered by Crystal Cruises and Star Cruises at MV Weften. The PC 6-rated vessels will all feature a complete ABB propulsion system, electric power plant, automation and marine software system. The three Crystal ships will each be powered by two Azipod D units, whilst the two new Star Cruises ships will each be installed with three Azipod XO thrusters.

Marcus Högblom, vice president of global sales, passenger vessels and Azipod propulsion, says: "We are seeing increased interest in the polar regions from the passenger sector, so our expertise in the cruise and ice-going sectors means we are ideally positioned and can fully support our customers with their new projects." Delivery of the five vessels is scheduled for 2019 onwards.

The ability of Azipod propulsion to satisfy a variety of hull forms and ice classes will be key in building up a reference list in the expedition cruiseship market over the coming years. The supplier's recommended starting point for PC class expedition cruise vessel designs is its gearless Azipod DO propulsor series, which ranges in power from 1.5MW to 7.5MW per unit. With strong hydrodynamic performance matched with good overall efficiency, a twin Azipod DO installation can achieve a 10% power saving compared to a twin shaftline installation with electric propulsion, says ABB. *NA*

Wärtsilä enhances product portfolio

The past 12 months have been busy ones for Finland-based Wärtsilä, with a series of new thruster and propeller products being launched to cater for the needs of a wide range of vessel types, reports Clive Woodbridge

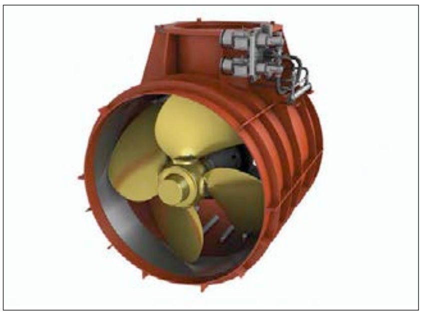
Over the course of 2016, Wärtsilä introduced several new products, strengthening its already influential position in the marine thruster and propeller sector. These include the retractable, underwater mountable thruster type WST-65RU; the WTT-36 and WTT-40 transverse thrusters; and the Wärtsilä EnergoProFin energy improvement device for controllable-pitch propellers (CPP).

The WST-65RU is an innovative product that combines a number of features that are of significant benefit to shipowners and designers of large offshore vessels. The WST-65RU has a power rating of 5,500-6,500 kW, which Wärtsilä claims makes it the highest powered retractable thruster in the market, with the capability to provide even the largest offshore construction vessels with dynamic positioning capability.

The WST-65RU features a gearbox tilted by 8degs which drives the ducted propeller. By using this tilted gearbox, which is also found on the Wärtsilä underwater mountable series of thrusters, the propeller and nozzle are both tilted to redirect the propeller flow. According to Joost van Eijnatten, manager, application engineering, Wärtsilä Marine Solutions: "This minimises thruster-thruster and thruster-hull interaction without compromising propeller efficiency, unlike other thrusters in which only the nozzle is tilted."

Wärtsilä claims that the WST-65RU is the first retractable thruster of which the outboard part can be removed while the vessel is afloat without using a specially constructed habitat. This allows for thrusters to be exchanged for maintenance on vessels without the need to enter drydocks.

Wärtsilä thrusters with tilted shafts are in operation on several drillships and semi-submersible drilling rigs. "The benefits of these thrusters for dynamic positioning and free-sailing performance are being widely recognised by owners, operators and designers and this is reflected by vessel specifications and quotation requests in which a thruster with a tilted shaft is specified," says Van Eijnatten.



The new WTT40 thruster; designed particularly for large cruiseships

Also in 2016, Wärtsilä introduced new WTT-36 and WTT-40 tunnel thrusters with power levels of 3,600 and 4,000kW respectively. These tunnel thrusters are particularly designed to meet the increasing thrust requirement for cruise vessels. The first units are currently being built and will be installed on a cruise vessel newbuild to be delivered in 2017.

The WST65RU design

According to van Eijnatten: "As cruise vessels become larger, they require larger thrusters in the bow and stern for manoeuvring. The higher and longer the vessel, and the more mass it has, the greater the wind force and other pressures it faces at sea, requiring stronger thrusters to counter with more propulsion."

The first WTT-40 units are now being constructed and will be installed on a cruise vessel newbuilding to be delivered later this year. These are the first Wärtsilä traverse thruster type specifically designed for the 4,000kw power segment and the design is available with either a controllable- or fixed-pitch propeller.

Greater manoeuvrability is one of the main improvements claimed by Wärtsilä for the WTT-40, as well as lower levels of noise and vibration. The company also highlights features such as new lubrication and hydraulics systems which have been designed to increase fuel efficiency and lower maintenance costs.

Alongside its higher power rating, the WTT-40 differs from earlier generation models in its propeller diameter. Whereas standard 3 or 3.5MW transverse thrusters employ a 3m diameter propeller, the new thruster uses a 3.4m diameter propeller for the first time. These larger propellers are more efficient and can provide more thrust, Wärtsilä notes.

The Wärtsilä EnergoProFin energy saving device (ESD) has been a popular option for shipowners specifying fixed-pitch propellers since its launch in 2013. Building on that platform, Wärtsilä has now introduced EnergoProFin for CPP.

The Wärtsilä EnergoProFin is a specially designed propeller cap with hydrofoil section fins on the downstream side of the propeller. Propeller caps with fins have existed for around 30 years, but their application has so far been primarily on fixed-pitch propellers. Van Eijnatten says: "The view of the industry has been that applying an energy saving device such as EnergoProFin to the technologically more challenging CPP would not be possible. We took on the development task and succeeded in creating a product that offers vessels equipped with a CPP an opportunity to reduce their energy consumption." The development work on this product was a spin-off from an EU-funded collaborative project between Wärtsilä and nine other companies.

The most recent technological development from Wärtsilä in the thruster segment was unveiled in December last year. The new Wärtsilä Thruster Preservation Bag is designed for protecting and preserving the steerable thruster system's underwater mounted parts during lay-up periods. This is a response to the prevailing market conditions in the offshore sector especially, where many operators are laying up their assets. During such stacking periods, using the Wärtsilä Thruster Preservation Bag, the thrusters can be kept safe and fully protected against corrosion and marine growth. By safely protecting the thrusters, the time between overhauls (TBO) can be extended while the bag also facilitates getting thrusters back into operation without the need for expensive and time-consuming overhauls or repairs.


The EnergoProFin for CPPs on a container vessel

Over the coming year, Wärtsilä says it will continue to release new propulsion products to complete a process of thruster and propeller portfolio renewal and extension that was started in 2014. Among the new releases planned for 2017 are retractable thrusters, transverse thrusters, CPPs and energy saving devices, as well as product updates providing environmentally accepted lubricant (EAL) compatibility, for example.

Wartsila's R&D programme will also be guided by a market trend to look more at overall propulsion efficiency, rather than focus on the open water efficiency of a single propulsor, such as for example a CPP.

To determine this efficiency, the vessel hull, the propellers, the rudder and their interaction are taken into account in a system-based approach. Wärtsilä points out that it is capable of bringing all these elements together in full-scale CFD calculations to determine vessel resistance, propulsion efficiency and interaction factors.

A benefit of performing full scale CFD calculations is that scaling effects which play a role when performing conventional model tests can be avoided. Wärtsilä suggests this is especially advantageous when determining the efficiency improvement that can be achieved with ducted propellers on cargo vessels at vessel speeds of 12-14 knots. *NA*

PM technology takes centre stage for Rolls-Royce

Rolls-Royce is expanding its thruster range with products incorporating novel all-electric systems including permanent magnet technology, writes Clive Woodbridge

Rolls-Royce unveiled its new azimuthing permanent magnet thruster, type AZ-PM, last September, following the successful completion of a year of sea trials aboard the 31m-long research vessel *Gunnerus*, owned by the Norwegian University of Science and Technology (NTNU), Trondheim. Over the course of the trial, researchers found a very high level of motor efficiency – 97% at nominal speed; an increase in bollard pull of more than 20%; and around a knot of additional speed over the range for the same input power. In addition, airborne and structural noise readings were lower or similar to previous performance, while hydro acoustic noise was significantly improved.


The Azipull Carbon 65 thruster could have applications in passenger ships and work boats, Rolls-Royce believes

The new AZ-PM thruster has fewer moving parts than conventional thrusters and combines a ring-type permanent magnet electric motor, propeller and nozzle in a tightly integrated propulsion unit. Simple bearings in the rotor hub carry all loads, and only a small oil circulation pump is required. This system carries less oil than conventional thrusters, reducing the risk of environmental damage if spilled. Rolls-Royce points out that the system uses biodegradable oil, which has the US Vessel General Permit (VGP) for Environmental Acceptable Lubrications (EAL) approval.

The azimuthing permanent magnet thruster is designed to be space-saving and easy to install and maintain. The only components to be found in the thruster room are the slip ring case that transfers power to the thruster, the compact electric steering motors and a small lubrication swivel. As it has a submerged motor, no cooling equipment is required, which saves further space and reduces installation cost.

According to Gunnar Johnsen, head of electrical systems, marine, Rolls-Royce: "Tests of our new PM thruster prove it can meet customer demand for a highly efficient, reliable and sustainable thruster, with low noise and vibration levels, which is easy to install and service. We expect to see a reduction of 50% in maintenance costs and in the event of any maintenance, our condition-based monitoring system shows operators the current health of the units and allows them to plan maintenance ahead."

Furthermore, later this year Rolls-Royce will make available a new PM type azimuthing pulling propeller (AZP-PM 120). This will be rated at 1,800-3,500kW continuous and will be followed by two smaller frame sizes, the AZP-PM 085 and AZP-PM 100, and one larger, the AZP-PM 150. The range will be available with power ratings from 900kW to 5,000kW and speeds up to 24knots.

The new AZP-PM, which will have an L-drive configuration, uses the same underwater unit as a conventional azipull thruster, but has a vertical shaft PM motor integrated into a new upper unit. This compact PM motor fits within the diameter of the mounting flange, providing a small footprint and eliminating the need for an upper gearbox. This avoids the complication of a coupling, foundations and motor, which would be required with a conventional Z or C-drive. According to Rolls-Royce, installation of the AZP-PM has been simplified through the

The new AZP-PM type thruster

introduction of a new weld-in tube hull fitting. This is a cylindrical steel element with a conical section to the mounting flange, which is said to be easy to weld into the vessel's hull structure.

Three propeller types – controllable pitch, fixed pitch and fully feathering –will be offered for the AZP-PM, with the choice dependent on the type of vessel and its operational profile. All three types have been proven in use on existing azipull models, Rolls-Royce points out.

Introducing the new AZP-PM, Johnsen said: "The PM motor provides a very high efficiency over a wide speed range and reduces the space required in the thruster room. The propulsion system is particularly well qualified for ships with ice class demand, and combined with the proven high propulsive and hydrodynamic efficiency of the azipull, this will be a winning combination."

The first reference for azipull propellers using PM technology will be the Rolls-Royce designed *Roald Amundsen* and *Fridtjof Nansen*, both of which are to be built at Kleven Yard in Norway for the cruise line, Hurtigruten. The first ship will be ready for delivery in 2018 and the second ship in 2019.

In another notable development, Rolls-Royce has signed a contract with the Italian builder Benetti to deliver a new generation of high performance, lightweight steerable thrusters that make comprehensive use of carbon fibre material for the first time. Rolls-Royce claims the Azipull Carbon 65 (AZP 65) will achieve a "substantial" reduction in the overall weight of the propulsion system and will also facilitate a better vessel layout while maintaining a high level of propulsion efficiency, excellent manoeuvring capabilities and easy maintenance.

The AZP C65 is designed for a power rating of 2MW and is fitted with a fixed pitch, pulling type propeller, meaning the propeller faces forward. The driveline is designed with two spiral bevel gear sets, installed in a supporting structure that ensures optimum load carrying capacity in all operating conditions. The thruster can be steered using a hydraulic system, while an automation and control system has also been developed to match the new thrusters, which each weigh only 2,800kg.

The initial target market identified by Rolls-Royce is large superyachts. However, it believes the Azipull Carbon thruster has further applications in passenger vessels and workboats.

Rolls-Royce also continues to achieve success with its Promas system, which integrates the controllable-pitch propeller, a propeller hub cap, a rudder with bulb and a twisted leading edge into one hydrodynamically optimised unit. Recently, Danish ferry operator Mols-Linien ordered a new passenger ferry from the Rauma Marine Constructions yard in Rauma, Finland, and Rolls-Royce will provide the main propellers and propulsion control system to the new ship, which is planned to operate between mainland Denmark and the island of Bornholm. Gearboxes, steering gears, two tunnel thrusters in the bow and a control system are part of the delivery. *NA*

CFD for performance monitoring

Volker Bertram, Dept. Mech. and Mechatronic Eng., University of Stellenbosch (also DNV GL), evaluates the current capabilities and limits of CFD for performance monitoring

Numerical ship hydrodynamics collectively denotes techniques to solve equations that describe the physics of flows (*Bertram and Couser*, 2007; *Bertram*, 2012). The most important techniques for us are:

- Potential-flow computations: Potential-flow codes do not model viscosity and associated effects like the boundary layer. They also cannot model breaking waves. On the other hand, they are fast and relatively easy to handle. They are widely used for seakeeping computations
- CFD: Codes (usually based on the Reynolds Averaged Navier Stokes Equations = RANSE) model viscosity directly in the field equations. All modern CFD codes are able to capture breaking waves. The main commercial codes and the open-source alternative OpenFOAM are verified in terms of numerical implementation, and their application is validated for many marine applications

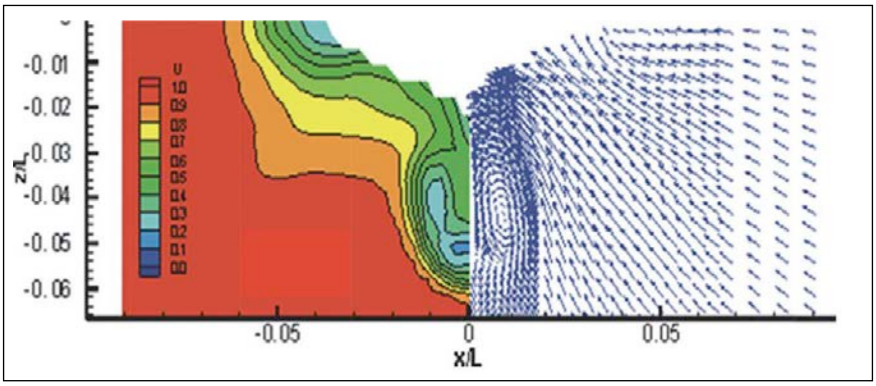


Figure 1: Measured (left) and computed (right) wake field of a tanker (*Peric and Bertram*, 2011)

Despite the growing complexity and level of detail in flow simulations, CFD projects today are often noticeably shorter than they were two decades ago (*Peric and Bertram*, 2011). This is due to more user-friendly software and parallel processing. Computations with systematic parameter variations are today performed within integrated environments, such as CAESES. The integrated design environment combines freeform hull description using parametric modelling, interfaces to most modern flow solvers, several optimisation algorithms, and software to handle process management and user interface.

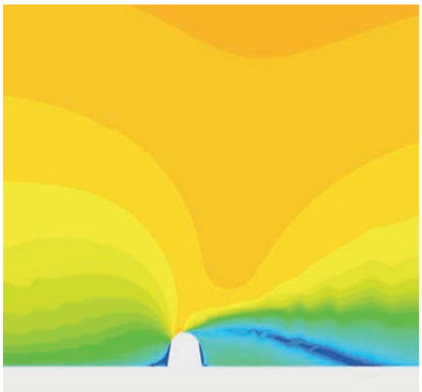
Another key aspect has led to flow simulation becoming the widely accepted and sometimes preferred tool that it is today, namely validation and the resulting trust it instils. Since 1980, dedicated workshops for the validation of marine CFD simulations have been held, more recently following a 5-year rhythm. The most recent one was the Tokyo Workshop on CFD in Ship Hydrodynamics in 2015. The high quality of the experimental data and the detailed comparison, e.g. Figure 1, has created confidence in CFD, particularly for resistance and propulsion applications. However, such validation workshops document best-practice results. As CFD is much more affordable and accessible than model basins, we see a much larger variation in quality (= accuracy of results).

For performance monitoring, we are primarily interested in expressing ideal (= for hydraulically smooth ships) power as a function of draught, trim, speed and possibly further parameters. Important points in this respect are wave making and wave breaking, whether computations are made at model scale or full scale, and geometry simplifications.

For the design condition, wave making is generally minimised (often using potential-flow wave resistance codes and model tests). For performance monitoring, however, we also need to look at off-design conditions which are not covered by classical model tests. For these conditions, breaking waves are important and thus CFD tools should be employed ("free-surface RANSE" simulations in the jargon of CFD experts).

Model tests violate some similarity laws (*Hochkirch and Mallol*, 2013); notably, wave breaking and boundary layers are different when compared with the full-scale ship. It therefore stands that CFD computations should be performed at full scale (perhaps as "numerical sea trials"). However, many CFD simulations in practice are performed at model-scale conditions, as customers like to use model tests to check the CFD simulations. With a growing understanding of CFD, we will hopefully see a change in this practice and a move towards full-scale simulations.

Figure 2: Welds lead to higher frictional resistance, but are generally not captured in global CFD models



Simplifications of a vessel's geometry mean that hull details such as welds are not captured by CFD models for power prediction. This is incredibly important as variations in welds can account for significantly higher resistance. *Ciortan and Bertram* (2014) suggest 2% should be given for poor welds in the case of a tanker. Such welds also generate higher turbulence intensity than generally assumed in CFD computations (Figure 2).

The propeller is often not geometrically modelled, although the main effects of the propeller are included via so-called body-forces. These are externally specified forces to mimic thrust and swirl of the propeller. For performance monitoring purposes, this modelling approach is absolutely sufficient, as only directly at the propeller does this introduce unacceptable changes in the simulated flow.

Krapp et al. (2016) report 5.6% variations in measured power in sea trials for seven sister vessels. It is anybody's guess how much of these variations are due to differences in the as-built hulls and how much due to variations in the measuring process. However, unless detailed scans of the as-built hull are used to generate the CFD model, such variations will always have to be expected. CFD predictions can therefore never be more accurate than these variations. Continuing this thought, microscopic or even changes in the order of mm are not captured geometrically in CFD models. The roughness of surfaces can be varied in CFD computations, e.g. *Eca et al.*, 2010; *Demirel et al.*, 2014, but there is no consensus among CFD experts how reliable such parameter studies are; the qualitative changes do appear plausible though.

Flow simplifications are also limiting factors. Model tests assume laminar-turbulent flow transition at a given distance from the leading edge. As this distance does not scale properly, model tests enforce the transition by turbulence stimulators (sand strips or studs). In CFD, fully turbulent flow is generally assumed from the very beginning, although some researchers have used "numerical sand strips". I believe that the standard approach with fully turbulent flow from the beginning reflects conditions at full scale and the realistic ocean environment better than the model tests. Waves and ship motions change the flow and should create fully turbulent flow essentially from the beginning.

CFD computations use simplified turbulence models. Up until the 1990s, turbulence modelling was the usual suspect to be blamed for unsatisfactory results. However, turbulence modelling has progressed significantly since then. The propeller behind the ship dominates the flow and makes discussions of the turbulence model rather academic for performance monitoring.

Properly performed CFD simulations are by now at least as accurate as model tests for full-scale predictions. Neither model tests nor CFD can account for as-built variations in sister vessels. For parameter variations, CFD is superior due to parallel processing and easier automation of analyses. CFD simulations for trim optimisation tools should be

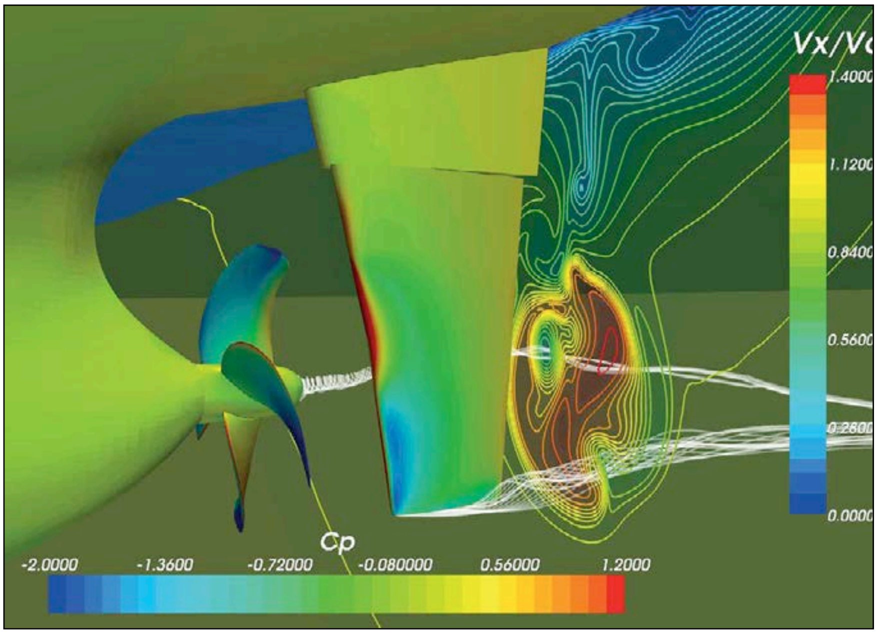
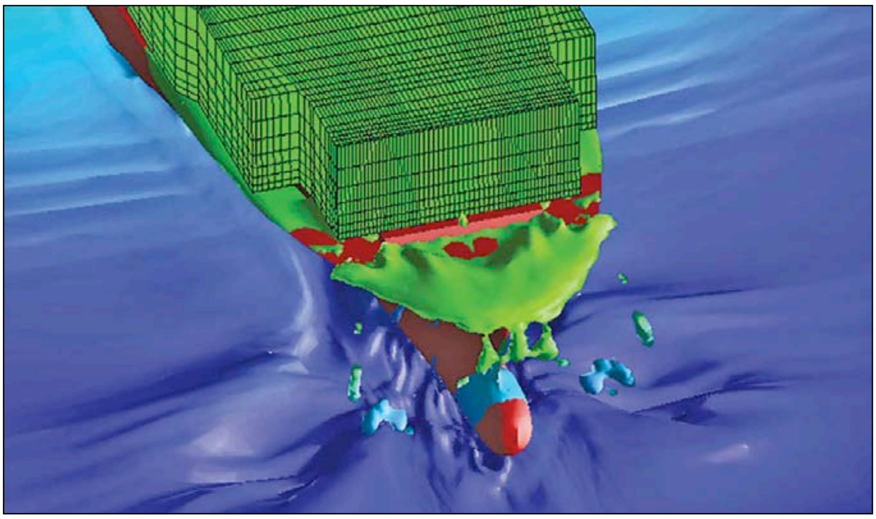


Figure 3: RANSE simulations capture the key features of the flow (breaking waves, boundary layer) and the key features of the ship (hull, propeller, rudder)

Figure 4: Seakeeping simulation for containership



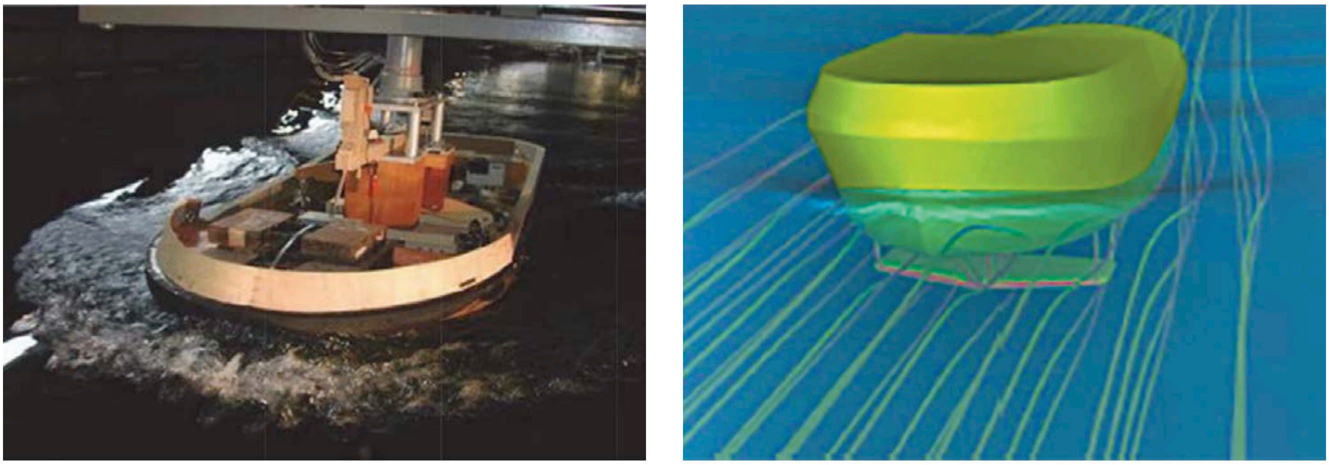


Figure 5: Model tests to determine hydrodynamic coefficients (left) are now replaced by virtual experiments using CFD (right), source: Voith Hydro)

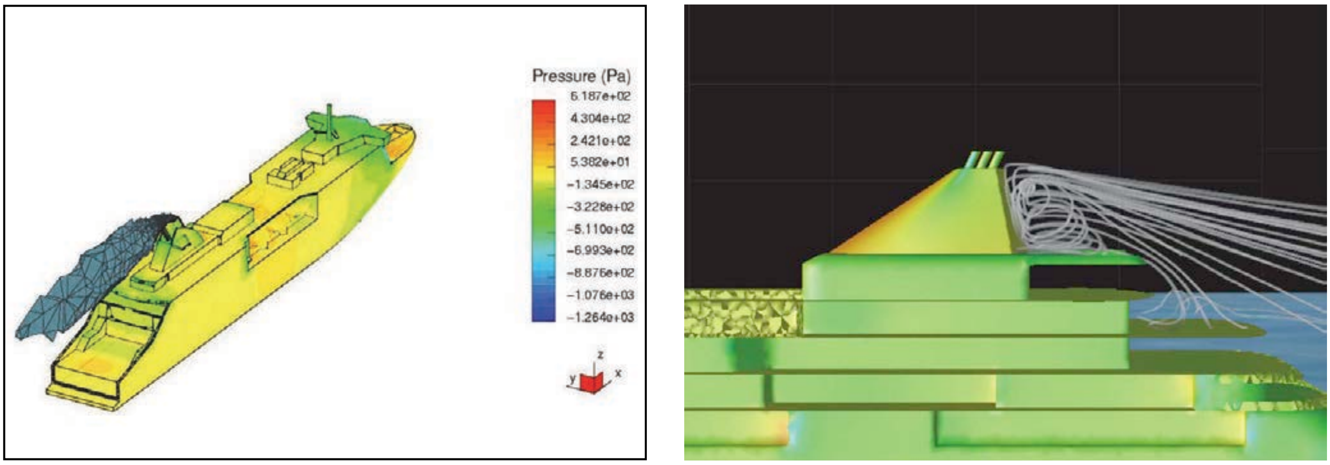


Figure 6: CFD simulations for wind forces (left) and local flow investigations (right)

reused for performance monitoring. If properly planned, this re-use of hydrodynamic information can lead to much better economics.

Seakeeping

There are many computational methods for seakeeping with assorted strengths and short-comings (*Bertram*, 2012; *Bertram and Couser*, 2014). Primarily, performance monitoring needs added power in small to moderate seaways. Here, linear analyses based on potential flow theory are the appropriate approach. These analyses are relatively fast, allowing the investigation of many parameters (wave length, wave direction, ship speed, draught, etc.). More complicated CFD methods usually do not give better results for added resistance in waves, due to a combination of insufficient grid resolution and problems with subtracting the calm-water resistance (*Söding et al.*, 2012b; *Bertram et al.*, 2016). For short waves (a wave length shorter than half the ship length), virtually all approaches fail to predict added resistance properly (*Bertram*, 2016). Notable exceptions are:

- MARIN's FATIMA code, *Dallinga et al.* (2011), a frequency-domain conversion of the time-domain code developed by *Bunnik* (1999)
- DNV GL's RANKINE code, *Shigunov and Bertram* (2014), mostly developed by Prof. Söding, *Söding et al.* (2012a,c)

Popular strip methods are not appropriate for capturing added resistance, especially for tankers/bulkers and for oblique waves. Published results showing good agreement with experiments are misleading as best cases (head waves, wave length between 0.5 and 2 times ship length) are shown. While computing added resistance is already difficult, it is not enough. The effects of seaway on propeller efficiency and indirect resistance parts due to compensation of drift forces should be included. I believe FATIMA and RANKINE can do the job. However, there is little sense in going to the required expense (think 5-digit Euro numbers if you want to cover the variations of parameters needed) as long as we use crude estimates for the seaway.

Maybe, in years to come, we will see simple formulas adapted to certain ship types which share certain similarities (e.g. tankers or container ships). Meta-models, based on numerical analyses of a series of ship designs with parameter variation, as proposed by *Couser et al.* (2011), could yield reasonably accurate predictions virtually instantaneously.

More recently, the performance monitoring community has discussed using shipboard sensors to derive ship resistance. The general idea seems to be as follows:

1. Sensors measure accelerations in six degrees of freedom (within linear ship seakeeping theory then also motions in six degrees of freedom are known)
2. By reverse engineering, the seaway causing these motion histories is derived (best-fit approximation)
3. For given seaway, the added resistance and power is then determined

For the second step, a simpler computational method, e.g. a strip method might be used. The reason is that motions and accelerations can be determined by an order of magnitude more accurately than added resistance. Then the problems of accurate determination of added resistance/power in waves apply again. However, using motion sensors onboard, we could come to a much better estimate of the ambient seaway than currently by crew estimates or coarse hindcast MetOcean data.

Manoeuvring and rudder flows

Rudder forces for rudders at small-to-moderate angles can be computed by semi-empirical methods (*Söding*, 1998). CFD can be used for rudder flows, especially for larger angles with massive flow separation or cavitation (*El Moctar*, 2007; *Brehm et al.*, 2011), but appears to be unnecessary overkill for the purposes of performance monitoring. In normal ship operation at higher speeds, rudder angles are small.

Most manoeuvring models (as in nautical simulators or in simple estimates, see e.g. the appendix of *Bertram*, 2017) use force coefficients to express forces and moments which in turn can be used in simulating manoeuvres. The approach is very fast, allowing real-time response. However, the determination of the force coefficients requires extensive (and expensive) model testing or CFD. The trend is towards using CFD (Figure 5). However, for performance monitoring, the budget constraints and the low importance of manoeuvring hydrodynamics mean that we will at best use published force coefficients for a "similar" ship for rough estimates.

Aerodynamics

Although wind tunnel tests are still widely used, CFD has evolved as an alternative that is comparable in accuracy, level of detail, time requirements and cost (*Schmode and Bertram*, 2002; *El Moctar and Bertram*, 2002). This can be seen in Figure 6. For larger parameter studies (considering not just variation of wind direction, but also draught), CFD would be the preferred choice due to easy parallel computing. Such parameter variations could lead to more accurate wind force models for performance monitoring. CFD might also be used to determine local flow variation at the location of wind anemometer to compensate for local flow distortion due to the deckhouse and other equipment.

The effort is still too high to use CFD-based, tailored wind models as a standard option in performance monitoring, but for ships where aerodynamic CFD investigations are performed in any case (typically cruise vessels), this knowledge should be re-used; more precisely, parameter variations should be added to the specifications to obtain better performance models at low price.

Requirements

Having discussed the applications of numerical ship hydrodynamics, let us have a brief look at the requirements for such simulations. In terms of software, it is generally preferable to use commercial software from large, well established vendors. Such software is extensively validated, with known scope and limits of applications. Large user groups add transparency and serve as informal help sources. However, commercial software still needs customisation for specific applications and efficient processes.

For hardware, state-of-the-art computations employ parallel computing (HPC = high-performance computing). More recently, commercial software licences and parallel computing capacity can be rented "by the hour". This makes HPC affordable for small and medium-sized enterprises.

Of course, none of this is possible without trained experts. Experience is needed in modelling and modelling determines response time, cost and the quality of the result. Computations should be put in the hands of CFD experts with domain knowledge (i.e. experts both in the field of application and in the code employed) to get good results.

The critical resource is undoubtedly expertise. So while hardware and software have become widely available and affordable, outsourcing to experienced providers will be the best strategy in most cases.

Conclusions

CFD has matured to be a viable and sometimes superior alternative to model tests, with specific applications with relevance to performance monitoring. Such applications include numerical sea trials of a ship at a steady speed in initially calm water with working propeller at full-scale conditions. These simulations give reliable hydrodynamic knowledge bases for the calm-water performance of ships. They should be based on RANSE simulations (CFD).

Seakeeping simulations are less important as we filter generally for moderate and higher seaways. The best options at present are 3d Rankine-source-method flow-codes offered by DNV GL and MARIN (*Bertram et al.*, 2016). Simulations only make sense if the knowledge is re-used for other applications and seaways are identified with greater accuracy.

Manoeuvring coefficients for force coefficient analyses might be based on CFD. For performance monitoring, however, the benefit achieved does not justify the effort involved. Instead, published force coefficients for similar ships or ship types may be taken as rough estimates. *NA*

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- Refereed Paper Submissions
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Giant FLNG unit simulated in waves

A scientific study undertaken by the Australian Maritime College (AMC) has used numerical simulation to investigate how various wave scenarios will affect the motions of the world's largest offshore facility

Situated 475km off the western coast of Australia, *Prelude FLNG*, the world's first floating liquefied natural gas platform, is about to revolutionise the way natural gas is produced. As the largest offshore facility ever constructed, *Prelude FLNG* boasts a length of 488m, a width of 74m and weighs around 600,000tonnes.

Still in its early days, the floating liquefied natural gas (FLNG) technology will allow the freshly extracted natural gas to be processed and stored aboard, before being loaded onto LNG tankers, thereby permitting the exploitation of offshore resources that have been too costly or difficult to develop otherwise. In a study undertaken by the Australian Maritime College (AMC) – a specialist institute at the University of Tasmania that focuses on seafaring and maritime engineering – numerical simulation was used to investigate how various wave scenarios will affect the motions and operations of such a facility. The computations were performed using STAR-CCM+.

The *Prelude FLNG* project, initiated by a consortium in which the energy group Royal Dutch Shell is the majority shareholder, is the first of its kind. In principle, the FLNG processing units are similar to the FSPO facilities (floating, production, storage and offloading) used for oil extraction, although *Prelude FLNG* will work on a much bigger scale. The natural gas produced at the field will be cooled to -162°C, at which temperature it turns into a liquid and its volume is reduced by a factor of 600. The liquefied gas can then easily be stored in tanks and loaded onto liquefied natural gas (LNG) tankers for onward transportation.

For the technology to reach its full potential the vessel must be able to cope with extremely adverse weather conditions, such as storms and heavy seas. The ship's structure must be able to withstand the enormous strains that arise in such conditions, and operations need to be maintained with as little disruption as possible, including during the docking and loading of the LNG tankers.

Figure 1: *Prelude FLNG* hull float launch, Geoje, South Korea, 2013 (image courtesy of Shell International Ltd.)

It was consequently necessary to gain a detailed knowledge of the conditions to be expected, and so AMC began an analysis of how such gigantic FLNG facilities behave at sea using numerical simulation and experimental validation.

The project

The three-year research project started in March 2014 with an initial phase (now completed) that consisted of investigating the influence of different wave frequencies on the motion response of the FLNG unit.

In the second phase, which is still in progress, the primary focus is on operational aspects of the facility, specifically on the interactions between the FLNG facility and the much smaller LNG tankers and supply ships during approach and mooring. These include the emergence of frequencies causing pitching and rolling movements, and undesired resonance waves.

The investigation's drive is to provide specific information to help with the development of the following target areas:

- Planning: determine design configurations suitable for critical conditions
- Operation: establish efficient procedures for safe operations
- Crew training: enable precise and practical crew training

Project analysis

The dimensions of the computational domain for the full-scale calculations were 3,000m x 800m. For these calculations, meshes from 4 to 12 million cells were used depending on the wave frequency being investigated. A total of 40 calculations were performed. The calculations required around 700hours using between 48 and 64 cores. Although *Prelude FLNG* operates in water depths of between 200 and 300m, a water depth of between 80 and 800m was simulated in order to assess the shallow water effects that may occur during tower tank tests and lead to inaccuracies.

The following STAR-CCM+ features were used:

- Overset mesh: The overset mesh capability permitted easy positioning of the LNG tanker in the vicinity of the FLNG unit, for example to analyse the effects of approach and mooring (e.g. resonance waves)
- Motion model: The dynamic fluid-body interaction (DFBI) model was used in order to account for the coupling between waves and ship movement
- Wave model: The non-linear Stokes 5th

order wave model was chosen for its accurate representation of wave movements in open water. The wave height, set to 4m, was determined using BMT Global Wave Statistics for the sea area of interest. Particular attention was paid to wave damping in order to avoid unwanted wave reflection

- VOF model: The Volume of Fluid (VOF) multiphase model was used in order to correctly capture the interface between water and air, and accurately depict the interaction between the hull and the free surface

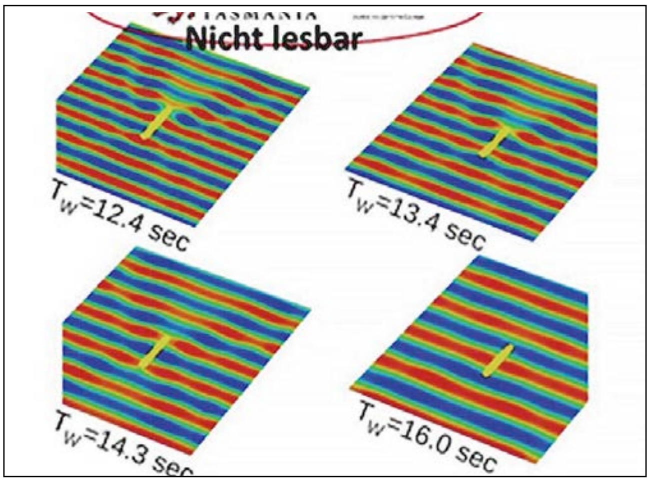


Figure 2: Resulting waves at various frequencies

Results

The simulations revealed two relationships. Firstly, that the wake from the FLNG overlays the ocean waves and forms a relatively calm area, and secondly that with high frequency ocean waves, steep waves (with deep troughs and sharp crests) are formed around the FLNG.

Future investigations will look at how the berthing of LNG tankers and supply ships will affect this configuration, in particular how to avoid resonance waves between the different hulls, how to control the pitching movement of the ships involved, and whether regulations need to be adopted to make the operation safe.

The comparison between simulation and model test results at a model to full-scale ratio of 1:100 shows an excellent agreement over the entire frequency range. It highlights the impact of a limited water depth, especially on the pitching movement of the FLNG for waves of low frequencies.

The study can therefore be seen to highlight how the use of CFD simulations can help engineers make decisions concerning not only hull design and layout configurations, but also ship operations. AMC Search, the commercial arm of the institute, will use the results from this study to develop recommendations and operating guidelines for three target areas: planning, operations and crew training. However, Dr. Max Haase (AMD Search)says the project is also valuable for another reason: "Compared with Europe where there are a number of model test basins, organisations and service providers with comparable interests, CFD has not yet unfolded its considerable potential for the maritime industry in Australia. We believe that with this project we have demonstrated the capability and scope of CFD simulations and have achieved an important milestone in the establishment of this method for maritime applications."

AMC Search & CFD

AMC specialises in shipping and maritime engineering. The institute has an extensive range of testing equipment, including a 100m-long towing tank, a circulating water tank, a cavitation tunnel and a 12m x 35m model test basin. It also has access to a computing capacity of over 1,500 cores.

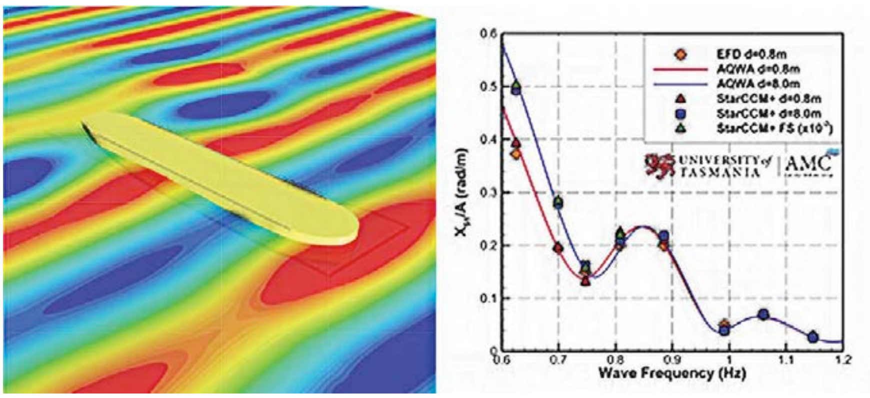
AMC Search has made the acquired knowledge and developed techniques from research and experimental testing available to the maritime industry in Australia, New Zealand and across the world for over 30 years. Dr. Haase is responsible for implementing CFD simulations in commercial projects. He states that in recent years, CFD has played an increasingly important role, due to more sophisticated requirements in performance evaluation and design optimisation which cannot be achieved by model testing in a timely and cost-effective way.

As a result, a growing number of engineers are turning towards numerical simulation in order to assess complex systems at a much earlier stage of the design process. Simulation software has been proven to be as accurate as towing tank tests, and, given realistic assumptions, allows ships and offshore platforms to be simulated at full scale, thereby eliminating some uncertainties introduced by the scaling process. This said, scale model testing remains relevant in terms of not only demonstrating software robustness, but also the validity of assumptions relied upon in carrying out various design investigations. *NA*

Authors

Dr. Max Haase, AMD Search, is responsible for implementing CFD simulations in commercial projects
Yuting Jin is a current PhD candidate at AMC

Figure 3: The FLNG's pitching rate was obtained through both simulations and experiments, and plotted against the wave frequency



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Cruising in China is moving in the right direction

Shanghai Waigaoqiao Shipyard has moved a step closer to building premium cruise lines, signing a formal agreement with Fincantieri to create a joint venture design company, writes Wang Sun

The lime-light has fallen on Shanghai Waigaoqiao's cruise manufacturing as the shipyard has formally put pen to paper to create the joint venture design vehicle that will commit the new vessels to paper.

On 4 July, 2016, China State Shipbuilding Corporation (CSSC) signed its formal contract with Italy's Fincantieri that establishes the joint-venture design company for cruiseship building in Hong Kong, China.

CSSC general manager Hao Qiang says that the joint-venture company will optimise the experiences of Fincantieri in cruiseship building as will CSSC's Shanghai Waigaoqiao Shipyard (SWS) with its top notch facility and designing plus its construction advantages. The priority in the cooperation is to introduce the world's most advanced large-cruise-building experiences to China and the Asia-Pacific region.

Fincantieri president Giuseppe Bono commented that he feels greatly honoured to partner with CSSC to undertake such a great mission. To promote the implementation of the project and the early delivery of the first of China's luxurious cruise liners, Fincantieri will contribute its resources and technology without reservation, pushing China's cruise industry to accelerate.

Up to this point, the made-in-China premium cruise strategy has entered the substantial launch phase and SWS will be the pioneer of the domestic premium cruise builder.

Premium cruising is invariably accredited as the jewel in the crown of world shipbuilding. To build such cruise liners is an essential demonstration of a country's competence in shipbuilding. Even the China Manufacturing 2025 strategy has listed cruiseship building as an important development for the industry.

Waigaoqiao Shipbuilding has proactively responded to the call of the nation and undertaken the task of building the first premium cruiseship

In recent years, China's prosperous cruise market has raised demand on the domestic designing and construction of deluxe cruiseships, which is also in line with the structure transformation and upgrading requirement to the mid-and-high-end ships for the shipbuilding industry, so that the country can develop high-tech ships, as well as attaining its objective of independent designing and manufacturing of large cruiseships.

Such a transformation is vital for the supply-side structural reform, stimulating the consumption, employment and high-end manufacturing. Building premium cruiseships, to a certain degree, represents the comprehensive competence of industry innovation and manufacturing.

As the top enterprise in China's shipbuilding industry, Waigaoqiao has proactively responded to the call of the nation and undertaken the task of building the first luxurious cruise liner, demonstrating the company's extraordinary sense of responsibility.

At the same time, Waigaoqiao regards the construction of premium cruiseships as a new engine to drive the enterprise for its own upgrading and transformation. The head of the company says that the world is expecting China to make its premium cruise liner debut.

The global demand for large cruiseships currently stands at about 13 vessels, yet now the annual turnover is only seven ships, resulting in a serious shortfall on the supply side.

China is also expecting the birth of domestic premium cruising among its own population. It's estimated that by 2020 and 2030, the country's cruise passenger population will reach 4.5 million and 17.5 million respectively, making it one of the world's largest cruise markets.

In the next 15-20 years, the annual demand for newbuild cruiseships for the Chinese market is expected to be five vessels. As the elite enterprise under the umbrella of CSSC in terms of shipbuilding competence and technology power, Waigaoqiao is positively involved in the mission of building China's domestic cruise vessels.

At the same time, this is beneficial for enhancing the enterprise's overall image and competitiveness, consequently improving its management, technology, competence and the upgrading and transformation of the industry and the shipyard.

Building a large cruise vessel is a complex systematic project that integrates shipbuilding, electromechanical, architecture, decoration, culture and arts, etc., all of which represent the most advanced shipbuilding crafts and management technology.

The international standards set for the comfort, safety, reliability and environmental protection are very high. The initial cruise project will also feature tough requirements with regards to project progress, management and supply chain management and will also bring a massive workload and with some tough technical challenges.

Currently, the global cruise designing, construction and supporting industry chain are mainly congregated in Europe. Italy's Fincantieri, Germany's Meyer Werft and STX in France are currently the most prestigious cruise shipbuilders, who take up over 90% of the medium and large cruise market in the world.

CSSC has resorted to multiple solutions to promote the domestic manufacturing of premium cruise liners. For example, on the demand side, CSSC has cooperated with a world-renowned cruise company; and on the supply side, it is co-working with cruise manufacturers to develop an innovative cruise industry business model.

On 20 August, 2015, CSSC and the China Investment Cooperation signed a Comprehensive Strategic Cooperation Framework and Premium Cruise Industry Joint-venture Protocol. According to this protocol, the two parties are to establish a joint-venture cruise investment company to support domestic cruise vessel design and construction and to nurture the domestic industry chain that will lay the foundation for China's cruise industry.

Construction site at Shanghai Waigaoqiao Shipyard

Bird's eye view of Shanghai Waigaoqiao Shipyard

On 21 October 2015, together with the China Investment Corporation, CSSC entered into another coalition, partnering with the world's biggest cruise operator Carnival Corporation & PLC.

In London, UK, they signed a co-investment agreement protocol for the joint investment that will establish a cruise shipowning company. This ceremony was witnessed by China's President Xi Jinping and the UK Prime Minister at the time, David Cameron.

On 30 May last year, CSSC integrated its cruise designing resources under its umbrella and the China Cruise Technology Institute came into being, which is formed on the basis of Waigaoqiao Shipbuilding and the naval architects GSI, MARIC and SDARI.

Its business priority is to develop deluxe cruise vessel designing and related fields' technology. It is reported that this cruise technology company will hold 60% of the share of the new cruise designing company and the remaining 40% of the equity will be held by Fincantieri. Shanghai Waigaoqiao Shipbuilding Co. is responsible for constructing and delivering the ships.

In the last two years, with support from CSSC, SWS has conducted a number of foundation projects that will establish infrastructure construction, the raising of capital, nurturing supply chain market, construction planning, and professional team building and training.

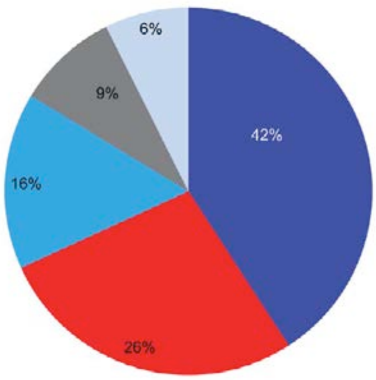
A senior company official said that with the advantages gained through an excellent delivery record, a reliable management system and premium resources, the company will enter the high-end cruise market, with smaller risks and with faster speed. They intend to work hard to make sure that the delivery of the first domestic deluxe cruiseship is successfully delivered before 2020.

SWS is confident of turning into a productive cruise builder craftsman that will challenge the hardest mission for the world shipbuilding industry that will honour the whole Chinese shipbuilding industry. *NA*

Clarksons Research: Historic and Scheduled Delivery
Data extract from World Fleet Register available at www.clarksons.net/wfr

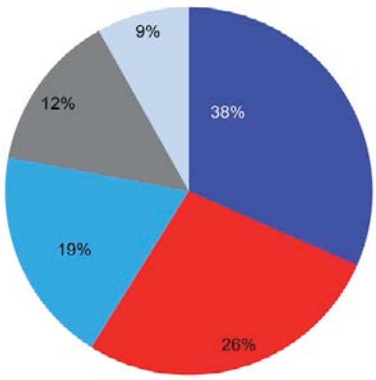
Vessel Type	2005		2006		2007		2008		2009		2010		2011	
	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half
VLCC >= 200,000	15	16	5	13	15	14	18	22	32	20	30	24	35	27
Suezmax 120-200,000	17	8	14	12	15	11	9	5	23	22	26	12	25	18
Aframax 80-120,000	37	28	29	21	29	27	26	42	62	33	39	31	28	31
Panamax Tankers 60-80,000	23	22	24	20	27	15	17	26	26	12	15	16	19	10
Products 30-60,000	58	49	60	56	71	69	73	91	93	68	66	46	46	28
Products 10-30,000	3	5	1	10	9	9	8	5	5	5	7	6	8	5
Chem & Spec. 10-60,000	29	40	55	43	60	62	84	103	105	69	76	61	51	41
Tankers < 10,000	30	27	30	28	32	45	63	89	72	70	64	51	53	52
Capesize > 100,000	22	25	32	27	30	27	20	24	34	77	101	112	128	123
Panamax 80-100,000	6	11	22	23	22	16	15	17	27	21	60	60	82	97
Panamax 60-80,000	41	33	36	26	22	22	23	20	18	15	18	33	36	44
Handymax 40-60,000	52	50	53	39	50	50	66	60	85	100	168	167	199	199
Handysize 10-40,000	34	45	38	38	48	63	74	71	113	149	158	169	170	173
Combos > 10,000	0	0	0	0	0	0	0	0	0	0	3	2	3	0
LNG Carriers	7	11	12	16	16	16	25	26	22	17	15	12	5	10
LPG Carriers	4	3	9	14	16	20	27	33	25	18	18	18	16	14
Containers > 8,000 teu	14	18	34	28	20	17	25	25	22	13	30	33	46	25
Containers 3-8,000 teu	38	52	45	53	58	71	71	61	61	57	79	41	33	26
Containers < 3,000 teu	62	78	89	115	105	122	139	109	67	52	55	26	33	30
Offshore	5	5	4	5	3	17	15	16	12	15	21	24	28	19
Cruise Vessels	3	1	6	0	7	3	6	3	3	6	9	4	4	2
Ro-Ro Ferries	13	5	11	5	12	10	20	6	11	8	10	13	10	9
Other	80	88	103	127	142	133	153	155	153	162	172	178	182	181
TOTAL	**593**	**620**	**712**	**719**	**809**	**839**	**977**	**1,009**	**1,071**	**1,009**	**1,240**	**1,139**	**1,240**	**1,164**

Orderbook by builder region (number of vessels)



BuilderArea	Actual number of Vessels
China	1233
Japan	826
S Korea	469
Others	270
Europe	223

Orderbook by sector (number of vessels)



Vessel Types	Actual number of Vessels
Bulker	2,030
Tanker	867
Other	532
Containe	440
Gas	354

2012		2013		2014		2015		2016				
1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half	OB2017	OB2018	OB2019
27	22	21	9	14	10	9	11	23	24	53	44	2
30	15	23	4	4	4	7	3	8	19	73	18	0
30	15	14	6	4	13	22	10	31	22	83	46	3
9	6	7	5	3	1	2	1	7	13	35	16	1
27	30	49	29	50	49	60	57	60	41	98	23	22
13	4	6	3	1	8	4	0	3	2	20	3	0
38	10	12	13	12	12	35	29	43	35	98	57	15
69	34	36	29	24	22	12	14	25	13	72	30	2
148	65	63	40	56	38	46	42	65	39	103	44	17
140	95	100	68	62	35	57	40	72	40	141	31	3
53	39	34	42	42	20	19	4	1	2	11	0	0
228	146	147	119	98	101	144	122	123	94	280	35	8
219	115	115	80	96	66	101	84	83	45	202	52	20
0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	4	13	14	19	16	16	15	16	61	44	21
13	7	23	16	14	14	25	40	49	32	80	24	8
50	28	51	33	59	41	59	62	37	26	95	56	12
40	19	46	29	26	24	19	6	2	0	27	11	0
33	38	29	17	22	27	26	34	37	24	119	70	19
29	10	11	19	31	30	25	14	25	20	91	44	14
6	1	6	0	3	2	5	1	8	2	12	14	18
11	8	6	6	12	5	12	6	6	14	35	22	3
190	97	99	80	72	62	65	46	51	55	198	75	19
1,404	**806**	**902**	**660**	**719**	**603**	**770**	**642**	**774**	**578**	**1987**	**759**	**207**

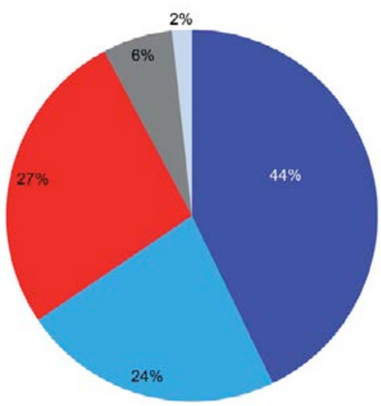
Data includes all vessels with LOA estimated at >100m

Where scheduled month of delivery is unknown an arbitary month of build has been applied for orderbook data

The orderbook by year of delivery on this page is based on reported orders and scheduled delivery dates and do not necessarily represent the expected pattern of future deliveries

All data taken as of 1st January 2017

Orderbook (DWT) by builder region



BuilderArea	Total DWT
China	94,937,865
S Korea	50,273,164
Japan	59,156,890
Others	13,532,723
Europe	3,805,826

Source: Clarksons Research

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