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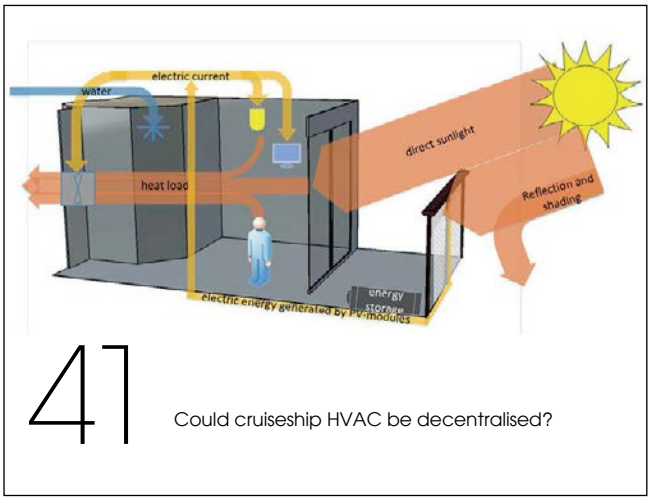

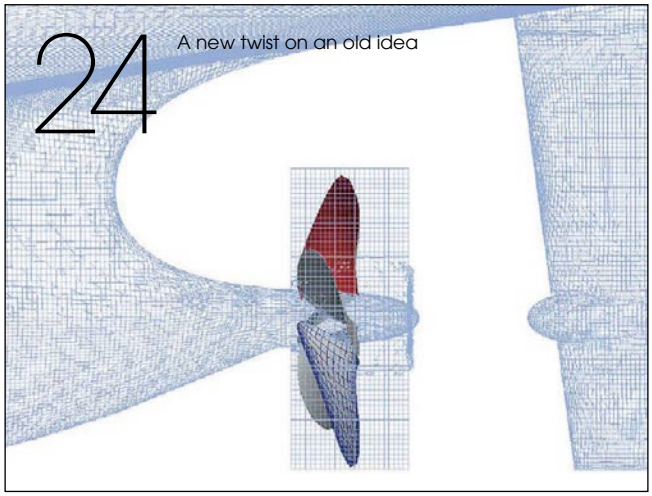

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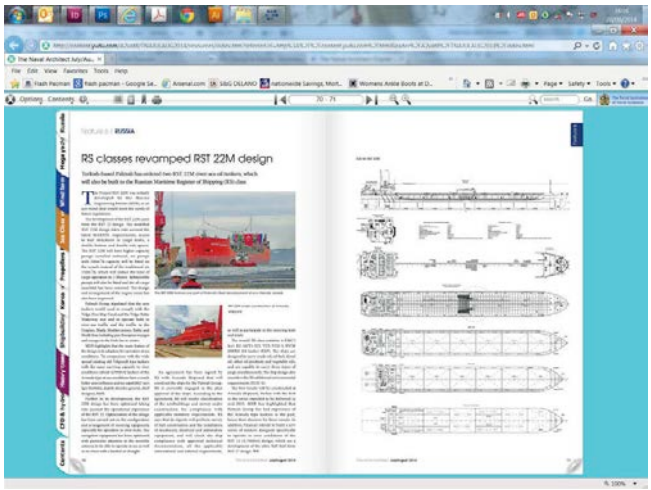

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Tomorrow's world today?

Concept design for Damen's wind-assisted cargo vessel

In May, the EU-sponsored Joint Operation for Ultra Low Emission Shipping, or JOULES, project held its final conference in Hamburg, bringing a formal end to four years of research on a variety of innovative concepts. One of JOULES' stated aims was the collation of a 'tool kit' of available technologies and energy sources for future ship designs. By combining with a Lifecycle Production Assessment (LCPA) Tool it is then possible to simulate the future energy use, environmental impact and financial cost of deploying a given combination of components.

The overarching consideration driving this is, needless to say, the EU's greenhouse gas policy, which aims to achieve a 40% drop in CO_2 levels by 2030 and an 80% reduction by 2050 (compared with 1990 levels). As such, the JOULES project considered low-energy design concepts for both the near-future of 2025 and further ahead in 2050. Unsurprisingly, the nearer deadline inspired more pragmatic solutions; Flensburger proposed a ro-pax powered by an 80/20 mixture of biogas and MDO; Damen a partially wind-powered cargo vessel. By 2050 it was widely expected that fuel cells would be a major energy source, with other projects proposing the Flettner rotors, synthetic diesel and LNG.

However, somewhat surprisingly, many of the concepts used fuels which are already available today, albeit not yet optimised to their full potential. It prompted me to ask whether the 2050 target was actually somewhat pessimistic and might realistically be achieved much sooner.

"I think you will find things move forward faster than we expect. Perhaps it's the willingness of the industry to have the confidence to invest," Peter Crawley, the JOULES EU-Project Officer told me. "To reach those higher TRLs [technology readiness levels] is very expensive and it takes confidence to make that step and invest on real deployment. Once it's in the market people see real benefits from this technology."

Drawing reference to the work on the aforementioned wind-assisted vessel, conducted in partnership with TU Delft, Damen's director of research Peter van Tersiga said the onus was really on shipowners. "We're in a state where we can do more accurate predictions of the performance of that ship, we can talk to the owners, discuss the application case and give them more accurate information on what they have to gain. There's a lot of scatter in the business in terms of the sustainability of operations."

> "We have to skate where the puck is going to be, not where it was"

Brian Simmers, head of energy and marine at Rolls-Royce, added that increased collaboration was essential. "It needs the ship builders to collaborate with the component suppliers and system integrators to deliver a system whose value is greater than the sum of its parts…I think the results we've delivered from JOULES has provided a basis on which partners can build the sort of globally optimised systems that we require to get on track."

Meanwhile, Klaas Visser, assistant professor of Ship Design, Production and Operation at TU Delft stressed that the changes projected for 2050 were radical and would take time to assimilate. "The concept of the ship may evolve but combustion related energy conversion is completely annihilated. So the big step towards fuel cells, for instance, and renewable energy and that has to do with TRL, market penetration, and price per kW."

Perhaps the other unmentioned part in this equation is society at large and the pressure that may come for increased environmental accountability. To those not affected by the matitime industry, it remains a largely unknown quantity but as more visible sectors, e.g. road transportation, clean up their act there will be greater expectations for shipping to accelerate progress.

The obverse to President Trump's cynicism about climate change is of course the frustration that things aren't being done quickly enough, but among ship designers and technologists it's not for want of trying, and while giving an NGO perspective on JOULES, Faig Abbasov, aviation and shipping officer for the European Federation for Transport and Environment, caustically noted that vessels built to IMO's EEDI standards are not driving efficiency and are often failing to exploit the more innovative technologies. In the case of some ship types, vessels are already significantly overcomplying with 2025 standards for a 30% efficiency improvement. "We have to skate where the puck is going to be, not where it was," he reflected.

EU's overall shipping strategy has been accused of being heavy-handed; however the JOULES project results suggest its targets are both feasible and in the long term not only commercially tolerable but also advantageous. If that same vision is not shared globally there is no shame in being ahead of the game. *NA*

Newbuildings

Ecoship names its yard

Finnish shipbuilder Arctech Helsinki Shipyard signed a letter of intent with Japanese cruise organisation Peace Boat to build the world's greenest cruiseship on 30 May.

Fittingly announced at a disruptive technology-themed NOR-Shipping, *Ecoship* features numerous energy-saving technologies and approaches that represent a paradigm shift in energy-efficient cruiseships, These include LNG fuel, wind propulsion, energy storage and recycling as well as water and waste loops that minimise the vessel's environmental footprint (see *The Naval Architect* January 2017 pp. 26-29 for more information).

"We are very excited to work with Peace Boat in the construction of this very special vessel," says Esko Mustamaki, CEO at Arctech Helsinki Shipyard, adding: "Ecoship will combine Arctech's know-how in technically advanced and environmentally friendly vessels with the well-established expertise of the Finnish shipbuilding network in designing and building of high-class cruise vessels and other special products. Arctech is a forerunner in developing and applying technological innovations, including LNG propulsion."

Peace Boat first discussed the Ecoship project in 2014 as a response to the ongoing cruise boom and began taking bids for construction of the vessel in the second half of 2016. In the same year, DNV GL signed a Memorandum of Understanding with Peaceboat at SMM, bringing the classification society onboard for design consultation following original design work from Spanish firm Oliver Design.

Knut Ørbeck-Nilssen, CEO DNV GL Maritime, commented: "It is always wonderful when such impressive projects using environmentally friendly technology take one step further towards being realized and we will continue to support this project."

A final contract for the 2,000 passenger, 60,000gt vessel is expected to be signed shortly according to Peace Boat, with delivery scheduled for spring 2020.

Regulation

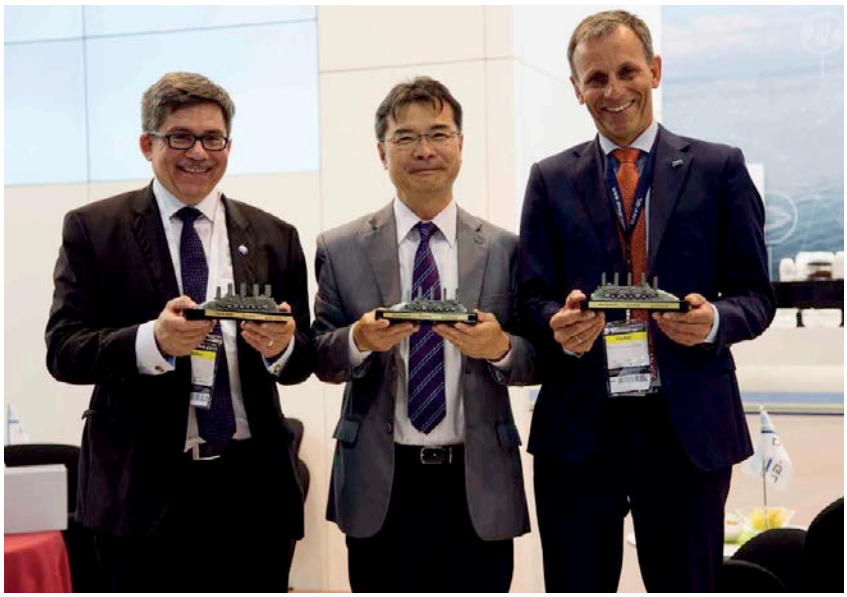
Push for ambitious CO_2 reductions

The International Chamber of Shipping (ICS) has upped its emission reduction rhetoric, calling for the International Maritime Organization (IMO) to adopt more ambitious CO_2 reduction objectives in line with last year's Paris climate change agreement.

A motion, to be made in conjunction with other shipping organisations, will propose that three aspirational objectives are taken up by IMO on behalf of the entire shipping sector as part of the initial IMO CO_2 reduction strategy to be agreed in 2018.

Firstly, to maintain international shipping's annual total CO_2 emissions below 2008 levels. Secondly, to reduce CO_2 emissions per tonne/km, as an average across international shipping, by at least 50% by 2050 compared with 2008 and, thirdly, to reduce international shipping's total annual CO_2 emissions by an agreed percentage by 2050 (compared with 2008) as part of a continuing trajectory of CO_2 emissions reductions.

Esben Poulsson, ICS chairman, says: "The long term future of the industry, like the rest of the world economy, must eventually be fossil fuel free. The trajectory for getting there, not least the development of alternative fuels, could well take us several decades. But this will only be achieved if the industry itself pushes for the adoption by IMO of some suitably ambitious



Peace Boat director and founder Yoshioka Tatsuya (centre), Arctech CEO Esko Mustamäki (left), and Jon Rysst, senior vice president & regional manager North Europe, DNV GL (right)

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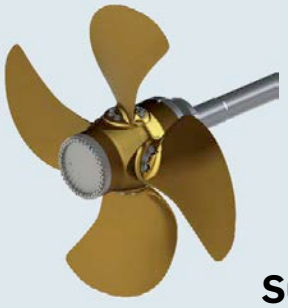

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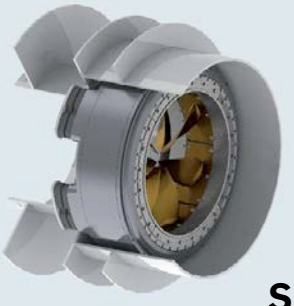

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objectives so that all concerned are under no illusion about the scale of the task ahead."

ICS is keen for IMO to control additional CO_2 reduction measures, motivated by the wish to prevent "the danger of market-distorting measures at national or regional level".

However, taking into account developing nations' concerns regarding knock-on effects for trade and sustainable development, the trade association asserts that "any objectives adopted by IMO must not imply any commitment to place a binding cap on the sector's total CO_2 emissions or on the CO_2 emissions of individual ships".

Newbuildings

Orders up at Ulstein Verft

An undisclosed shipowner has signed a letter of intent (LOI) with Norwegian yard Ulstein Verft for the construction of one or more expedition cruise vessels.

The vessel(s) will be based on Ulstein's CX104 design type, which features the yard's X-Bow hull design, measures 120m x 20m, and has a passenger capacity of 120-130 people.

According to the yard, the vessel design for these ships will surpass the latest regulatory demands of the Polar Code and illustrates its focus on safety and comfort for passengers. In meeting these demands, environmentally friendly and sustainable solutions are set to be implemented; the X-Bow improves efficiency and reduces emissions design, but also performs well for passenger and crew comfort, reducing motions.

Gunvor Ulstein, Ulstein Group, says: "The past few years we have worked strategically to target the exploration cruise market. This LOI proves that we are now confirming our position in this market."

Delivery is scheduled for 2019 and 2020, which suggests more than one expedition cruise vessel could be built for the anonymous shipowner.

Classification

ClassNK updates rules

Japanese class society ClassNK released amendments to its Rules and Guidance for the Survey and Construction of Steel Ships on 1 June 2017 as part of its continued effort to adapt guidance in line with new industry developments.

The latest set of amendments include: incorporating research and development findings related to the Torsional Strength of Container Carriers; incorporating feedback from damage investigations related to Measures for Steering Control System Failures; changes to the Marking of Safe working Loads in response to industry requests; amendments to the Recording of Engine Status etc. in Nitrogen Oxide Emission Control Areas as a response to changes in international conventions; and amendments to the Welders and Welder Qualification Tests due to changes in IACS Unified Requirements. *NA*

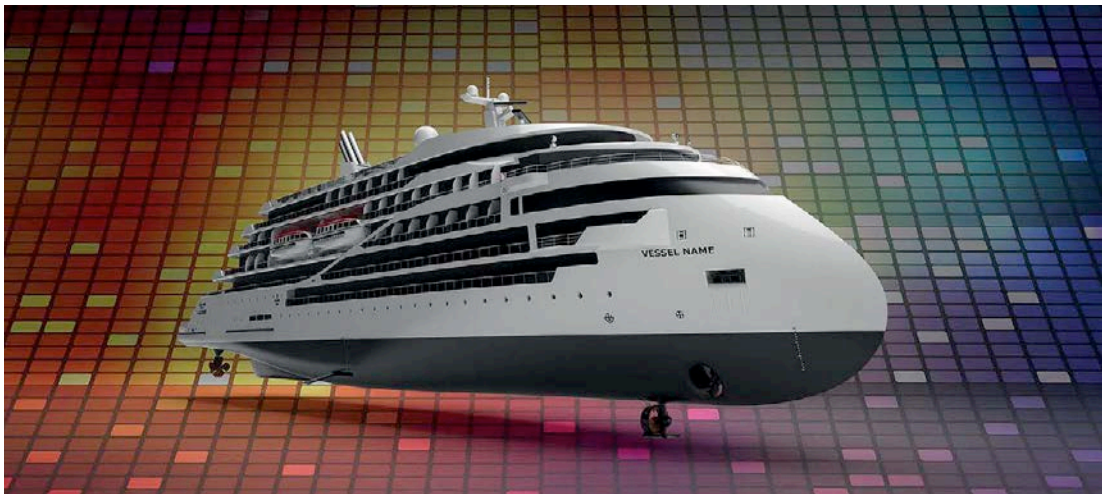
Correction 1

In May's article "A quiet incentive" it was reported that BV's specialised partner for noise & vibration related issues was "TDI SL". BV's specialised partner is in fact Técnicas y Servicios de Ingeniería SL (TSI SL). Our apologies for any confusion caused.

Correction 2

The article "Fighting the windbreak" in NA's May issue stated that its authors were all from CE Delft University. Jonathan Köhler is affiliated with Fraunhofer ISI, Dagmar Nelissen with CE Delft and Michael Traut with the University of Manchester. *The Naval Architect* apologises for this error.

Ulstein Verft lands LOI with unnamed shipowner (source: Ulstein Group)



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Design awards announced

A unique feature of the bi-annual NOR-Shipping Exhibition is its awards programme that recognises the efforts that shipowners, designers and others go to in order to keep ships evolving to meet today's demands, writes *Malcolm Latarche*.

There is some overlap in the criteria for the Energy Efficiency Award and the Next Generation Award but whereas the former is for an existing ship, the latter is for a ship or concept that has yet to be completed. In both instances, the ship or project has to be entered by the owner or an organisation with a strong connection to it so the jury members are not at liberty to pick from all vessels or projects.

This time there were around 20 entrants in each category. Several of those in the Energy Efficiency Category will be familiar to *The Naval Architect* readers as they have been featured in *Significant Ships of 2016*. The short list for the Energy Efficiency Award included a cruiseship, a ro-pax ferry, an LNG carrier and a handysize bulk carrier, but the full list also comprised car carriers, containerships, tankers and cement carriers.

On the short list, *Harmony of the Seas*, the latest and largest in the Oasis Class which features no less than 89 different energy efficiency improvements over the original ship that have all contributed to making it 20% more efficient; *Seaspan Swift*, the first of two innovative ro-pax ferries with an LNG/Hybrid propulsion system consisting of Wärtsilä dual fuel engines which run mainly on LNG and a Corvus battery energy storage system; *Seri Camellia*, an LNG carrier with enclosed Moss type tanks that save weight and add strength and featuring Mitsubishi's Ultra Steam Turbine Propulsion Plant giving a 13% improvement in efficiency over conventional steam turbines and *Venture Joy*, a 43,500dwt, geared Handysize bulker designed by Deltamarin for Hamburg Bulk Carriers, Germany.

It was the latter vessel that most impressed the jury as its optimised hull form and propulsion system allows it to meet EEDI Phase III requirements nine years ahead of time. The ship is a modification of the designer Deltamarin's B.Delta43 type with an optimised hull and a lower draught intended to accommodate the trading pattern of the owner.

The B.Delta43 is itself an elongated version of the B.Delta37 type, featuring an extra 10m to give an loa of 189.99m, a beam of 30m and a maximum draught of 10.7m. It is claimed to have improved manoeuvrability compared with standard class bulk carriers and very low vibration levels due to its optimised propulsion arrangements.

The vessel is equipped with a MAN-B&W 5S50ME-B9 main engine developing 6,050kW at 99rpm. This is one of the most popular engine choices for mid-size bulkers and tankers and was chosen as it is possible to modify it to ME-GI configuration by fitting a modified cylinder cover, electronic gas injection valves, large volume accumulators, double wall pipes and control and safety systems. The conversion is not cheap, but having an LNG-ready engine, the ship's flexibility and emissions will make it attractive for most of its working life.

There was a similarly eclectic mix of ship types and projects for the Next Generation Award, which included two containership designs, another bulk carrier from Deltamarin, expedition cruiseships, ferries and a conversion project to incorporate hybrid propulsion on two existing ferries.

The short list comprised a series of feeder container designs by Danish naval architects Knud E. Hansen, one of which employed a trimaran hull form intended to overcome cargo handling problems associated with high sided narrow vessels; the LNG-ready /chemical tanker design FKAB 7990 for use in SECAs with a PTI 'Take me home' device, through a retractable bow thruster powered from the auxiliaries; conversion of two existing diesel powered ferries *Tycho Brahe* and *Aurora* to all electric propulsion using ABB technology and shore-side charging using industrial robot mooring.

The final vessel on the short list was the recently announced large hybrid plug-in ferry for Color Lines. Hybrid propulsion systems have attracted a lot of attention in the last few years, but so far most have been on small ferries or offshore vessels. The 30,000gt ro-pax ferry currently known as *Color Hybrid* has been designed for international service by Fosen Yard and is being built by Ulstein Verft.

Full details of the ship's equipment have yet to be released but it will be diesel electric and fitted with four main engines. The battery energy storage system can be topped up using the ship's power system with engines running at optimum speed for the circumstances, and also from shore-based charging stations at the berths.

Because of its size, the award jury felt that the ship had the ability to influence the design of many more types of vessels, addressing the topical issue of the impact of ship emissions at ports on human health. By installing a hybrid propulsion system, this vessel will be able to enter ports without any emissions and emitting much less noise than conventional vessels. *Color Hybrid* also has other attractive features, including a waste heat recovery system and other energy saving measures. *NA*

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Engines

MAN Diesel engine completes ethane trials

MAN Diesel & Turbo has announced that gas trials of the world's first gas injection ethane engine (ME-GIE) onboard the liquefied ethane gas carrier *Gaschem Beluga* have been a success.

The two-stroke Mitsui-MAN B&W 7G50ME-C9.5-GIE unit is the first in a series of two engines serving as the main propulsion for two 36,000m^3 LEG carriers ordered by Hartmann Reederei of Germany and Ocean Yield of Norway. The engines were built at Sinopacific Offshore Engineering (SOE) in Qidong, China.

MAN Diesel & Turbo said that the ME GIE had responded as expected to different loads when operating on ethane and that ethane levels within the double-walled piping fell comfortably within the lower explosive limit. *Gaschem Beluga*'s trials were conducted between Houston and the Bahamas but it has subsequently crossed the Atlantic powered solely by ethane.

Capt Ulrich Adami, fleet manager of the vessel's operator Hartmann Reederei, says that the development process was hard work. "We already knew that *Gaschem Beluga* is a very good ship with a pioneering technology. But there is always a difference between a plan and its successful implementation."

Gaschem Beluga's propulsion package also includes an AT3000 remote control system, VBS 1350-ODS Mk 5 propeller and shaft generator with frequency convertor that can run from 80-100rpm.

MAN Diesel & Turbo has a further eight ME-GIE engines on order. Earlier, the company revealed that further research had proven the ME-GIE could also operate on other gas types, including waste gas and volatile organic compounds (VOCs), opening the door for further applications in offshore or FPSOs.

www.dieselturbo.man.eu

The 7G50ME-C9.5-GIE onboard the *Gaschem Beluga*

Wastewater management

ACO Marine chief's wastewater warning

"Wastewater management presents a challenging dilemma that if not addressed in the design stages can impact a vessel's operational flexibility," Mark Beavis, managing director of ACO Marine told delegates at a Royal Institution of Naval Architects conference in May.

Beavis said that while water treatment is a 'mission critical' component to operations, it is, in reality, "an afterthought" for naval architects involved in the design and construction of arguably the world's most prestigious and innovative vessels.

"Many systems onboard can technically malfunction without passengers and staff ever noticing… but if the wastewater system associated with the bathrooms and toilets fail, it will not go unnoticed by the owner and guests…A process overload or even breakdown could result in pollution and environmental breaches often attracting hefty fines and, in extreme cases, criminal proceedings against the crew and owner of the vessel," he said.

Beavis emphasised the importance of not just the treatment aspect of the problem, but to consider wastewater treatment from a "whole ship" perspective.

"To understand what wastewater is being produced where, in what quantities, at what frequency and how it will be stored and transferred around the vessel prior to, and after, treatment, is crucial to not only meeting stringent wastewater requirements, but also to optimising the operational performance of the vessel."

Considering the impact of IMO MEPC 227 (64), the revised wastewater discharge rules that entered into force in January 2016, Beavis added: "Given the increasing trend for expedition-type yachting in ecologically sensitive areas such as the Baltic, the new regulation will make some existing plant incompatible as MEPC 227(64) changes both discharge requirements and test protocols. It has the specific aim of reducing nitrogen and phosphorous from passenger vessel treated water discharges, preventing the acceleration of nitrification of the seas."

www.acomarine.com

Ballast systems

Evoqua launches upgraded BWMS

Evoqua Water Technologies has launched a re-modelled version of its SeaCURE electrochlorination ballast water management system (BWMS).

Launched at Nor-Shipping 2017, the next generation SeaCURE is a skid-mounted, plug-in-and-play BWMS

The remodelled SeaCURE

that is 76% smaller and 85% lighter than earlier generations of the technology.

"Without reducing the high flow rate capacity of the existing SeaCURE system, we have dramatically reduced the number of components to create a modular system mounted on a 2m x 1.5m, easy to install skid. It is one the of smallest ballast water management solutions available capable of treating flow rates of up to 6,000m^3/h," explains Matt Granitto, business manager for Evoqua's ballast water business

The new SeaCURE can fit through standard hatchways and can be installed by riding crews, substantially reducing pre-installation work and time required during drydock.

Already IMO approved, the system is in the final stages of USCG testing at Netherlands-based Marine Eco Analytics (MEA-nl) with a view to formally applying for USCG approval in the summer.

www.evoqua.com

Stabilisers

Rolls-Royce sells Intering business

Rolls-Royce Marine Deutschland has sold its Intering business to Hamburg-based marine engineers Hoppe Marine in order to concentrate on the core areas of its business. Intering, which Rolls-Royce originally acquired in 2001, builds U-Tank Systems for roll damping and both blower and pump-based anti-heeling systems.

Hoppe Marine has taken over all new building projects as well as related spares and servicing activities. First established in 1949, the company is already firmly established in engineering tailor-made anti-heeling and passive roll damping systems. In 2010 it acquired US firm Flume Stabilisation Systems. It also has a subsidiary company in Shanghai.

www.hoppe-marine.com

Propulsion

Veth launches compact propulsion unit

Netherlands-based propulsion manufacturer Veth Propulsion used Nor-Shipping as a platform to launch its compact propulsion unit: the Veth Integrated L-drive.

Described as the "most compact electrical propulsion system in the world" the Integrated L-drive can be fitted across various ship types. The permanent magnet (PM) motor, which was developed in collaboration with Visedo, is said to allow for a much lower mounting height and is 40-60% more compact than an asynchronous motor.

In addition to being diesel-electric driven the L-drive includes water-cooling, electrical controlling and is said to guarantee greater noise reduction. The L-drive has only one-gear transmission which is also said to improve efficiency as there is no gear transmission within the vessel. The company's CEO Erik Veth was also keen to stress the superior performance of PM motors in part load, noting: "For example at 25% load, there is an improvement in efficiency of 5.2%."

www.vethpropulsion.com

Coatings

Selektope wins Stena RoRo contract

Selektope, the organic non-metal antifouling compound will be applied to the hulls of four newbuild ropax vessels being built for Stena RoRo, it was announced in June.

The biorepellent ingredient, which repels barnacles by temporarily stimulating the barnacle larvae, will be added to the paint coatings used on the vessels. Tests have proven the compound to be effective even at low concentrations (0.1% w/w) and can either be applied to copper-based coatings or as a replacement for copper.

To date, marine coatings containing Selektope have been applied to over 150 vessels, including tankers, containerships and LNG carriers. In addition to lower maintenance costs from reduced water resistance and fuel savings, its hardfouling protection continues to work even when the vessels are idle.

Speaking to *The Naval Architect* at Nor-Shipping in June, Philip Chaabane, CEO of I-Tech AB, which developed, manufactures and markets Selektope, said that they expect to sign contracts with a number of paint manufacturers in the near future.

www.selektope.com

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MOSS improvement to fuel global growth

MISC Berhad (MISC) is expanding its LNG fleet with five 150,200m^3 Seri C Class MOSS carriers. Its Project Management Team tells *The Naval Architect* about the cutting-edge engineering technology being deployed and how this technology is helping to build a better world

The first two vessels in the series, *Seri Camellia* and *Seri Cenderawasih*, were delivered by Hyundai Heavy Industries (HHI) on 30 September 2016 and 20 January 2017 respectively. The remaining three will be delivered progressively in 2017 and 2018.

Seri Camellia was nominated as one of the top four candidates for the 2017 Nor-Shipping Energy Efficiency Award in recognition of its outstanding design. The vessel was also named as one of the Great Ships of 2016 by MarineLink. The vessels are designed for the export of LNG from the conventional onshore LNG terminal as well as from state-of-the-art Floating LNG (FLNG) vessels.

Figure 1: Aerial Photo of Seri C Class LNGC

Design process

During the pre-contract stage, numerous ideas and design concepts were tabled due to the Seri C Class' requirement to load cargo from FLNG offshore. With such high requirements and the need for FLNG operations, many factors were studied, particularly the strength of a cargo tank that can withstand sloshing loads during partial loading at open seas.

Membrane and MOSS containment systems, which have a proven track record over many years of operation, have been studied thoroughly in all the relevant technical and commercial aspects. Both systems offer high integrity and unique advantages in the design and day-to-day operations of a vessel, and Hyundai Heavy Industries (HHI), a builder of both Membrane and MOSS systems, was ready to provide either solution upon MISC's request. In the end, MISC decided to move ahead with MOSS containment systems for the new Seri C Class, complementing its existing Membrane ships to offer greater operational flexibility.

Figure 3 shows a simplified comparison between a typical Membrane LNGC and an IHS MOSS LNGC of similar size. The larger cross sectional area of an IHS MOSS LNGC is translated into a windage area about 18% larger than the Membrane system and 7% (longitudinal only) larger than a conventional MOSS LNGC. On the other hand, an IHS MOSS LNGC shows an improved wind coefficient over conventional MOSS and Membrane LNGC based on wind tunnel test results carried out at Force Technology, Denmark. This improved wind coefficient was recorded due to better air flow on the flush tank cover.

The breadth of Seri C Class is sized for the New Panama Canal with the limitation of 49m. The large cargo hold area surrounding the cargo tanks, continuous tank cover and the breadth limitation have resulted in a narrower ship side passage way area compared with conventional MOSS and Membrane LNGC systems. Hence, designers gave significant consideration to the layout and position of deck outfittings such as the cargo manifold, accommodation ladders, mooring, safety equipment, etc. Even with constraints of this kind, the Seri C Class LNGC is still compatible with almost 97 terminals, ensuring the flexibility of trading routes. Moreover, the greater distance between MOSS tank and hull side shell creates a protection barrier to reduce the possibility of tank damage in an event of grounding or collision.

In terms of hull strength, the IHS tank applies the concept of structural continuity, enabling the tank cover to be integrated with the primary structure. The overall structural strength of the vessel has consequently been improved while achieving a 3% reduction in steel weight. With the continuous tank cover, the support of the piping and outfitting on the IHS deck have been redesigned with simplified structures compared to conventional MOSS LNGC. Such a design also improves the maintainability of the vessel.

For the past decade, research on side-by-side loading has advanced

tremendously, making a breakthrough in the understanding of offshore cargo transfers. The important criteria for side-by-side loading with a FLNG includes the multibody dynamic motion and mooring analysis, site specific environmental conditions, wind shielding effect, hydrodynamics interaction, etc.

Several novel model tests in side-by-side condition between IHS MOSS LNGC and FLNG have been conducted at the Marine Research Institute Netherlands (MARIN) to analyse the effect of liquid motion during partial loading conditions in a MOSS tank. The detailed berthing simulation performed at the Malaysian Maritime Academy (ALAM) is also crucial to simulate the offshore conditions for navigation and manoeuvring prior to actual side-by-side loading operation.

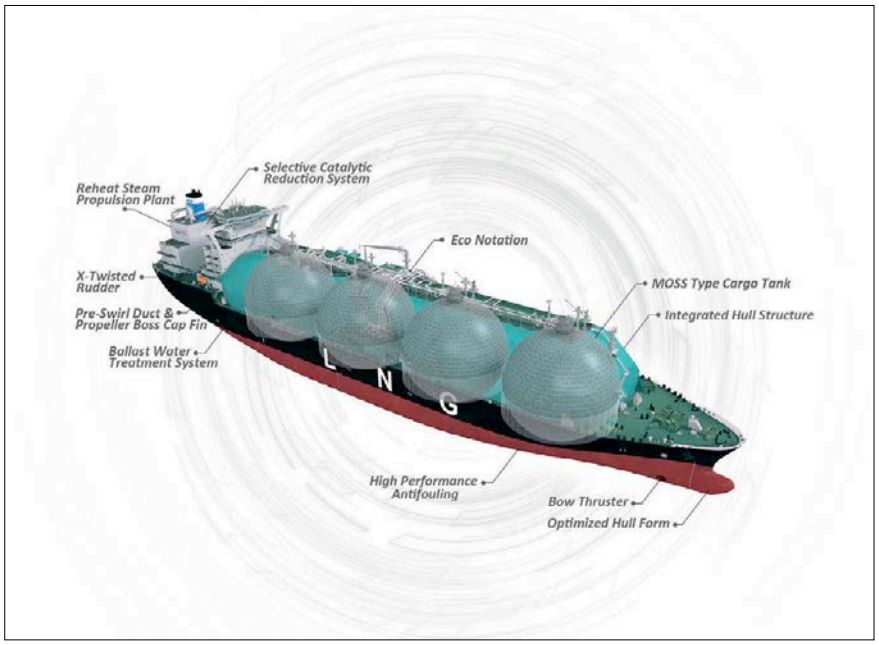


Figure 2: Features of Seri C Class MOSS LNGC

Construction

Synergy between the Project Management Team (PMT) and the builder, HHI has been pivotal to the success of the project so far. HHI, as the world's largest shipbuilder has revived the production for MOSS cargo tanks after more than 10 years of inactivity.

The novel design of the vessel and a short engineering phase (due to a tight delivery timeline) resulted in huge challenges during the engineering and construction stage. The MOSS LNGC build started off with construction of the aluminum cargo tank, and was followed by construction of the hull structure. This was due to the fact that the MOSS tank is independent from the hull structure, and can therefore be fabricated separately and erected onboard when the hull structure is ready. The separate construction of MOSS tanks offers the benefit of making the fabrication process less complicated and improves quality control.

Another noticeable advantage of the construction, inspection and repair for MOSS tanks is how their insulation works. Constructed of panels and installed on the outside wall of the cargo tank surface, it is easily accessible via a working platform during installation works.

Another challenge during the construction was the large painting surface that includes the external and internal facades of the IHS tank. Relatively speaking, the painting job is larger than those for the Membrane and conventional MOSS LNGC systems, requiring higher manpower and safety precautions to be taken during construction.

Project management

The PMT for the new generation MOSS LNGC was established early on in the conceptual and pre-contractual stage and has seen completion of the project through. Involving the team in the complete project cycle (pre-contract, design review and construction supervision) was advantageous, providing continuity in terms of engineering, project interface, lessons learned and project development.

The PMT implemented several initiatives beyond typical shipbuilding practice, namely detailed bulk material testing, joint 3D engineering reviews, and extensive subcontractor/vendor audits. Bulk material tests were carried out on the steel plates, insulation materials, electrical cables and other items that do not undergo specific Factory Acceptance Test (FAT). This was based on previous experiences in which some items with type approval failed or did not meet necessary requirements. The joint 3D engineering review by all parties was essential in the initial development of the new design, pulling optimum human factor engineering, system integration, operability, maintainability and constructability together.

The design verification and construction supervision of the vessels

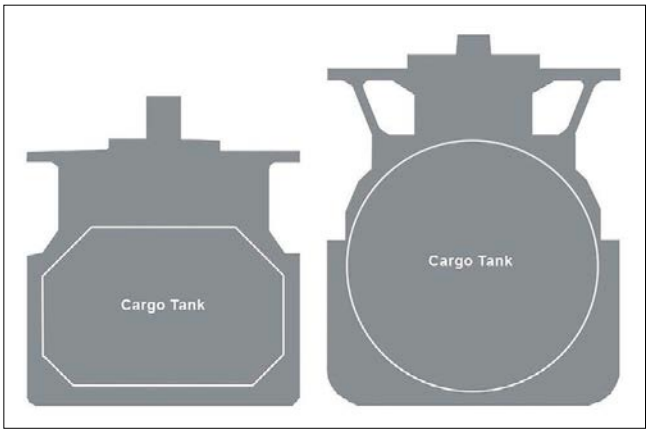


Figure 3: Transverse View Comparison of typical 150,000 m^3 Membrane LNGC (left) and IHS MOSS LNGC (right)

were carried out by two Classification Societies (Lloyd's Register & ABS) for the project with a "Sunshine Clause" that enables open access to comments on the engineering drawings made by Classification Societies.

Engineering sustainability

The Seri C Class LNGC has adopted several advanced technologies which include energy efficiency and emissions reduction. The vessels are also installed with the Ozone Ballast Water Treatment System, as well as Selective Catalytic Reduction (SCR) systems in compliance with IMO NOx Emission Tier III requirements. Voluntary adoption of the Eco Notation provides safe working conditions for the ship's crew and protects the marine environment. No material contains asbestos, Halon, PCB, HCFC, CFC and toxic materials. The usage of Low Friction Anti-Fouling Paint on the vessel also contributes to reduced speed losses during operation. By applying the latest available and proven technology, the Seri C Class LNGC has achieved an attained Energy Efficiency Design Index (EEDI) of about 7 [g-CO_2/ton.NM].

Seri C Class is designed for sustainability, not only in terms of lifecycle energy efficiency and green technology, but also for prospective LNG shipping requirements. The successful loading of the world's first FLNG cargo is one of the many capabilities and features of the Seri C Class, but it offers more. The robustness of the MOSS cargo tank can provide a future conversion option, allowing conversion of the vessel to a Floating Storage Regasification Unit (FSRU) without further strengthening of the cargo tank. *NA*

Figure 4: Cargo tank insulation works in progress

Cradle of innovation

Ship design and ship operations continue to be bolstered by new, technologically empowered approaches. Nick Danese, NDAR, presents highlights from COMPIT 2017, a conference dedicated to the latest leaps and bounds in maritime technology

First settled some 230,000 years ago, Wales was an international commerce centre by the time ancient Greeks arrived searching for tin. Celtic Britons gave way to the Romans, who were followed by the Anglo-Saxons. Finally, centuries later, delegates from across the maritime industry made their way to the Welsh capital, Cardiff, for three days of technological insight at COMPIT 2017.

In overview, sea-breaking concepts included voluntary slow steaming aimed at reaching port faster; exploiting Big Data beyond the still infant Digital Twin to drive simulation by parametric regression of large and disparate but analogous data sets; and the handling of encounters between COLREG compliant ASVs, UAVs and "rogue" vessels. None are new per-se, but they brought an arguably unprecedented thrust, pushing forward an otherwise slow to react industry.

Day 1 – a means to design

COMPIT 2017 started off gingerly with David Andrews, University College London, arguing the importance of selecting a "style" of design in the early ship design process, especially when working with complex multi-functional vessels. Mark Roth, TU Delft, reported on the application of network theory in pursuing an understanding of the physical relationships in General Arrangements by applying the TU Delft packing approach coupled with centrality measures to rank nodes and quantitatively assess the qualitative properties of the arrangement. The well-worked packing approach was also benchmarked by Siebe Cieerad and a team from The Ministry of Defence (The Netherlands) in re-designing a Walrus class submarine; a great way to assess legacy while employing leading edge strategies such as extensive and CAD-connected use of virtual reality.

Rachel Pawling, University College London, called for a more holistic approach to the early stages of ship design. Online implementation of a Design Building Block approach and Queuing Theory applied to "design systems rather than ships & craft" were reviewed.

Big Data was lingering in the work of Ted Jaspers, TU Delft, who presented "Elucidating Families of Ship Designs using Clustering Algorithms", and Javascript was showcased by NTNU's Henrique Gaspar as being sadly underused in our industry.

"4GD Framework in Ship Design", by NTNU's Greta Levišauskaitė, clearly presented how the strategic application of cutting-edge technology is all too often blocked by the underlying requirement to change established mindsets. In this scenario, successfully combining rich product lifecycle management (PLM) systems, efficient design tools and a 3D model made of thousands of parts requires innovative thinking, which can unfortunately be perceived as risk.

Epilysis, a new Finite Element solver developed by betaCAE, Greece, was identified as faster than current methods, and Siemens illustrated how their ongoing development will transform vessel development from a discrete sequence to a continuous process that feeds real-life data into the design process. An interesting look at traditional design decision-making based on the system and component levels came from Sabah Alwan, NTNU, who found that a Process Integration and Design Optimisation strategy (PIDO) requires well experienced, discerning engineers to interpret the results.

Offering a taste of the autonomy presented on day two, Heinrich Grümmer, aXatlantic, presented a first principles, self-righting, solar powered ASV designed to go transatlantic propelled by a steerable, ring-driven thruster.

Yard 4.0 quickly became the focus of the afternoon. A team from SENER described a PLM-integrated approach to the age-old puzzle of quasi-sister ship design and production, while a method for production work prediction, based on a four tier hierarchical organisation of empirical data collected during past projects, was presented by Lode Huijgens of TU Delft. Authors from Seoul National University, Xinnos Co. and Korea Maritime and Ocean University described how a Process Centric Modelling Method was applied to Block Transportation shipyard logistics, thereby improving build efficiency.

COMPIT 2017 reports changing technological sights (source: EMIT)

Day 2 – sensing a change

Coltraco Ultrasonics' CEO, Carl Hunter, began day two discussing how inadequate fire regulation and onboard fire-fighting systems have become in an age of difficult to reach cargo and ill-maintained gas and water delivery lines. He particularly focussed on how onboard sensors can aid a vessel's fire safety. This led into subsequent discussion of the use of wireless communications in condition monitoring by the University of Strathclyde's Anna Michala, a concern that was shown to turn crucial when addressing security, especially in the case of military vessels, according to Scott Patterson, Babcock International.

Steering the pure technology course, Gunnar Brink of Fraunhofer Institute of Optronics, System Technologies and Image Exploitation charted the lack of technology for deep-sea floor mapping (acoustical, light and electromagnetic), the same technology required by underwater communications.

Autonomous Vessels were the subject of many interesting presentations, touching upon path-selection, collision avoidance, navigation and decision making. Fast ASVs were shown to efficiently adhere to COLREGs (Collision Regulations) by Howard Tripp, ASV LTD., while, according to work undertaken by Yogang Singh and fellow researchers at the University of Plymouth, it is possible to compute path cost and length of autonomous journeys to ensure travel effectiveness using an obstacle-repulsive/goal attractive algorithm. Perhaps most interesting was the MAXCMAS project presented by representatives from Lloyd's Register, which discussed collision avoidance when at least one converging vessel does not comply with COLREG – a very pragmatic study that will extend into the times of ASV-only navigation. In addition, Axel Hahn from the University of Oldenburg demonstrated how a research team built and sailed a testbed ASV with the aim of verifying and validating e-navigation technologies.

Stephan Procee, NHL Hogeschool, argued that, while a seemingly good idea, bringing augmented reality to the ship's bridge by, for example, showing vessels made invisible by fog but tracked by radar on the windscreen using heads up display technology (HUD), is hampered by various considerations, not least culture and the value and significance attributed to colours by different people. Seppo Helle, University of Turku, mentioned the generally overlooked virtual reality (VR) olfactory, gustatory, aural, and haptic methods, and importantly point out mental and physical workload demand and rated performance and frustration levels – key factors if VR is to be accepted by operators. Added to this was Hahn's (University of Oldenburg) discussion of damage minimisation strategies when collision is unavoidable, such as by steering a least-energy impact course – an excellent example of applied research!

The history and future of VR were subsequently discussed by Denis Morais, SSI, followed by recognition by DNV GL's Christian Cabos of the need for continued human presence when remotely performing hull surveys with drones and VR to provide line-of-sight piloting and on-site hull condition assessment.

Day 3 – end game

Day 3 illustrated how to exploit hundreds of millions of daily AIS (Automatic Identification System) transmissions ranging from ship's position to operational data for commercial, logistics and condition monitoring. André Keane, Ulstein, picked up on the subject of how to exploit heterogeneous data referring to the same measures, introduced earlier by Siemens' Patrick Müller ("Marine 4.0 – Condition Monitoring for the Future"), and explored the Fast-Track Concept Design Analysis tool developed by Ulstein to integrate a multi-disciplinary platform that takes into account the volatile, uncertain, complex, ambiguous world.

Instrumental to expanding the Digital Twin model to learn from many other ships proposed by the author, Hideo Orihara (Japan Maritime United Corporation) collected ship performance data on an operating bulk carrier to be used in estimations based on parametric regression of real ship data.

Enter C3PO and R2D2 of Star Wars fame, only underwater: CADDY, a diver assistant robot developed by Marco Bibuli, won the DNV GL COMPIT Award, and of all the burgeoning technologies of late it is the one that stands out. "The robot communicates with the diver by understanding gestures and acknowledges by light signals and task execution", while operating in less than ideal visibility and adapting to the unique variants specific to each master. Will CADDY read the diver's mind by COMPIT 2018? Last but not least, Tracy Plowman (DNV GL) and Volker Bertram (DNV GL) discussed "Maritime training in the 21st Century", touching upon the rapidly and vastly changing culture of young people going through higher education, the paradigm shift offered by technology commonly used outside academia but not within, shortening of courses in parallel with extension of training to life-long periods, and indirectly connecting to Rachel Pawling (UCL), who argued that the current "21st Century students are being taught 19th Century methods using 20th Century tools".

Bertram's "Future of Shipbuilding and Shipping – A Technology Vision", was a pragmatic, if not at times sober yet vibrant critical review of the industry which does not exploit the potential offered by currently common technologies and strategies. Many passages deserve highlighting, such as the strategic adoption of low speed steaming, the persistence of strong and cheap steel, time-based image processing for automatic condition assessment, lengthening of ships lives, the inception of metal foams and disposal-managed composites (perhaps reducing the requirement for recycling), anti-fouling nano-coatings, LNG fuels rendering heavy machinery obsolete, fuel cells and batteries, air lubrication, wind assisted propulsion, knowledge based computation. Other predicted developments already exist in commercial form, such as smart glasses (ex. the interactive Daqri helmet) and 3D printing (the first ever 3D printed propeller was submitted for Class approval in May).

Castello di Pavone, situated in the Italian Alps, will play host to COMPIT 2018. The castle's halls are worthy of the undoubted excellence of the papers to be read; dates are blocked, steady as she goes!

Author

Nick Danese is the founder of Nick Danese Applied Research (NDAR), specialising in engineering and system integration around unique software products like ShipConstructor, MAESTRO, ShipWeight, GHS, Navisworks, etc. He regularly presents at various ship design, ship building and related research conferences. *NA*

Old idea yields fresh gains

Asymmetric stern designs may be set for a revival thanks to advanced CFD and improved manufacturing approaches. Karsten Hochkirch and Bardo Krebber of DNV GL explain why

The art of ship hull design has dramatically changed within one generation (30 years), moving from simulation-based design to multi-objective optimisation. This latter approach has become state-of-the-art both for hull design in newbuildings and bulbous bow retrofits. However, the achieved improvement varies greatly due to design constraints.

A general design guideline is: the stricter the constraints, the smaller the potential for improvement. Or, vice versa, the more freedom the design (or optimisation search) is given, the higher the potential savings are. Following this adage, we may expect significant further improvement in fuel efficiency if we lift the classical constraint of having to design symmetrical ship hulls. Indeed, for single-screw ships, the propeller introduces a hydrodynamic asymmetry and an asymmetric propeller inflow may increase the propulsive efficiency and thus reduce fuel consumption.

The idea of a twisted aftbody (Figure 1) was proposed by Ernst Nönnecke in 1965. Schneekluth and Bertram (1998) neatly summarise its beneficial characteristics and why power savings of 5-10% may be seen:

- Bilge vortex generation is reduced on the side with V-section characteristics (portside for clockwise turning propeller). Local separation is reduced on this side. This may lead to lower resistance for the asymmetric ship than the corresponding symmetrical ship in some cases.
- The pre-rotation induced by the hull improves the propeller efficiency.

Blaurock (1990) further discusses the asymmetric stern in his overview of propulsion improving devices, but also states that "The physical mechanisms that produce the power saving with the asymmetric aftbody have never been elucidated completely."

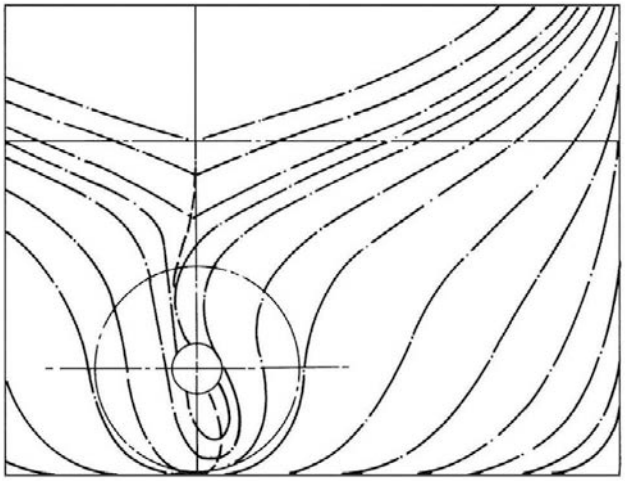


Figure 1: Asymmetric stern lines, Schneekluth and Bertram (1998)

Some ships of this kind have been built, such as the Norasia ship *Schiff der Zukunft*, but the technology was regarded to be hard to engineer and expensive to build, and patent claims added to the reluctance of shipyards to adopt the idea.

"There is no longer resistance to building twisted sterns in shipyards"

These difficulties stemmed from the complex nature of the flow field; finding optimum solutions by manual design was a challenging and time consuming undertaking when the idea was first proposed and hydrodynamic assessment was limited to model test technology (Figure 2).

However, taking full advantage of today's CFD capabilities and combining these with formal parametric optimisation (Figure 3), the asymmetric stern can be directly optimised for best propulsive efficiency.

In addition, complicated shapes are now much easier to build due to the progress made in computer-aided plate cutting and forming. High-fidelity CFD in combination with parametric formal optimisation also now enables the assessment of many hundreds or even thousands of design options within a few days. As a result, there is no longer resistance to building twisted sterns in shipyards, according to DNV GL clients who have also suggested that there was no discussion of substantial extra costs for such designs, and it is possible to directly engineer optimum twisted sterns with higher fuel efficiency gains.

To design an optimal asymmetric aft ship, resistance and propulsion figures must be assessed and brought to an optimum. DNV GL has developed a procedure to directly compute the propulsion measures fast enough to be efficiently used in a formal optimisation. The technology is based on coupling viscous Reynolds-averaged Navier Stokes equations (RANSE) simulations for ship and rudder with a state-of-the-art propeller analysis code (Figures 4 & 5). The approach is computationally efficient and allows the required power to be used as a direct measure in the optimisation.

Computational procedure

Today, the calm-water power of ships can be determined in numerical simulations,

Glossary

Simulation-based design: Typically less than 10 variants are assessed by more or less sophisticated computational fluid dynamics (CFD) simulations. Recommendations for design changes are based on human inspection and insight.
Concept exploration: Concept exploration a.k.a. "design of experiment" (DOE) generates a large set of candidate solutions by varying design variables. Each variant is evaluated in key performance indicators and stored, thus creating a "map" of the unknown design space. Using suitable graphical displays, the designer gets a feeling for how certain variables influence the performance of the design.
Optimisation: Optimisation looks at thousands or even tens of thousands of designs and uses an optimisation algorithm to find the best design for a single given objective function. Genetic algorithms (GAs) are the preferred choice these days.
Multi-objective optimisation: Multi-objective optimisation combines concept exploration and (single-objective) optimisation. The concept exploration helps in formulating constraints and objectives (which may be an artificial objective function combining weighted single objectives).

reflecting all key elements realistically. This takes into account wave making, including breaking waves and the dynamic trim and sinkage of the ship; flow conditions for full scale (i.e. having full-scale dimensions and viscosity of sea water); and hull, rudder and propeller (and possibly propulsion improving devices such as pre-swirl fins).

State-of-the-art CFD software based on solving the unsteady RANSE allows DNV GL to address all the above in one comprehensive and consistent model, capturing all interaction effects.

However, combining all aspects in one monolithic model is often computationally inefficient. Depending on the purpose of the simulation, simplified models may yield sufficiently accurate results in a much shorter time and with a lower overall cost. Such is the case for hull optimisation allowing twisted sterns. Splitting the problem into smaller isolated tasks, the procedure runs in three stages.

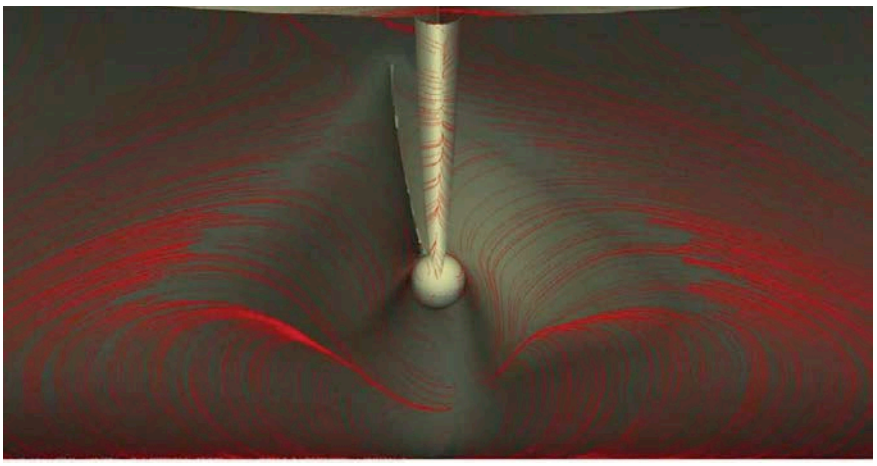
Stage 1
The steady resistance problem is simulated in a free-surface RANSE simulation, yielding the calm-water resistance. Simulations are performed in the time domain with the ship free to sink and trim until a steady condition for free surface (wave making), trim and sinkage is obtained. The ship is simulated without propeller.

Stage 2
Next, the ship is simulated in double-body flow (using symmetry at the free surface) in a RANSE simulation. Subtracting the computed resistance force from the resistance obtained in Stage 1 gives the resistance contribution due to wave making. The double-body simulation neglects the free-surface effects and models the propeller in a different inflow than that with dynamic trim and sinkage. For the typically low speeds of cargo ships, the resulting errors are considered to be small enough to be acceptable, especially for slow ships such as bulkers and tankers.

Stage 3
Finally, another double-body simulation includes the ship's propulsion. The wave resistance of Stage 2 is added to obtain the total resistance and the thrust is adjusted iteratively such that the self-propulsion point is reached (balancing resistance and

Figure 2: Model test evaluation of an asymmetric stern (left)

Figure 3: CFD evaluation of an asymmetric stern (below)



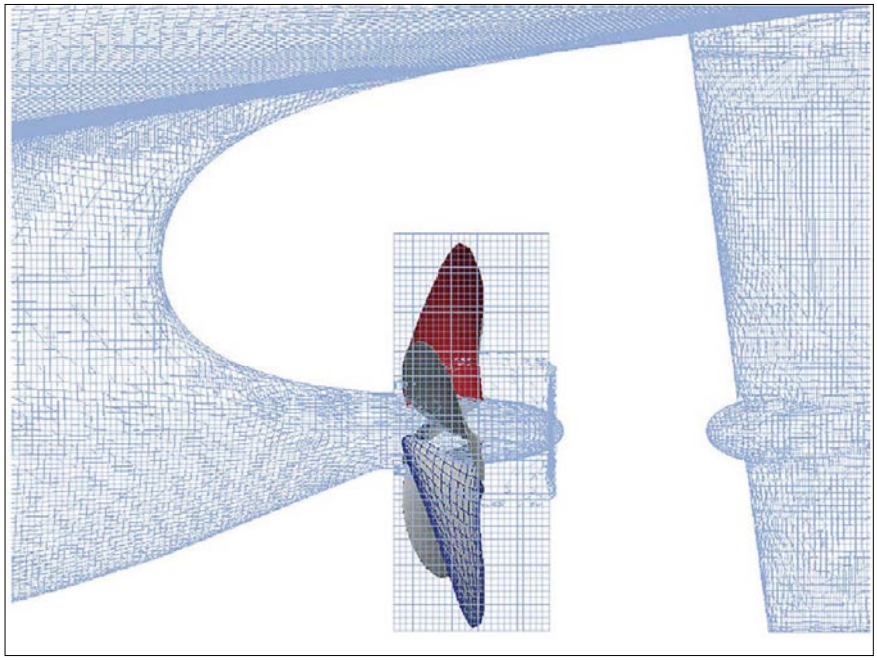
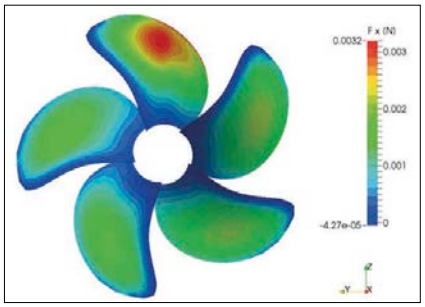


Figure 4: CFD model of a stern, rudder and propeller (left)

Figure 5: Pressure distribution on the propeller as used in DNV GL's simulation process (below)



thrust under consideration of the thrust deduction factor). Instead of physically modelling the actual propeller, only its effect on the fluid is mimicked. Body forces accelerate the flow in the propeller plane, yielding the same thrust and swirl as the propeller overall. The propeller body forces are determined in an unsteady boundary element method (BEM) which is a standard state-of-the-art propeller design tool. This method uses the ship wake distribution from the RANSE simulation as a steady inflow condition to the rotating propeller. It then computes (very rapidly) the force distributions on the blades for the propeller rotating in this inflow. These forces are distributed over the cells in the propeller plane of the RANSE grid to yield thrust and swirl forces for each cell. The RANSE and BEM simulations exchange information (inflow velocities and body forces) iteratively until convergence is reached. The process converges typically within less than 20 iterations.

The errors introduced by the simple approximation of the propeller quickly decay away from the propeller. This approach is thus inappropriate if the propeller design as such is the purpose, but well suited for hull design or power prediction in numerical sea trials or numerical propulsion tests. Results for required power and flow field on the hull are virtually the same as for explicit modelling of the propeller in a CFD simulation, but computations are typically accelerated by a factor of 100. Consequently, this computational efficiency permits the assessment of many more variants to densely cover the available design space for asymmetric hull shapes.

The simulations can be performed at model scale or at full scale. Here, various approaches may be followed:

1. Simulation in model scale (possibly for

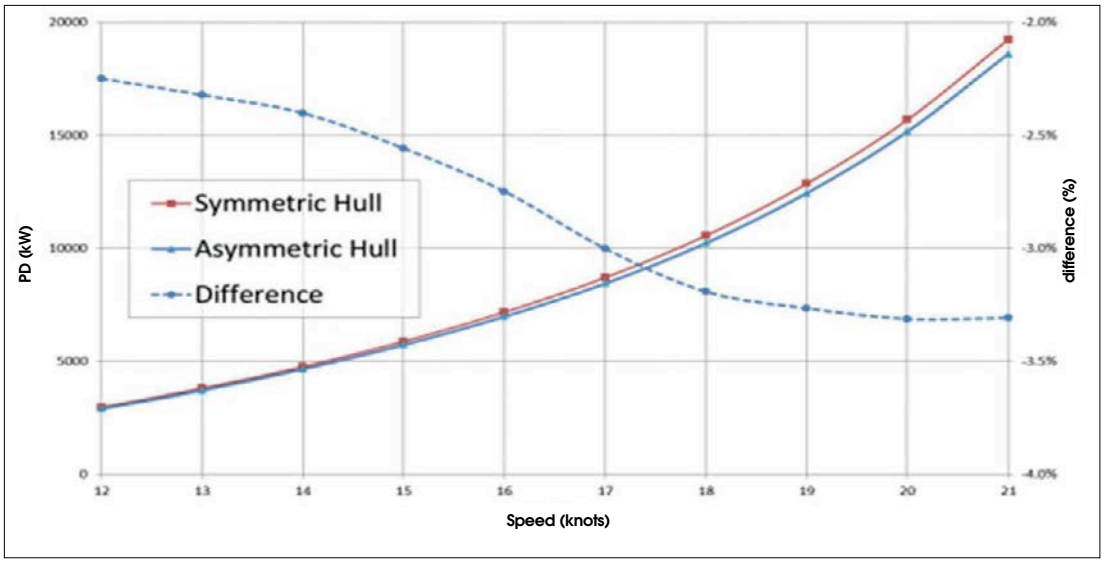


Figure 6: Model test predictions for an optimised symmetric hull and an asymmetric hull showing a 3% improvement for the asymmetric hull near a design speed of 17knots

validation/comparison against model tests). Then scaling to full-scale uses standard procedures of a given model basin. This is problematic as each model basin has its own scaling procedures and these procedures are based on experience for symmetric sterns without propulsion improving devices.

2. Simulation in model scale and in full scale. This allows scaling to reflect the peculiarities of pre-swirl flows, even if model test results are used as the base for the scaling. It is as such likely to be more accurate than the procedure in Point 1.
3. Simulation only in full scale. This is the condition of interest for obtainable energy savings, but no longer allows validation of results for original and optimised geometries in model tests. This procedure requires sufficient confidence in simulation approaches by all stakeholders involved.

In order to achieve maximum fuel efficiency for a 3,000TEU containership, a first stage detailed optimisation of the slot cost, i.e. the cost per container on a designated trade, was undertaken based on symmetric lines. In the second stage of the study, the additional freedom for asymmetric aftbody shapes was taken into consideration and an additional propulsion power saving of more than 3% was confirmed by model testing at the Hamburg Ship Model Basin HSVA (Figure 6).

Conclusion

Increasing the freedom in optimisation generally increases the chance of finding better results. In particular, allowing asymmetric sterns can lead to significant additional savings of 2-5%. As the gains of the asymmetric aftbody build on similar physical effects as other propulsion saving devices (e.g. fins, spoilers) where gains are generally found to be higher for full hull forms (bulkers and tankers) than for slender hull forms (containerships, multi-purpose vessels, LNG tankers), the same trends are expected for asymmetric hull shapes. The asymmetric stern improves propulsive efficiency similar to pre-swirl devices, albeit with much higher structural robustness, avoiding potential problems with vibration and fatigue strength. The time appears ripe for a renaissance of this idea from the 1970s. *NA*

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Route to compliance for unmanned vessels

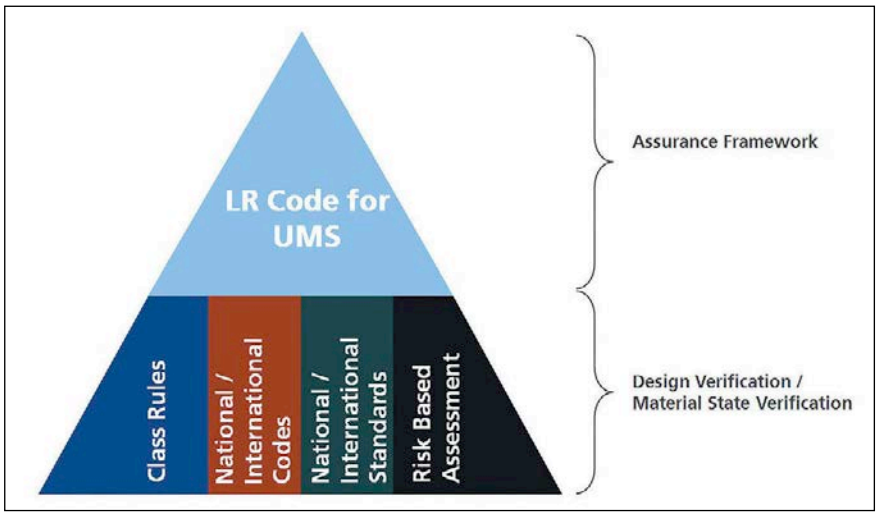
In response to growing demand for regulatory support for unmanned vessels, Lloyd's Register (LR) has developed the *LR Unmanned Marine Systems Code*

With developments in autonomous and remote systems and the expectation that Unmanned Marine Systems (UMS) will be in widespread use in many sectors of the maritime industry within the near future, LR has been active in understanding how it can support the industry in demonstrating safe design and quality of manufacture aspects for these systems.

The goal-based code takes a structured approach to the assessment of UMS against a set of safety and operational performance requirements. It has been written to support innovation, establishing requirements from which compliance can be demonstrated using a tailored combination of standards, or where standards do not exist, the application of risk-based assessment techniques. Verification methods are then applied according to the solution selected.

It aims to provide an assurance process in order to assure the safe design, build and maintenance of UMS against an established framework that minimises the effort required by an Owner or Operator to achieve certification and which is acceptable to Flag States, local Regulators and other interested parties. Whilst initially targeted at small non-conventional UMS, including naval systems, it is scalable and is capable of being applied to larger, more complex vessels as technology and regulation develops.

The Code has been written using a goal-based structure, providing the minimum level of safety acceptable for UMS and a method to define and assess against the Owner or Operator's declared tolerability of risk for loss or damage to its asset. The benefit of using the goal-based structure is that it defines an ultimate safety objective whilst allowing for the consideration of alternative designs and solutions that meet the safety objective; thereby supporting innovation in an area that is developing rapidly.



The *LR Unmanned Marine Systems Code* aims to support innovation in the field

The Code follows a structure similar to that used for the NATO Naval Ship Code (ANEP 77), a safety code which is written to provide naval equivalence to commercial conventions (the development and implementation of which LR has also been contributing to). It has a high level Aim: "The Unmanned Marine System (UMS) shall be safe, dependable, capable and resilient in all Reasonably Foreseeable Operating Conditions." Followed by a Goal, Functional Objectives and Performance Requirements for each of eight functional chapters:

- Structure
- Stability
- Control Systems
- Electrical Systems
- Navigation Systems
- Propulsion and Manoeuvring
- Fire
- Auxiliary Systems

Each of the lower level Performance Requirements combine to support the Functional Objectives, which in turn support the Chapter Goals and thereafter the Aim. Performance Requirements are achieved through the use of Solutions, which are not specified in the Code. This is because of the potential diversity in design and operation of UMS. The Code expects an appropriate solution to be selected from a combination of: Classification Rules, National or International Codes and Standards or, where standards do not exist or are not appropriate, through the application of risk-based assessment methodologies that demonstrate that the Performance Requirements are achieved.

Solutions are required to be justified against the Code requirements and their scope and application bounded through the use of a Concept of Operations (ConOps) which describes how and where the UMS will be used, what roles it will undertake, and what the Owners or Operators expectations regarding its performance, dependability, capability and resilience are. This information is used to inform the definition and verification of solutions.

In order to apply the Code, a level of integrity is established for each system of the UMS. This is determined using a combination of System Safety

Consequences for people onboard, for people or objects in the vicinity, and for the environment, in order to establish a minimum level of integrity. In addition, Operational Safety Consequences for capability and for resilience can be used to enhance the minimum level according to the tolerance of the Owner or Operator to the risk of loss or damage to the UMS (as established in the ConOps). The level of integrity determined will then inform the selection of the appropriate solution and required verification processes, which are scalable according to the risk profile of the UMS. Requirements, templates and guidance on how the required level of integrity is determined and applied are provided in the Code.

The Code has been developed against a hazard analysis of UMS design and operation and benchmarked against existing commercial and naval regulatory requirements, including SOLAS and the Naval Ship Code. It has been validated against several existing UMS designs.

Initially, the Code has been limited to the safe design of the UMS only, and does not cover any safety, environmental or commercial risks resulting from embarked cargo, dangerous goods or mission-specific equipment; however, these can be covered through separate hazard identification and risk assessment techniques and included as necessary. Furthermore, it does not address operational aspects related to safety management or environmental safety, but does include design requirements to support safe operation and maintenance.

If the UMS is *periodically* manned it is expected that all relevant manned requirements will be complied with although it is acknowledged that these will not always be suitable for *occasional* manning (ie. berth operations), and as such future development work will focus on the creation of an additional functional chapter that centres on safe design for human interactions.

LR sees the Code as providing a valuable assurance process for the safe design of UMS in what is a rapidly developing area of the maritime industry. It allows for the certification of novel and emerging technologies against a structured framework and is scalable according to the risk profile and autonomy of the UMS, from the very small or simple to the very large or complex. It complements our existing work on cyber-enabled ships and is also intended to support any future regulatory development by the IMO or national bodies. *NA*

ABS gears up for the future

Dr Kirsi Tikka, ABS executive vice president of Global Marine and RINA fellow, explains how the classification society is positioning itself to assist shipowners in performance management and regulatory compliance

Tikka assumed her current role last year, having previously led ABS' Environmental Solutions Group. "ABS Global Marine was formed to deliver a global vision across marine markets with local touchpoints of the ABS global network," she explains. "This view of global marine trends means we can better anticipate client needs and issues."

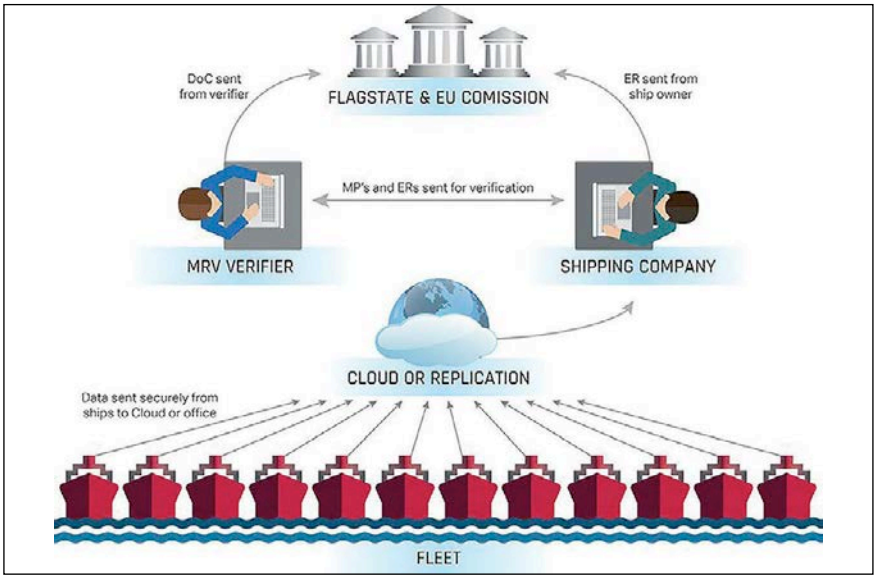
The class society has developed the ABS FutureClass brand as an umbrella for its portfolio of evolving class services and client tools. Tikka believes this focus on technology, combined with a commitment to safety, will help put ABS to develop a framework which will keep it on the front foot in terms of technical leadership and innovation, leveraging data and technology to improve accuracy and efficiency.

She adds: "Class is evolving to become more condition-based and risk-based in its approach to safety and performance management. This new framework…will help keep us continuously aligned with industry and will help our clients better capture and utilise data throughout the service life of a vessel, focusing on enhancing safety, efficiency and environmental protection."

Kirsi Tikka

According to Tikka, at a time when some class societies are expanding their services into other industries beyond maritime, ABS' core focus remains shipping and offshore classification, and helping its clients bridge the divide between shipping's present and the digital future. This includes concepts such as wearable technologies, drone-supported inspections, mobile apps and cybersecurity.

Historically, ABS has a track record across all of shipping's key sectors, including containerships, bulk carriers and offshore. However, tankers and gas carriers are the areas for which it is best known and ABS has also become a particular specialist with LNG shipping and LNG as fuel. Tikka's own background is in tankers; prior to joining ABS in 2001 she served as professor of Naval Architecture at Webb Institute in New York, where she conducted research on the structural strength of tankers and risk analysis.



ABS facilitates EU MRV compliance using its Nautical Systems (NS) fleet management software

Offering some insight into how these sectors may evolve in the next few years, Tikka says: "Tanker owners considering newbuildings want to optimise the performance of their vessels for the intended operational profile, and to evaluate compliance options for the various regulatory requirements ranging from ballast water management to the 2020 sulphur cap.

"ABS can carry out techno-economic analyses to assess sulphur cap compliance options based on assumptions on fuel cost differentials. And we can evaluate the feasibility of ballast water treatment technologies for a specific vessel or a fleet.

"The gas carrier market is evolving rapidly, driven to a great extent by gas exports from the US. Demand for power generation around the world, and the availability of natural gas is also driving innovation in floating gas liquefaction and regasification plants, as well as a trend towards smaller LNG carriers serving niche markets."

ABS can boast a number of accomplishments in this sector, including classification of the world's first very large ethane carriers (beginning with *Ethane Crystal* in November 2016) and the world's first compressed natural gas carrier, *Jayanti Baruna*. Tikka adds that ABS is also classing a number of newbuildings featuring innovative LNG containment systems and propulsion concepts. These are currently under construction in South Korea and Japan under the supervision of the Global Gas Solutions ABS team, which was founded in 2013 to support industry in developing gas-related projects.

Although LNG as a marine fuel has now reached what Tikka describes as a "tipping point" in terms of the size of vessels being designed as LNG fuelled or LNG capable, ABS continues to research renewable and hybrid energy options. Earlier this year it published its Advisory on Hybrid Electrical Power Systems, which intends to help marine and offshore owners and operators make more informed decisions about available energy generation and storage options.

The class society has also participated in a study led by Sandia National Laboratories, Elliott Bay Design Group, and the Red and White Fleet on the feasibility of building and operating a zero-emission high-speed ferry powered entirely by hydrogen fuel cells, issuing Approval in Principal to verify the resulting design. "It's very hard to say how long it would take for this technology to be widely commercially viable, but we are certainly seeing interest in bringing it onboard ships," she observes. "With the adoption of any new technology there are growing pains, and I expect the commercial application of hydrogen fuel cells to have its fair share."

ABS recently became the first classification society to be granted accreditation for verifying ship operators with compliance with EU Regulation 2015/757 concerning monitoring, reporting and verification (MRV) of CO_2 emissions. How then does Tikka think these further regulatory obligations are influencing attitudes towards ship efficiency among owners?

"It's an important question and I think the answer is that the amount and the complexity of the environmental regulations, including EU MRV, overshadows the appreciation of the goal of reducing the environmental footprint. We are so focused on figuring out how to comply with regulations that we don't often discuss whether EU MRV will actually drive reduction of CO_2," Tikka reflects.

Whether owners are placing orders for newbuildings, which allows for greater flexibility, or optimising the performance of existing tonnage, ship efficiency is at the top of the agenda for owners. Tikka says the discussions ABS has with owners indicate they view regulatory compliance and ship efficiency as interconnected issues, and believes that it is now a key consideration in remaining competitive.

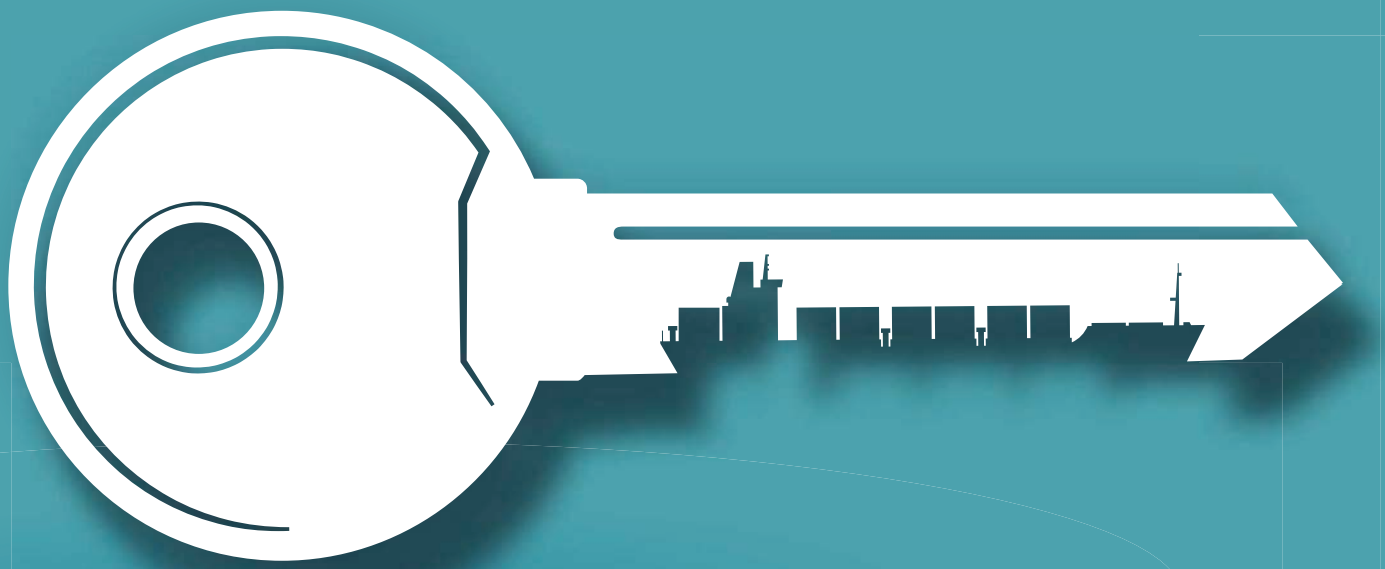
"In future, a more efficient, less polluting ship is likely to have a different compliance profile, even if this is the result of voluntary schemes rather than mandatory regulation. At the same time, more charterers and shippers are asking shipowners to demonstrate that their environmental performance is at or above minimum standards."

Tikka thinks the best solution for shipowners would be if the IMO and regional regulations were better aligned, but that here political motives come into play, something which falls outside the consultational role of the class societies.

"Class has a role in providing technical input to the regulators and to participate in the dialogue at that level. EU MRV is the start for shipping of a tighter focus on CO_2 emissions and we know that IMO action will follow. Much of what is learned during the former compliance process can be applied to the latter, but international shipping needs international regulation.

"In this way owners have an opportunity to prepare for a future which is much more focussed on bringing these two elements together into a unified operating profile." ***NA***

Simplicity is the key to success



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Forward thinking

A three-year joint project led by Arista Shipping has culminated in a design solution that's both greener and more economical

Project Forward was launched initially between Arista Shipping and ABS in 2013 and was developed in a Joint Development Project (JDP), with new partners, Deltamarin, GTT and Wärtsilä, added through 2016.

The project aimed to develop a merchant ship design, respecting the peculiarities of the segment, with a focus on improved total cost of ownership, environmental friendliness, low opex and capex, simplicity and operational flexibility.

As most readers will be aware, the environmental regulations concerning air emissions, both in force and the forthcoming ones, require significant reductions in CO_2, SOx and NOx. For regulatory compliance, a number of possible methods can be applied, such as scrubbers and catalysts, but each needs to be evaluated based on its operational and regulatory compliance impact. The JDP decided to use the new requirements as a means of promoting efficiency.

After carefully evaluating all possible alternatives, it became evident that LNG as marine fuel offers a unique potential for compliance with the rules and would have certain advantages over traditional fuels. Adopting LNG as fuel for this project, however, introduced technical challenges that would have to be addressed.

The project's scope included the systematic study of all issues related to using LNG as marine fuel in ocean-going cargo vessels, such as bulk carriers and tankers.

A modern and proven ship design was required as a platform for the studies and to act as a host for all modifications needed. The B.Delta82 (an 82,000 dwt Kamsarmax vessel designed by Deltamarin) was selected as the representative modern ship because of its low fuel consumption, high cargo capacity and performance. Although the easiest way to reduce the CO_2 emissions is by operational means (i.e. reducing service speed), the choice was made to maintain the original service speed of 14.5 kn.

	2 STROKE DF HP Concept	2 STROKE DF LP Concept	4 STROKE DF Concept
Environmental Criteria			
THC (Total Hydrocarbons)	🙂	😐	😐
CO2 equiv incl THC	🙂	🙂	🙂
SOx	🙂	🙂	🙂
NOx	☹	🙂	🙂
PM	😐	🙂	🙂
Technical Criteria			
Power density	🙂	😐	🙂
Efficiency on gas	🙂	🙂	🙂
Efficiency on liquid fuel	🙂	😐	😐
Methane No dependency	🙂	😐	😐
Financial Criteria			
Main engine cost	😐	😐	🙂
Gearbox	-	-	☹
Cost of FGHS	☹	🙂	🙂
Fuel cost	🙂	🙂	🙂
Maintenance cost	☹	🙂	😐
Operational Criteria			
Compliance with environmental regulations	😐	🙂	🙂
Safety / redundancy (2 engines driving propeller)	😐	😐	🙂
Propeller efficiency – Light Run Margin	☹	🙂	🙂
Transient response / Load control of CPP	🙂	☹	🙂
Slow speed maneuverability	😐	😐	🙂
Thermal overload of main engine in case of hull fouling	☹	☹	🙂
Reserve of el.load carrying capacity	😐	😐	🙂
Weight compared to standard vessel	😐	😐	🙂

Figure 1: Propulsion machinery was evaluted across a range of criteria

The quantity of LNG was selected to provide sufficient autonomy for deep-sea ocean going shipping on long voyages with limited refueling options.

LNG storage

The main challenge with using LNG as marine fuel is the volume required for storage. Despite its higher heating value, its low specific gravity requires significantly larger volumes compared to liquid fuel for the storage of the same energy.

The various options for onboard LNG storage were evaluated, with the membrane type from GTT selected as the most optimal for the intended large volume. This type of membrane allows the maximum utilisation of existing space and involves a lower cost and weight.

The International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code), which came into force in January 2015, introduced a probabilistic approach for calculating damage probability, which allowed a reasonably large tank to be accommodated on board. The size of the tank was selected at 2,500m^3 and the team decided the tank would be incorporated by increasing the ship's length. This option offered benefits, such as no loss of cargo space, but also increased the dwt (by 1,500

tonnes). Other benefits include having the flexibility to adjust its size depending on the particular needs of each owner, no negative impact on ship's stresses and stability, no operational limitations due to increased length, and equal applicability for the conversion of younger vessels should future conditions justify this move.

Due to inevitable heat input in the tank, the liquid evaporates and builds up pressure (natural boil off). At sea, the total gas consumption requirement is far higher than the natural boil-off rate, which helps control the boil-off. At port, the natural boil-off rate is slightly higher than the quantity needed to cover the electric load alone. This can be managed with cold liquid fuel sprayed at the top of the tank which effectively cools the gas and significantly reduces the rate of pressure increase while meeting the IGF Code requirements.

Engine selection

The team also carefully evaluated the main propulsion machinery. Typically, commercial vessels are propelled by a large 2-stroke main engine driving a fixed pitch propeller, and auxiliary power is produced by three auxiliary generator sets.

A major objective of Project Forward was to deliver a vessel that would operate full-time on LNG fuel and would operate on liquid fuel only in the event that LNG was not available. Major factors accounted for in the machinery selection included safety, reliability, efficiency, environmental-friendliness, initial investment, redundancy and flexibility.

By contrast with liquid fuel, which has a rather fixed supply pressure to the engine, LNG can be fed at either high or low pressure. Engine makers have taken different approaches to using LNG as fuel. In the case of Project Forward, the different advantages and disadvantages of engine alternatives (High-pressure-Diesel cycle vs Low-pressure-Otto cycle) were investigated. Unlike traditional assessments that focus on fuel consumption alone, the Project Forward solution had to take into account several factors, including overall system performance. Figure 1 summarises the selection matrix used.

The selected machinery arrangement consisted of two Wärtsilä 31 DF (4-stroke) engines which provided power to a twin input single output gearbox driving a controllable pitch propeller (CPP). There are no additional generator sets for auxiliary power production.

One or two engines are configured to operate at an optimum efficiency point depending on the vessel speed. A variable speed mode of the engines can be applied. Auxiliary electrical power (hotel load) is produced by two shaft generators with frequency converters driven through Power Take Off. Each has a load capacity sufficient to cover the complete range of the vessel's needs at any operating condition.

The latest generation Wärtsilä 31 DF engine ensures very high efficiency due to the two-stage turbocharging, as well as Tier III compliance when operating on gas with no after treatment requirement. The hull lines of the B.Delta82 design have been modified to accommodate the new propulsion machinery and LNG tank hull insert resulting in optimised and improved propulsive efficiency. Gas engines running on Otto cycle have accumulated several million running hours.

This concept is equally applicable to all types and sizes of vessels, and although it cuts in half the number of engines on board, it doubles the redundancy in terms of propeller drive.

The technology built into the selected engine, Wärtsilä 31DF, delivers an optimum scavenge and combustion process, addressing methane slip by means of the design parameters of the combustion chamber, the higher scavenge pressure, the sophisticated injection system and variable valve timing. As a result, the engine has a significantly reduced GHG footprint (inclusive of methane slip), in the range of approximately 25% at the design load compared with similar diesel version.

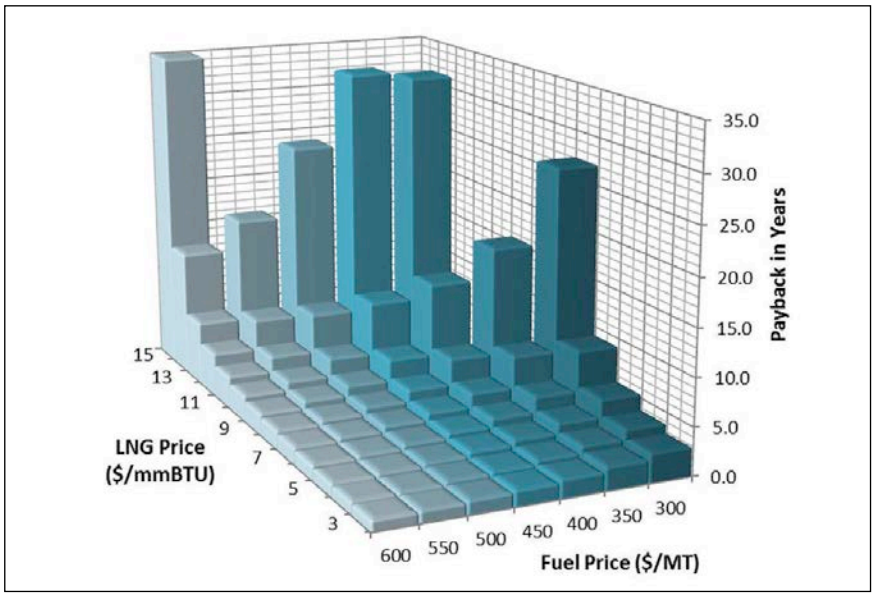
The selected option comes with the lowest cost among the options that use LNG as fuel. Vessels that will be delivered in the near future will have to bear the extra cost for compliance with NOx Tier III and be furnished with SCR or other method such as EGR.

Minimum capex

Mainly due to the cost of its tank, LNG comes at an extra cost compared to a liquid fueled vessel. Project Forward succeeded in delivering a solution employing LNG as fuel with minimum capex compared to all other available options. Following the evaluations for the use of LNG as fuel, investigations were carried out to determine whether the reduced operating expenses could compensate for the increased capex.

The maintenance cost of the proposed solution is comparable to traditional solutions on conventional vessels. Piston overhaul comes every five years, lubricating oil consumption is greatly reduced, while costs related to maintaining the CPP and reduction gear are not significant. Certain additional maintenance costs related to

Figure 2: The payback period for different LNG scenarios



LNG have not been considered, as similar costs would be accrued by vessels with a selective catalytic reduction (SCR) and scrubber solution.

Therefore the difference in opex has to be sought in the cost of fuel. Projections allow the team to estimate that a reasonable future price for LNG (including delivery on board) as infrastructure develops will be approximately $9 USD/MMBTU.

With this LNG price, the opex of the Project Forward solution matches that of a "conventional vessel" running with liquid fuel priced at $365 USD/MT. Although it is not possible to predict today the price of 0.5% sulphur fuel, it is fair to assume it will be higher than today's price. Figure 2 shows the payback period for various scenarios of LNG and 0.5% prices which for the most expected range is very short.

It is worth noting, based on energy content, even at today's prices LNG is less expensive than HFO. Therefore compared to a vessel fitted with SCR and scrubbers, the Project Forward proposal will have similar capex and opex, but offer unprecedented simplicity and reliability.

HFO is available nearly anywhere in the world but for obvious reasons related to cost it is preferable to bunker ships at major ports only. And this is very well confirmed by Figure 3 which shows the percentage of bunker uptake of bulk carrier vessels employed in tramp service over the past years, as we can see only major ports are involved.

Because activities around LNG bunkering already are envisaged or planned for these ports, LNG availability in the coming years should not be an obstacle to its adoption as marine fuel. Furthermore, Project Forward and Shell have held discussions to investigate the options for supplying LNG powered vessels and assess the bunkering requirements of global trading bulk carriers, tankers and container vessels.

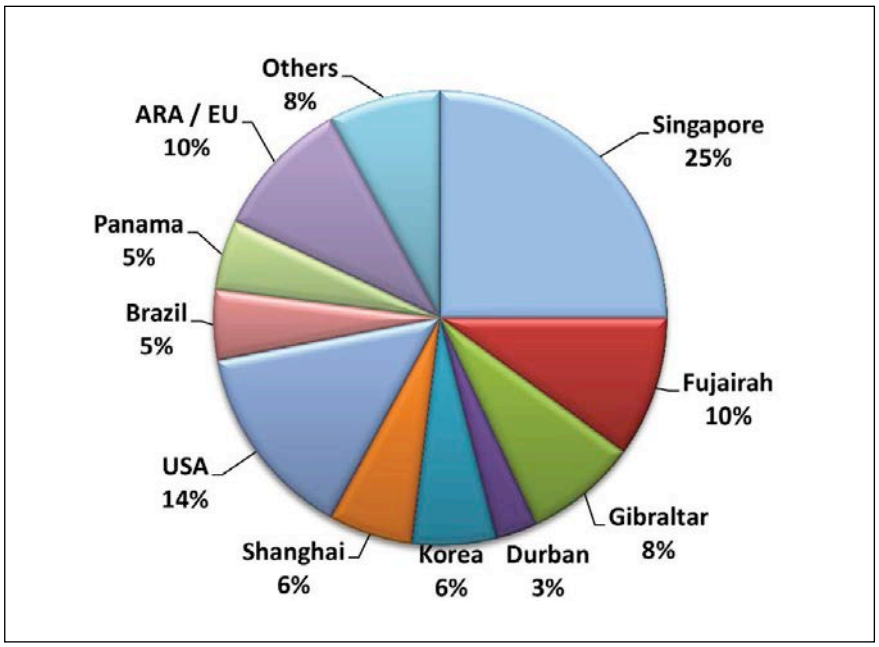


Figure 3: Bunkering uptake of vessels employed in tramp service

Conclusion

By incorporating a range of innovative solutions, Project Forward succeeded in delivering a technically reliable and financially feasible solution for meeting new requirements and providing a truly deep-sea LNG-fuelled ship design applicable to various sizes and potentially all types of vessels.

The design has been evaluated for compliance with regulations and has been granted Approval in Principle by ABS. *NA*

Authors: Antonis Trakakis, Technical Manager, Arista Shipping; Elias Kariambas, Marine Business Development Manager, ABS; Dionysios Antonopoulos, General Manager, Marine Solutions Sales, Wärtsilä Greece S.A.; Patrick Englebert, Julien Bec, GTT; Konstantinos Fakiolas; Jacques Danton

Deltamarin's B.Delta82 design was chosen as a representative modern bulker

Coatings forecast: smoother, cleaner, stronger

The coatings industry may synthesise a number of key developments to provide future efficiencies. Diego Meseguer Yebra, Hempel, gives a run down of the industry's current trends and future sights

Despite the drop in fuel prices following the 2008 peak, interest in fuel saving options has not decreased. Neglected for decades, the quantification of hull performance as an input to improved hull management decisions is progressively being seen as an area in which substantial fuel savings can be achieved. This will further spur developments in the field of hull efficiency in order to cater to market demands and environmental considerations. Below are some thoughts on the most likely hull management trends for the next couple of decades and where the industry sits at the moment.

Figure 1: Differences in added frictional resistance between two sister vessels with significantly different surface preparation during drydock. When only minor repairs are performed, the vessel's frictional resistance remains too high

Reduced plate roughness

During a normal maintenance docking, two main types of surface preparation are performed on ship hulls prior to coating application:

- Spot repairs, where local areas with coating defects (e.g. blisters, cracking, mechanical damages, corrosion, etc.) are grit blasted or hydro-blasted down to bare steel. A new full coating system is applied only on those areas, while the aged coatings in the remaining areas of the hull are "refreshed" with new fouling control coatings. This induces significant roughness due to the application on aged, porous coatings, but also due to the difference in dry film thickness between the spot repaired and the rest of the area.
- Full removal of the existing coating system, so a completely new coating system is built from the bare steel. This results in a significantly smoother hull overall but it is often avoided due to increased drydocking and off-hire costs.

The result of each approach can differ greatly when it comes to reducing fuel consumption. Propulsion Dynamics highlighted an example of this at the Ship Efficiency Conference in 2013. Two sister ships entered drydock with similar hull efficiency calculated before docking. One ship blasted a much smaller portion of the hull leading to a significantly higher resistance after docking (Figure 1) than the sister ship. While the actual numbers are only indicative, full blasting certainly leads to lower average hull roughness and thus better performance. As hull efficiency will gain in importance, full blasting should become the normal procedure in drydock stays or at least be applied much more frequently than today – typically at every 10 or 15 year docking. Blasting robots are also a likely part of that future.

Smoother hull coatings

A silicone-based top-coat gives a smoother hull than a conventional antifouling system. Assorted studies have shown a reduction in plate frictional resistance of 1.5 to 6%. Self-polishing copolymer (SPC) coatings have rougher surfaces, especially after the biocide particles and other water soluble ingredients have dissolved into seawater. Silicone-based coatings, on the other hand, keep a very low microroughness and a wavy macrotexture during the entire service period. Figure 2 shows surfaces of a silicone based and a conventional SPC coating have been measured by laser when freshly applied and after having been exposed to 30°C seawater for seven weeks and at 12knots. The difference between the silicone surface and the anti-fouling surface becomes larger in service.

Improved application

Regardless of the choice of coating technology, application methods are likely to improve significantly in the near future. Two key developments in this respect are painting robots and pre-applied adhesive sheets.

Today, hull painting is frequently carried out by unskilled labour in outdoor conditions. Hence, "dry spray or spray dust" due to poor spraying technique and wind, paint sags (paint running down due to an excess of wet thickness), etc. are frequent defects encountered on hulls.

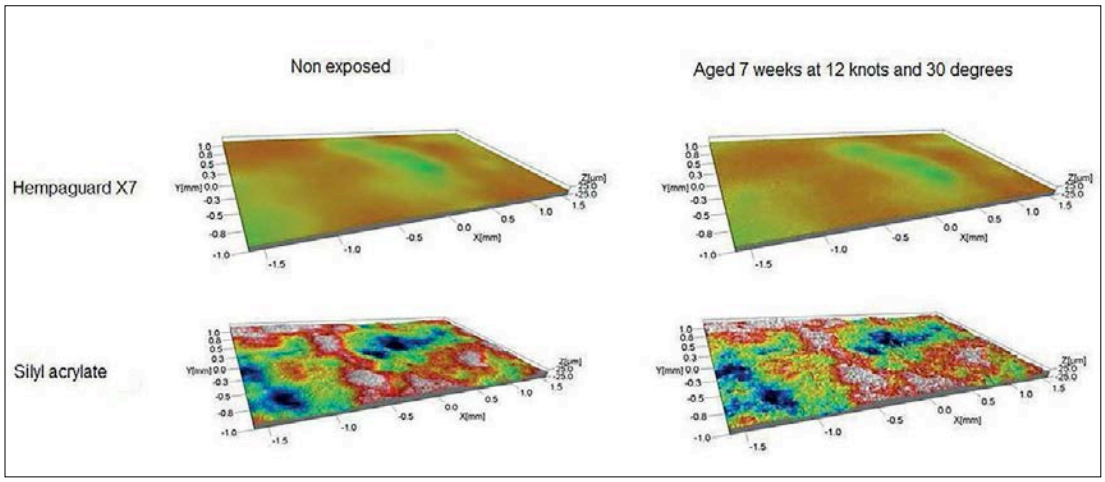


Figure 2: Micro roughness of a silicone based coating (Hempaguard) and a conventional anti-fouling (silyl acrylate type) when freshly applied and after being exposed to seawater at 30°C for 7 weeks, at 12knots

Painting robots, such as the HTC from Palfinger Hubert, claim to achieve a very low macro-roughness, in line with the values that can be obtained in lab (ideal) spraying conditions (~65 microns average hull roughness), Hentschel et al. (2016).

The maximum level of smoothness can probably be achieved by adhesive sheets applied in a carefully controlled painting line and then "glued" to the ship hull. PPG Industries in collaboration with a number of industrial partners announced a project to develop such sheets, coated with their silicone-based SigmaGlide hull coating technology last year. The ongoing eSHaRk project (see *The Naval Architect*, June 2016, pp. 38-39) will address two key aspects relating to marine anti-fouling coatings. The first is productivity improvement through the development of an easier and faster application without the traditional constraint of over-coating intervals. The second is ensuring the minimum impact on the environment, health and safety requirements, waste reduction, no VOC (volatile organic compounds) emissions and minimising the need for safety equipment at the time of application. The surface morphology of the film will be optimised to reduce drag and thus fuel consumption and emissions. Shark skin surface topographies (see e.g. Stenzel et al. [2016]) or riblets are likely under consideration.

Minimising added roughness

It is widely acknowledged that the impact of fouling on the efficiency of the hull greatly exceeds the gains of e.g. improving roughness due to coating application. Hence, preventing biofouling in service will remain the main goal of future technology developments. The choice of hull coating can have a dramatic impact on the settlement of fouling on the hull (Figure 3). While the hull coating market is dominated by low-to-medium cost coating solutions, the most advanced coatings in the market can delay fouling settlement and its undesired consequences dramatically. The remaining hurdle is motivating shipowners to take up more advanced solutions; however, with more reliable ways to compare hull efficiencies, the ships with the best hulls are likely to be chartered first or will be able to charge more.

Anti-fouling paints

Very little has changed in self-polishing copolymer (SPC) technology from the Yebra et al. (2004) review published shortly after the market shift from tin-based coatings. However, the silyl acrylate technology, which was already commercially available in the

Figure 3: An advanced coating being applied side by side to a conventional antifouling coating. The fouling observed on the main area of the hull is expected to slow the ship down more than 20% according to Schultz (2007) vs. a ship fully coated with the product applied on the test patch

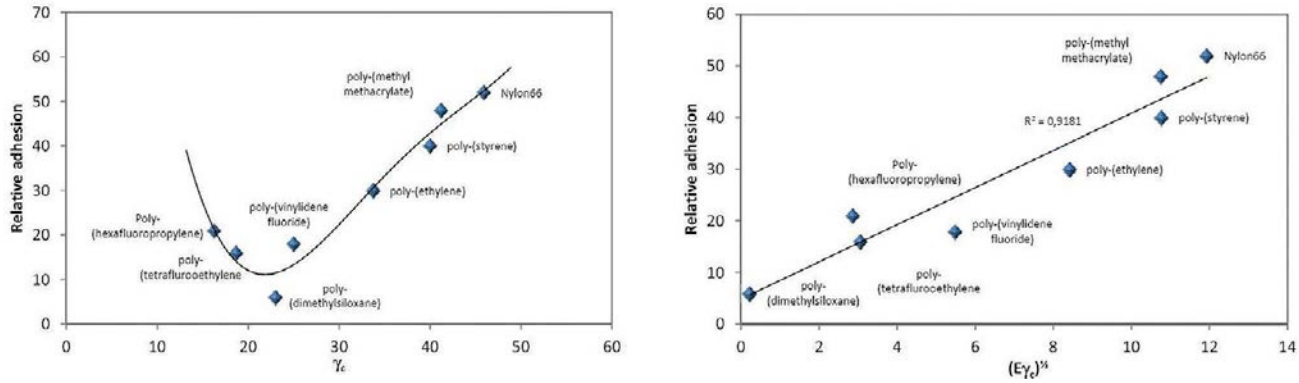


Figure 4: The 'Baier curve': Relative adhesion as a function of surface tension (left) and relative adhesion as a function of the square root of the product of the substrates elasticity and surface tension (right), Brady and Singer (2000)

early 2000s, has significantly gained market share since then – mostly driven by their good performance on fast moving vessels before slow steaming became the norm. The latest developments in silyl based polymers aim to improve mechanical properties, Niimoto et al. (2013), rather than to expand their fouling prevention capabilities for low sailing speeds and increased idle periods, which remains challenging. Nano Acrylate Technology was launched in 2005 by Hempel, Yebra et al. (2006), while Lubyon® technology was launched in 2013 by AkzoNobel. These two are perhaps the largest "new" binder technologies launched in the post-tin era.

There is little innovation on the biocides embedded in the antifouling paints too. Two new substances have reached the commercial stage, but their main features are more their environmental profiles (replacing copper) than performance. Selektope®, for example, has very good activity at extremely low concentrations, but addresses barnacle fouling mainly; i.e. requires a wide range of additional biocides to offer full anti-fouling protection. Econea® is the other copper-free alternative on the market.

Biocide-free silicones

Silicone-binders for fouling control coatings were first invented in 1972. However, it wasn't until the mid-1980s that the underlying mechanisms were understood. The Baier (2006) curve depicted in Figure 4 (left graph) shows the relative adhesion of marine bacteria as a function of surface tension. Baier explains the superior properties of silicone surfaces against fouling by the very low surface-tension which acts water-repellent (hydrophobic). However, as seen in Figure 4 (left graph), for some materials with very low surface tension such as fluoropolymers the Baier curve turns up again, i.e. the relative adhesion of marine bacteria to such surfaces increases. Brady and Singer (2000) explained this by the elasticity. Silicones are inherently flexible, and the combined surface tension and flexibility proposed by Brady and Singer nicely predicts the relative adhesion of marine bacteria (Figure 4, right graph).

> "With more reliable ways to compare hull efficiencies, the ships with the best hulls are likely to be chartered first or will be able to charge more"

Contrary to early technologies, and in agreement with the latest findings from Baier (2006), modern silicone coatings include substances for the formation of an extremely hydrophilic hydrogel on the outermost surface of the coating. These are similar to substances used in soft contact lenses to keep them free of surface deposits.

The working mechanism of modern silicone-based hull coatings with hydrogel technology is three-fold.

1. Water trapped in the hydrogel layer creates a similar surface to that of slush ice with water, Yebra and Catalá (2011). Fouling organisms actively exploring the surface do not recognise the surface of a hydrogel and opportunistic foulers that do not exhibit exploratory behaviour cannot displace the water-molecules bound in the hydrogel-layer with their glue.
2. The silicone-based matrix underneath the hydrogel layer offers very low surface energy for the fouling organisms to anchor their glue.
3. Silicone has very good fouling release characteristics.

The combination of highly hydrophobic and flexible coating matrixes and surfactants with highly hydrophilic groups provides state-of-the-art non-fouling properties. With this combination, coatings are transitioning from "foul release" to "non-foul", Yebra and Catalá (2011). Being a young technology, further improvements will surely be made in the years to come.

Silicone-based coatings with biocides

Only two such products exist on the market. Hempaguard®, based on the Actiguard® technology, Sorensen et al. (2015), works by forming a biocide-activated hydrogel on the surface of the coating. The hydrogel traps the biocide during diffusion out of the film, thereby increasing the surface concentration of the biocide and prolonging the retention time of biocide in the coating matrix and on the surface. Figure 5 shows the working mechanism of Actiguard®. The concentration of biocide in the hydrogel surface of the coating increases for a coating based on Actiguard®. This mechanism allows a much

smaller amount of biocide (compared to an SPC) to remain in higher concentrations at the paint-water interface for the full service period, and subsequently provides fouling protection that reaches levels far beyond any other technology on the market, especially during idling. There is little public information on the other product claiming similar working principles, Bioclean Plus (Chugoku Marine Paints).

Cleaning schedules

A relatively mature alternative to biocide-containing paints and silicone-based fouling release paints is to use hard coatings and frequent underwater cleaning. This is the business model for e.g. ECOSPEED, a glass-flake reinforced, anticorrosive coating developed by Subsea Industries.

For conventional hull coatings, aggressive underwater cleaning will markedly shorten the lifetime of the sensitive coatings. For this reason, a number of Remotely Operated Vehicles are already on the market, claiming both a very mild impact on the hull coating, but also the ability to capture any debris from their operation, eliminating environmental risks.

The next step in robotic cleaning is using Autonomous Underwater Vehicles (AUV), Albitar et al. (2016). The US Navy's HullBUG, Tribou and Swain (2010), is probably one of the first prototypes. The Robotic Hull Bio-Mimetic Underwater Grooming system, or HullBUG, is an autonomous underwater hull grooming robot specifically designed to prevent the accumulation of marine fouling. The current developmental model of the HullBUG uses four wheels and a negative pressure device to attach to the hull. Onboard sensors support obstacle avoidance, path planning and navigation capabilities that include detection of fouled and groomed surfaces.

Next steps

Looking into the crystal ball for upcoming trends, the most fuel-conscious owners will likely fully blast their hulls after short regular intervals (5-10 years) to eliminate the added roughness caused by mechanical impact, corrosion and old coating systems. This will be backed up by advanced hull performance studies which will clearly show the positive business case for such operations compared to the added fuel cost of performing only partial surface preparations. The hull will subsequently be protected by a smooth new coating system via painting robots and/or pre-applied adhesive sheets. During operation, the hulls will be kept free from significant fouling-related roughness via a combination of improved fouling prevention properties and, if still necessary, more frequent underwater cleaning operations potentially using automatic underwater vehicles. Such a strategy will increase the demand for milder cleaning methods and/or tougher hull coatings with enough antifouling protection to protect the hull between cleaning operations. *NA*

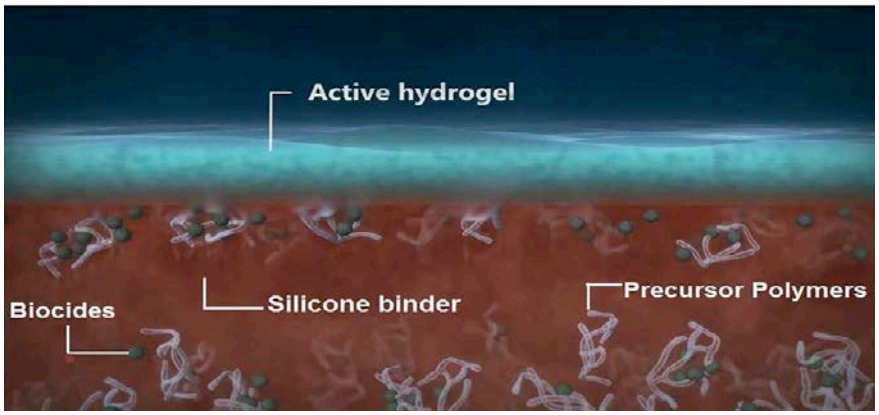


Figure 5: Working mechanism of ActiGuard®

Note: This article is based on a paper delivered at HIPER 2016.

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More than 'paint'

Market pressure and regulatory developments are forcing the maritime industry to focus on energy efficiency and meeting environmental challenges. Jotun is helping shipowners and operators to optimise vessel hull performance through its Hull Performance Solutions (HPS)

Although shipping is generally recognised as the most efficient form of commercial transport in terms of CO_2 emissions, the large scale of the industry means it is still a substantial contributor to total greenhouse gas emissions. The International Maritime Organisation (IMO) says shipping is responsible for around 3% of all man-made greenhouse carbon emissions and set out its latest strategy for achieving this at the 70th session of the Marine Environment Protection Committee (MEPC 70) in 2016.

Efforts to reduce carbon emissions are well known and include technical methods such as improved ship/hull design to reduce drag, and more efficient propulsion systems, including engines that use low carbon fuel. Operational methods include employing advanced information technology to manage vessel weight, reducing speed, and improved weather routing to maximize fuel efficiency.

Advanced antifouling coatings and application technologies are also central to optimising vessel hull performance and efficiency. Indeed, most of the major paint manufacturers regard the demand for hull performance monitoring as a business opportunity.

Headquartered in Sandefjord Norway, Jotun established its Hull Performance Solutions (HPS) unit back in 2011. The idea was to position Jotun as a marine coatings specialist that "doesn't just make paint, but also adds value in the form of tangible returns on investment," says Geir Axel Oftedahl, director of business development at Jotun Marine.

Ecological and economic drivers

"Poor hull and propeller performance is estimated to account for around 10% of the world fleet's energy costs and corresponding greenhouse gas emissions," says Oftedahl, "so any measure that saves fuel meets both ecological and economic drivers."

Jotun technicians at work

Jotun HPS helps customers to improve the hull and propeller performance of their vessels. "Our service offering consists of four key pillars, the first of which is antifouling coating systems which build on the SeaQuantum brand. Secondly, there is our technical services which focus optimising application procedures. In addition, we have performance monitoring services over the full docking interval and the vessels entire sailing period. Lastly, we have our performance contracts that have been designed to offer customers unrivalled flexibility in terms of operation," explains Stein Kjølberg, global concept director of Jotun HPS. See boxed text for more information.

A number of high-profile operators have found the HPS solution attractive, and are applying it to their vessels. *Penquin Arrow*, operated by Gearbulk Norway, was the first vessel to use SeaQuantum X200, a hydrolysing silyl methacrylate antifouling coating. It was applied to the underwater hull of the 51,000dwt general cargo vessel in September 2010 and last year completed its first full five year survey docking. The vessel was equipped with a sensor set-up to enable full performance monitoring. Speed loss was found to be less than 0.5%on average over 60 months, compared to a market average speed loss estimated at 5.9%, and a historical speed loss of 6.4%for *Penquin Arrow* itself. The data revealed an estimated fuel saving and CO_2 emission reduction of USD$1.5million and 12,055tonnes across the 60-month period.

Return on investment

According to Kjølberg, "a hull performance solution from Jotun can be expected to deliver a "guaranteed speed loss of 1.5%over 5 years", an 8.5% fuel cost saving and a reduction of vessel greenhouse gas emissions by a similar margin, with payback in usually less than one year. According to documents submitted to

MEPC by the Clean Shipping Coalition, the typical (market average) fuel cost saving for comparable services is 5.9%.

"The benefits from using HPS will justify the outlay," says Kjølberg. "Besides the fuel consumption optimisation and environmental conservation, HPS brings other benefits such as operational efficiency gains, extending the ship's commercial lifespan and increasing the ship's second hand value. These outcomes can mean substantial cost savings for ship operators."

More than 600 contracts have been secured since the launch of the HPS concept. And despite a weakening market, Kjølberg is confident that the benefits of Jotun HPS will continue to be reaped. "Going forward, you need to be relevant for shipowners and shipyards, you need to link in to what is on top of their minds. In today's market, the focus on energy efficiency and green, sustainable shipping is of extreme importance."

He believes that decision makers should be prepared for the entire spectrum of their operations to be measured according to recognised methods and standards, including hull performance monitoring on ships.

"We are committed to delivering predictable performance and not just paint" – Stein Kjølberg, global concept director Jotun HPS

The HPS team is working with a growing list of customers to develop comprehensive cases for investments in hull performance, including environmentally responsible owners and operators such as Gearbulk, Berge Bulk, UASC, Maersk and MSC. Oil and gas major Petronas also recently selected Jotun's HPS antifouling system for two LNG vessels chartered from Malaysia International Shipping Corporation.

"Improving hull coatings is a fundamental part of the push, but more needs to be done because while hull performance monitoring systems all have a similar basic approach, the available approaches are difficult to compare," emphasises Oftedahl. Kjølberg adds: "Most of the performance monitoring companies look at speed loss, efficiency loss or additional fuel consumption, but the KPI's they use are different. In addition they use slightly different sensor set-ups, high frequency and low frequency data collection, noon reports or other manual reporting systems and this makes a direct comparison between them difficult."

The Jotun Group has therefore welcomed the long-awaited ISO 19030 standard, recently published by the International Organization for Standardization. It has been estimated that the potential for fuel savings and GHG emissions reductions related to improvements in hull and propeller performance is between 7 and 10% across the world fleet. "This translates into about USD$20 billion fuel cost saving per year and an estimated 0.3% reduction of all man-made carbon emissions," says Oftedahl, who managed the development of the standard on behalf of ISO.

"With this standard we can finally quantify how solutions, such as advanced antifouling coatings, can contribute hugely to reducing losses caused by poor hull and propulsion performance. This is a huge leap forward for shipping and the environment, and it would not have been possible without an extraordinary spirit of collaboration and consensus," added Oftedahl.

Jotun made its hull performance measurement method available as a starting point for work on the new standard, which involved collaboration by over 50 expert industry stakeholders. The standard was published by ISO November last year. *NA*

Performance tracked

Jotun's HPS analysis services fully complies with ISO 19030. It isolates the impact of a ship's underwater surfaces on its energy efficiency by tracking relative changes in the relationship between the power delivered to the propeller and speed through water over time.

Significant sources of random and systematic error are managed by collecting data with a very high frequency, by using a set of pre-defined data filters and normalisation procedures, as well as a quality assurance protocol that includes monitoring of the correlation between different sensors.

The services clearly demonstrate hull and propeller performance over the full docking interval and enables the investment to be monitored throughout lifetime.

Jotun has also developed a set-up for performance-based contracting where Jotun either documents that high hull performance has been delivered or returns the additional investment in the hull performance solution.

The performance contract is based on the type of antifouling to be used in combination with SeaQuantum X200, and this combination will define the guaranteed performance level in terms of speed loss in percent over time. The monitoring is carried out in full compliance with ISO 19030-2, where a reference period is established over the first 12 months, followed by an evaluation period over the remaining period. The delta speed loss between these two periods define if the guaranteed level has been achieved or not. Failure to meet the guaranteed speed loss level triggers the payment of the guaranteed amount. (Further information on the standard can be found in *The Naval Architect*, January 2017, pp. 16-19.)

Cutting cabin costs

Research by Meyer Werft as part of the EU JOULES project has identified significant energy saving potential in a decentralised approach to passenger ship HVAC

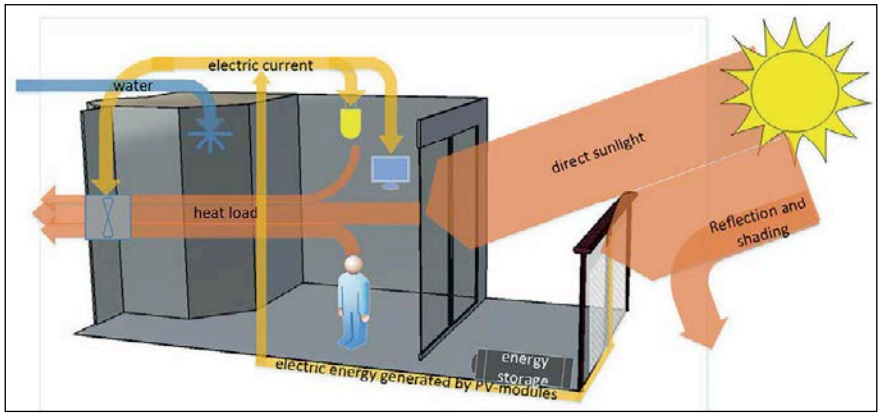
Launched in June 2013, the EU's JOULES project was a four-year study to explore possibilities for ultra-low emission shipping. The EU has set a target of a 40% reduction in greenhouse gas emissions by 2030 and an 80% drop by 2050 and critical to shipping's contribution to these aims is the development of green technologies. In particular, the JOULES project – which brought together more than 40 industry partners including major players such as DNV GL, Rolls-Royce, Bureau Veritas and STX France – focused on simulation of vessel energy grids during the early design stage and the potential impact of existing and future technologies, both environmentally and economically.

In May 2017, *The Naval Architect* attended a conference in Hamburg which showcased the JOULES project's final results, including presentations from 11 application cases and three 'demonstrator' cases. Among the most intriguing of these, certainly judging by the response it drew from delegates, was Meyer Werft's research into developing a low-energy HVAC system for cabins onboard cruiseships.

Low enery cabin

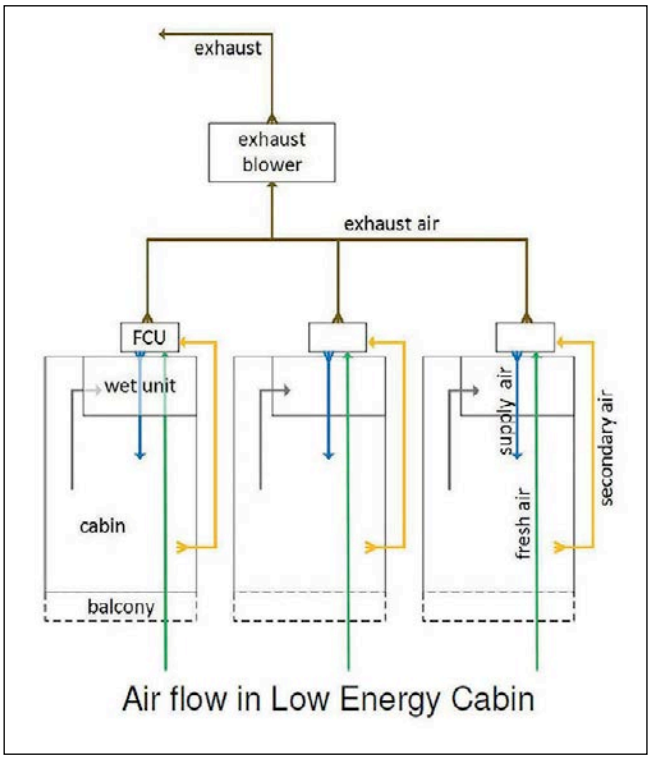
The Meyer Group – which includes Meyer Werft, Meyer Turku and Neptun Werft shipyards as well as cabin manufacturers EMS PreCab and Piikio Works and the Marine Airconditioning Centre (MAC) Hamburg – typically builds three large cruiseships per year, comprising of around 10,000 cabins in total. Therefore, any energy saving which might be gained will be subject to a significant 'multiplicator effect' for these vessels.

Modern cabins are usually supplied with energy from the ship's system, but the transportation of air through a vessel for a cabin's air conditioning unit (ACU) sometimes requires more energy than the distribution of air itself.



The energy flow in the LE Cabin (Copyright Meyer Werft)

Kurt Sommer, of Meyer Werft's Research & Development division, explains: "In a conventional air conditioning system the hot air is lifted from cabins back to central unit, where some heat recovery is done and then blown off to a central blow-off point. The fresh air is taken from the central suction point, conditioned in the AHU [Air Handling Unit] and distributed to the many cabins on the ship… For that reason [high energy consumption] we already have to decentralise the secondary air systems so every cabin has a Fan Coil Unit (FCU)."



The LE Cabin decentralises fresh air supply

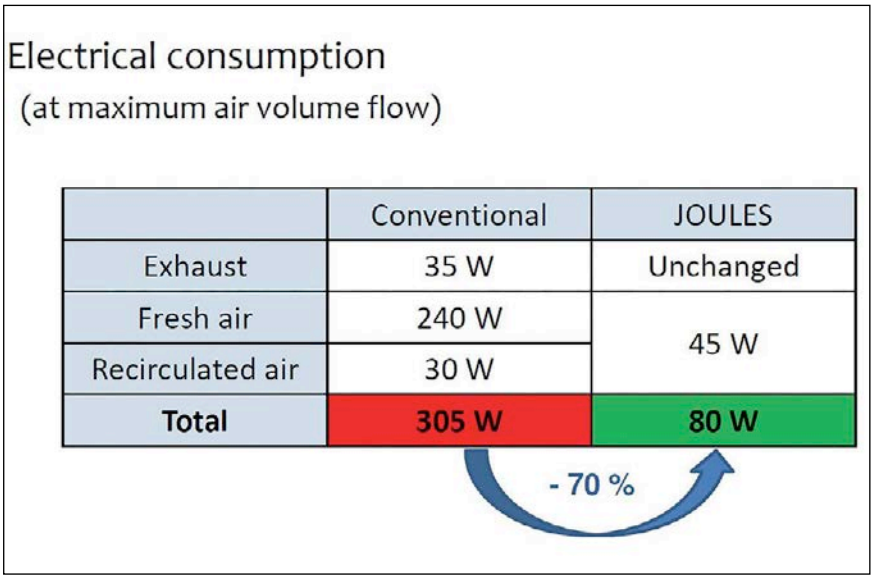
Meyer Werft's Low Energy Cabin instead takes a more cellular approach to cabin air conditioning, going one step further by decentralising the fresh air system. Instead of drawing air from a central suction point it draws it from the balcony to the FCU, which in effect becomes a mini AHU, albeit with a centralised exhaust air system. The new air conditioning unit is slightly larger than a conventional FCU but still fits in the service corner cupboard of the cabin (see illustration) and is virtually silent, according to Meyer Werft.

"The concept of Meyer Werft's air conditioning system depends on the reduction of pressure losses and therefore the reduction of electrical consumption from the transport of air. Weight is always a problem on a ship, especially in cabins, because they are quite high, so it's an essential requirement to compensate additional weight which is caused by batteries, other electronics and air conditioning," says Sommer.

Charging

In theory, each cabin would harvest its own solar energy using organic photovoltaic modules located on the windows, door and balcony (balustrade). This energy would then be stored within a battery system with an expected 10-year lifespan for supply during the night. Meyer Werft, which has been investigating the energy efficiency of cabins on both river cruisers and larger passenger ships, has also identified a large savings potential in the use of direct current (DC) distribution within the cabin grid, which allows for easier integration of alternative energy sources (i.e. like batteries, fuel cells and photovoltaics) without the conversion losses associated with AC. Measurements taken from the simulation model indicate that ACU-related electrical consumption per cabin would drop from 305W to 80W (a 74% saving).

Theoretically at least the German company is confident enough solar energy will be harvested during the day to supply the cabin for the next 24 hours, although Sommer admits that there would also be a back-up system given that the photovoltaics (which occupy a surface area of around 3.4m^2) are unlikely to perform optimally on vessels operating in the north or in cloudier weather conditions.



Cutting fresh air transportation brings significant energy savings

Although the Low Energy Cabin ACU would be slightly heavier than current ACUs Meyer Werft is also exploring the use of lightweight composite materials for the walls, floor and ceiling of the cabin, which would more than compensate for the additional weight. Further energy savings have also been identified with the cabin lighting and television, again with a switch to DC grid. The units would require some additional maintenance time – one option considered during the early stages of research was for 'clusters' of cabins instead – but Sommer says this is "not excessive" and individual installations are far more straightforward overall.

> "Meyer Werft's air conditioning system depends on the reduction of pressure losses and therefore the reduction of electrical consumption"

A pilot Low Energy Cabin will shortly be installed onboard a drydocked cruise vessel in the US. Looking ahead, Sommer says Meyer Werft's next step is to develop a DC exhaust system in addition to further refinements to the DC cabin grid, and to further explore the potential savings to be made from composite materials. *NA*

Simulation of the LE Cabin's service corner

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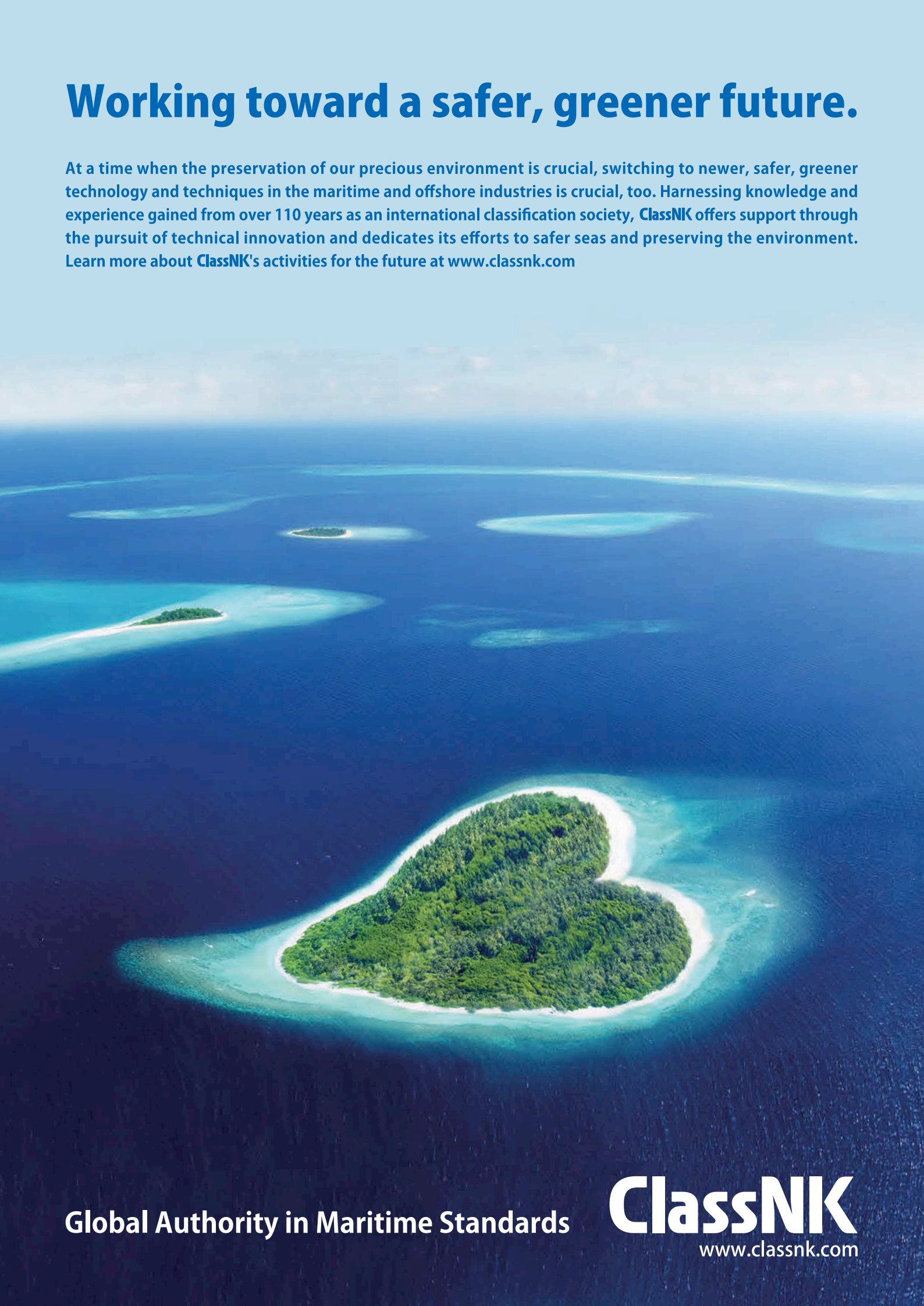

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