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IACS RINGS THE CHANGES

By **Richard Halfhide**

As we enter the autumn and the effects of Covid vaccination programmes begin to be felt, so too the maritime calendar is beginning to see a revival... sort of. London International Shipping Week, the bi-annual event that sees various maritime seminars and conferences hosted across the capital, appears to have been fairly well attended, albeit for the most part – such as the Wind Propulsion event RINA co-hosted with the IWSA – offering a hybrid option for those who would rather be there virtually. I suspect however that trying to judge numbers may become a bugbear for many PR teams; at a press event in Westminster in late September for the International Association of Classification Societies (IACS) I was one of only two journalists who had opted to be there in person!

At the end of last year, IACS announced several changes to its organisation, including having a two-year elected (and potentially re-elected) Council Chair, instead of the previous model of annual rotation between the member societies. Being of a cynical disposition, I felt compelled to question whether this had been driven by a desire by the senior IACS members to wrestle back control of the agenda from some of the more recently admitted societies.

However, newly elected Council chair Nick Brown, who only took over Lloyd's Register's CEO at the start of this year, told me he believes it will allow for greater opportunity for sustained effort in certain areas. While acknowledging there was some risk of undermining the more egalitarian rotational approach, Brown said that the new addition of a Chair's office ensures there is ongoing representation from class societies of all sizes so that all these voices can be fed into the chairman's office and that decisions will continue to be made by all 12 current members.

Brown was keen to highlight the rise of remote surveys during the pandemic, and the drive towards a standardised approach, as proof of IACS collaboration at its best. "I don't think there are many other examples where we've been so keen to get together and respond to such an urgent need," he commented. But he did concede that within the wider industry there are lots of bodies working on similar things, whether that's specific to a ship type or safety, where research and development is at cross-purposes and wasting resources in creating a solution for the same problem.

Indeed, the press conference's headline announcement that work is underway on a long-term strategic roadmap to support the industry through decarbonisation creates a distinct impression of déjà vu, albeit that as IMO's principal technical advisor it is more likely to be aligned with those aims as they develop. IACS is also concerned that not enough discussion is focusing on the safety implications of that energy transition, perceiving its role as to take conceptual ideas and novel technology and build implementable regulations around them, using a risk-based approach.

NICK BROWN, LR CEO AND IACS COUNCIL CHAIR

Forestalling the chicken and egg paradox and ensuring that naval architects, shipbuilders and equipment manufacturers have enough latitude to keep pushing the envelope has always been at the heart of the work done by class societies. Brown says that more needs to be done by the industry to support first movers seeking to trial new technologies and fearful of being left with stranded assets, and also that better government incentives might be necessary to accelerate progress. It's notable that LR itself has bucked the trend of more recent years for class societies to diversify their range of services beyond maritime, recently selling off its business assurance division (see News p.8), and it will be interesting to follow how this translates into further strategic acquisitions.

IACS also intends to specifically address the human element within its strategy, including a joint industry working group that will assess the existing SOLAS regime and look at the role of humans as "an essential part of technological solutions". It's a prevailing message in the industry at the moment, with the theme of this year's World Maritime Day being 'Seafarers: At the Core of Shipping's Future', although one can't help but suspect part of that stems from collective guilt over the mishandling of the crewing crisis caused by Covid.

Still, while decarbonisation and digitalisation continue to dominate discussion, the investigation into *Golden Ray* demonstrates (p.26), sometimes it can be human autonomy that's the issue. Conversely, the US-based International Longshoremen's Association announced in September that its members will not load or unload autonomous container ships, anticipating the inevitable rise of unmanned operations like the imminent *Yara Birkeland*. When one factors in the sorts of high-level training that might be required for ships powered by alternative fuels, and the demands that may be placed on crewing, it suggests the human element may eventually become the human problem. ■

NEWS

CLIMATE CHANGE

INDUSTRY LEADERS SIGN CALL FOR ACTION ON SHIPPING DECARBONISATION

More than 150 maritime companies have signed a Call to Action for Shipping Decarbonization, urging world leaders to align shipping with the Paris Agreement's goal of keeping average global temperatures less than 2°C above those of pre-industrial levels, it was announced on 22 September.

The document, which will be delivered to governments ahead of the United Climate change conference, COP 26, being hosted in Glasgow in November, implores them to provide greater clarity in decarbonisation policies. Although the International Maritime Organization (IMO) has previously set a goal of a minimum 50% reduction in overall greenhouse gas (GHG) emissions by 2050, the signatories believe that a clear target needs to be set for the shipping sector to run entirely on net-zero energy sources by that point, in order to achieve IMO's GHG Strategy when it is adopted in 2023.

It also calls for governments to support 'industrial scale' zero emission projects through national action and deliver policy measures that will make zero emission shipping the default choice by 2030.

Among the organisations pledging their support, which are all members of the Getting to Zero coalition, are classification societies ABS, Bureau Veritas, China Classification Society, ClassNK and the Korean Register. Hiroaki Sakashita, president & CEO of ClassNK comments: "ClassNK commits to support both public and private approaches to zero emission by carrying out reliable regulatory service, developing broader certification service responding to emerging needs, and extending outcomes from partnerships with industry pioneers. With all our strengths, ClassNK will accompany the journey to shipping decarbonisation."

Another signatory is Swedish equipment manufacturer Alfa Laval. Dr Markus Hoffmann, who leads the company's Marine Separation & Heat Transfer Equipment and heads its work on the initiative says not only should maritime's goals be more ambitious, but require the conditions to make the emerging zero-emission technologies scalable and commercially viable. He believes this can only be done with the use of market incentives to make them more attractive compared to traditional choices.

"Maritime businesses should see opportunity in taking swift steps towards decarbonisation, rather than additional risk," Hoffmann stresses.

SALVAGE OPERATIONS

LANDMARK SALVAGE OPERATION IN PAKISTAN

Salvage contractor Seamax Marine Services, a Pakistan based company, successfully completed the country's first unassisted salvage operation in September when it refloated a 98m deck cargo ship.

Heng Tong 77 had been stranded on the Clifton beach, Karachi, since 21 July after it drifted while en route from Shanghai to Istanbul. Although an initial survey had taken place shortly after the incident, previous refloating attempts in August had been thwarted by unfavourable weather. Subsequently, Seamax's salvage engineer and owner, Humayun Shaikh, led what is described as a "bullet-proof plan" that recovered the vessel without casualties or damage to the environment. *Heng Tong 77* was then taken to Karachi Port for inspection and repairs.

"For the first time, a stranded ship has been rescued safely using local capabilities – a milestone in the country's shipping industry," said Mr Mehmood Maulvi, special assistant to the Pakistan Prime Minister (Imran Khan) on maritime affairs, speaking at a media briefing.

Mr Shaikh commended the 130-strong team, offshore and onshore, who had been involved in the salvaging for delivering "100% efficiency". He also thanked the shipping agent, Pakistan navy, Ministry of Ports and Shipping and coastguard, among others, for their unwavering support throughout the operation.

HE TONG 77, SHORTLY AFTER ITS STRANDING IN JULY

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ALTERNATIVE FUELS

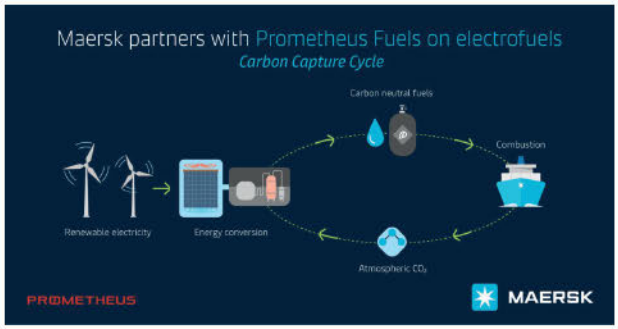
MAERSK BUYS STAKE IN E-FUELS STARTUP

A.P. Moller – Maersk's venture capital division, Maersk Growth, has announced a minority investment in Prometheus Fuels, a Silicon Valley-based startup that is developing a direct air capture technology that will convert CO_2 into carbon-based electrofuels.

Morten Bo Christiansen, A.P. Moller – Maersk's head of decarbonisation, comments: "Prometheus Fuels is developing a very exciting and innovative technology to produce carbon based electrofuels from direct air capture of CO_2. Electrofuels are expected to play a key role for the decarbonisation of shipping and, if scaled successfully, Prometheus Fuels' technology will address a key constraint for carbon based electrofuels – namely the cost competitiveness of direct air capture."

According to Prometheus's website, the company has developed a unique solution that combines integrated direct air capture of CO_2, with cutting edge catalysts for converting it into fuel, and a novel membrane that eliminates the need for distillation.

Prometheus founder and CEO, Rob McGinnis, says: Our zero net carbon, zero sulphur electrofuel doesn't compete with food production – it comes from renewable electricity and air so its feedstock is limitless. Our electrofuel offers a truly viable solution to decarbonise shipping – one that can scale and be implemented in time to avoid catastrophic global warming. We're excited to partner with Maersk, a global leader in decarbonisation in the transportation and shipping industries, to accelerate this transition."



THE PROMETHEUS CARBON CAPTURE CYCLE

The Danish shipping giant says that it expects several fuels to exist alongside in the future fuel mix and in particular has identified four potential fuel pathways to decarbonisation: biodiesel, alcohols, lignin-enhanced alcohols and ammonia. It expects synthetic alcohols and other electrofuels to play a big role in the decarbonisation of shipping.

In August, Maersk revealed it had partnered with REintegrate, a subsidiary of the Danish renewable energy company European Energy, to produce green fuel for its first carbon neutral container ship, expected to be operational from 2023. A further series of eight series large ocean-going container vessels capable of being operated on carbon neutral methanol are being built by Hyundai Heavy Industries, with delivery expected to commence in early 2024.

VOYAGE OPTIMISATION

LLOYD'S REGISTER ANNOUNCES GREENSTEAM ACQUISITION

Lloyd's Register has acquired GreenSteam, a marine data intelligence company that uses machine learning (ML) to improve ship efficiency, as part of its goal of becoming the go-to consultant to the maritime industry.

Founded in 2007 by three Faroe Islands academics studying at Copenhagen technical University, Denmark, GreenSteam processes sensor-derived data through learning algorithms for ship specific voyage optimisation solutions, including such variables as fouling analysis and trim planning (see *TNA*'s *Green Shipping* supplement, January 2021). The acquisition will be managed and integrated by LR's i4 Insight subsidiary, a digital platform that provides shipowners with insights on vessel performance and fuel consumption across their fleets.

Nick Brown, LR CEO, says: "We want to help clients drive growth and solve complex problems through human expertise, integrated software solutions and the right insights from data. When certainty is scarce, a trusted advisor is vital, which is why Lloyd's Register is expanding its portfolio of fleet management and fleet optimisation services."

GreenSteam's executive chairman, Shaun Gray, says that having previously worked with LR as partner in the i4 Alliance, a single web-based application for vessel performance insight, convinced GreenSteam that the acquisition was the right thing. He comments: "Lloyd's Register is an ambitious organisation with a long history in shipping and outstanding relationships with its customers. This, combined with i4 Insight's innovative spirit to give the shipping industry the tools to make truly informed decisions about fuel consumption, is a win-win. Together we will support shipowners in optimising vessel operations while also delivering on emissions targets."

The acquisition comes a few months after LR announced it was spinning off its Business Assurance & Inspection Services division into an independent business, branded LRQA, to be acquired by funds managed by Goldman Sachs Asset Management. The divestment, which included LR's cybersecurity division, is intended to generate capital for accelerated growth of its advisory services capabilities, as it focuses on providing insight on compliance, performance and sustainability for the maritime supply chain.

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NEWS ANALYSIS

DECARBONISATION DEBATE GOES ON AS DUTCH FEEDER DEMONSTRATES ONBOARD CCS

By **Malcolm Latarche**

With COP 26 and MEPC 77 both on the horizon, it was always certain that the subject of decarbonisation would be high on the list of hot topics for September. Ever since MEPC adopted the EEXI and CII rules for existing ships this has been the subject of many debates and seminars over how to meet the requirements although with no real conclusion as to the best choice.

September opened with Maersk – which had ordered a series of eight methanol-fuelled 16,000TEU boxships in August – admitting that the decision would be a costly one with regard to bunkering. Analyst S&P Global Platts quoted Maersk's head of Decarbonisation Innovation and Business Development, Jacob Sterling, as saying: "There will be a roughly two-fold increase in the cost of fuelling these ships. The renewable methanol will cost at least as much as conventional fuel oil on a metric tonne basis and as methanol's density is around half of fuel oil's this implies the renewable fuel will cost about twice as much."

Sterling also mentioned that all future Maersk vessels will be dual-fuelled and that the company's bunkering procedures would probably need changing. The new vessels will need around 360,000tonnes of methanol each year and securing the fuel "will be a challenge and could mean less of a focus for the methanol-powered ships on traditional bunker hubs, such as Rotterdam, than for conventionally fuelled ships. Especially in the first years, when the supply of green methanol will be scattered in different places," Sterling said, adding: "Putting a price on carbon will be crucial to making new bunker fuels economically viable".

That issue was raised shortly afterwards when the Methanol Institute (MI) said in a statement that all fuels should be assessed on a well to wake basis rather than the approach being taken by the IMO in regulating emissions.

According to MI applying a well-to-wake approach would provide an investment signal, foster innovation in renewable power generation and avoid transferring the reallocation of GHG emissions to upstream fuel production processes. Methanol Institute chief executive Gregory Dolan said: "The tank-to-wake approach currently used by IMO undisputedly places the burden of GHG emissions solely on shipowners and it implies that to achieve decarbonisation, they are held wholly responsible for ensuring decarbonisation of the sector. A well-to-wake approach would share the burden with fuel suppliers, power generators, port authorities and national governments – we cannot just look at what happens in the engine room and ignore how the fuel got there in the first place".

VISSER SHIPPING'S *NORDICA* WILL BECOME THE FIRST VESSEL TO CAPTURE AND STORE ONBOARD CO_2

By granting vessels propelled by ammonia or hydrogen from natural gas 'zero-emissions' status, policymakers ignore the fact that they emit more GHG than any of the other potential alternative fuels. If policymakers truly intend to apply a metric to GHG emissions which reflects reality instead of a false impression of progress, the well-to-wake approach represents the only viable path forward.

Elsewhere, one project has been taking a very practical approach and preparing to do some genuine decarbonisation. Dutch scrubber maker Value Maritime has developed an onboard CO_2 capture and storage solution as an add on for its Filtree scrubber.

The new device would capture the CO_2 in an onboard storage facility which can charge and discharge CO_2 infinitely. The charged CO_2 Battery – as the storage containers are referred to – will be offloaded in ports and transported to CO_2 customers such as the agricultural sector. After CO_2 discharge, the CO_2 Battery returns to the vessel, to be recharged with CO_2 in a fully circular operation.

Value Maritime's first CO_2 Capture Module and CO_2 Battery will be installed on Visser Shipping's 1,040TEU feeder vessel *Nordica* in October this year, making *Nordica* the first vessel to capture and store CO_2 onboard of whilst in operation.

Although the system is ingenious and practical, its application in the circular function might be limited on a global scale. Nevertheless, it is indicative of shipping actually being seen to be doing something concrete and probably an idea that will be better received that imposing cost burdens on the industry either by way of bunker levies or entry into enforced emission trading schemes. ■

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NEWS EQUIPMENT

ENGINES

WINGD DEVELOPS ENGINE 'ECOSYSTEM'

Swiss engine manufacturer WinGD has launched a new ecosystem of solutions around the main engine that it believes will enhance energy efficiency and facilitate the transition to low-carbon fuels.

Intended to improve the efficiency of its two-stroke range, the new solution combines digital vessel optimisation and battery-hybrid energy systems. While it's commonly accepted that burning LNG in an engine in WinGD's low-pressure X-DF series can reduce GHG emissions by around 20% compared to HFO, when used in tandem with these additional enhancements that figure can be drastically reduced to well byond IMO's target of a 40% reduction in carbon intensity by 2040.

Unsurprisingly, WinGD believes engines should be at the heart of today's integrated power systems. Klaus Heim, CEO, WinGD says: "These systems, including our engines, are fully ready for the future fuels that will take ships much further than IMO's target of cutting greenhouse gas emissions by at least 50% by 2050."

One recent project it highlights is a collaboration with Japanese owner NYK Line for the hybrid energy management system onboard four pure car and truck carriers. Powered by LNG, the vessels are equipped with WinGD's 7X62DF-2.1 two-stroke engines, complemented by DC links and battery systems. By optimising the spinning reserves, peak shaving, and energy flow to run the main engine at its sweet spot as much as possible, WinGD's new Hybrid Control System is able to minimise the use of auxiliary engines.

The new offering is also enhanced by WinGD's Integrated Digital Expert (WiDE), which it describes as a cutting-edge engine monitoring and optimisation solution and the standard on all its medium and large bore engines. Remote monitoring and support capabilities are made possible by the WinGD Integrated Control Electronics (WiCE).

POWER SYSTEMS

THE SWITCH SELLS 100TH PMM SHAFT GENERATOR

Yaskawa Environmental Energy/The Switch has secured the 100th order for its permanent magnet machines (PMMs) for in-line shaft generators, the company has announced.

With a large orderbook for LNG and LPG carriers, The Switch's PMM solution is gaining traction as shipowners look to take advantage of the increased efficiency of variable-speed shaft generators for electrical power generation, instead of auxiliary gensets. These have traditionally been electrically excited synchronous generators (EESG), which is bulky and complex, whereas the PMM shaft generator offers higher reliability, efficiency and flexibility, while occupying up to 50% less space. Unlike EESGs, PMM generators do not require external energy for their magnetisation, relying instead on neodymium magnets that improve efficiency by 2-3% across the entire operating range.

Although PMMs offer only modest improvements for high-speed applications compared to conventional machines, these gains increase significantly when operated at partial load or slow speed. Consequently, they have become a popular choice not only for LNG and LPG carriers, but also products tankers and car carriers.

"Using PMMs for electrical power generation is a game-changer in terms of greater efficiency, reliability and flexibility especially where slow steaming is a desired function," declares Jussi Puranen, who leads the company's electrical machines product line.

"People are starting to see what I call the 'magic' of permanent magnets and realising how it can accelerate the shift to enhanced performance and sustainability. We're targeting many more PMM-powered generators and direct-drive propulsion solutions in the coming years so the story will only get better," he adds.

THE SWITCH'S PMM 1500 SHAFT GENERATOR

BALLAST WATER TREATMENT

ECOCHLOR SUBMITS FILTERLESS BWMS FOR USCG APPROVAL

Ballast water management systems (BWMS) manufacturer Ecochlor has filed applications with the US Coastguard (USCG) for its EcoOne Filterless and EcoOne Hybrid solutions. The US-based company expects the application, which is an amendment to Ecochlor's existing BWMS Type Approval, to be a formality and that certification should follow by the end of this year.

First covered in May's *TNA*, the system uses Ecochlor's patented chlorine dioxide (ClO2) technology, which primarily reacts with living organisms and causes less damage to ballast tank coatings than electrochlorination, while also consuming less power. Although the company maintains that no filter is required, even in more turbid waters, the hybrid variant was developed to avoid salty discharge in freshwater environments.

Andrew Marshall, Ecochlor's VP of business development, says that shipowners have embraced the EcoOne and EcoOne Hybrid BWMS entries into the market with great eagerness. "In the first half of 2021, we received a record number of orders from new customers [such as] Companhia de Navegação Norsul, JMB Shipping, Seanergy Maritime Holdings Corp., and Sirius Shipmanagement, they were looking for the flexibility we offer with our one-stop-fits-all options of BWMSs, along with our superior global servicing capabilities."

LNG

KNUTSEN ORDERS WÄRTSILÄ COMPACT RELIQ PLANTS

Norwegian shipowner Knutsen OAS Shipping has taken the option on three further reliquefaction plants from Wärtsilä, the recently-developed Compact Reliq, for a trio of LNG carriers currently under construction at Samho Heavy Industries (HSHI) shipyard in South Korea.

Launched last year, the Compact Reliq boasts a compact design that is said to be suitable for installation on vessels of all sizes. The solution is based on reversed nitrogen Brayton cycle refrigeration technology, whereby boil-off gas (BOG) is reliquefied, while a portion of the BOG is used as fuel for the main engines. It uses easily obtainable commercial grade nitrogen, and includes the capability for remote monitoring as part of Wärtsilä's Operim (Operational Performance Improvement & Monitoring) programme.

"We received an order for two systems last year to be delivered to the HSHI yard for installation on Knutsen's newbuild carriers. There was an option for additional vessels and this option has been taken up with contracts for three new Compact Reliq plants. These are important projects that further strengthen our relationship with both HSHI and Knutsen OAS," said Pål Steinnes, sales manager, Wärtsilä Gas Solutions.

WÄRTSILÄ'S COMPACT RELIQ

LNG

GTT REAPS BENEFITS OF LNG CARRIER ORDER GLUT

French membrane containment system specialists Gaztransport & Technigaz SA (GTT) announced multiple orders for its tank design solutions in September as bookings for LNG carriers (LNGC) continue to surge.

Among these are the 174,000m^3 capacity tanks for a pair of LNGCs under construction for an unnamed European shipowner at Hyundai Samho Heavy Industries (HSHI). Tanks of the same capacity will also be designed for a trio of vessels for an Asian shipowner at Hyundai Heavy Industries, while another pair will be built at Hyundai Samho Heavy Industries (HSHI) for a different European shipowner. All the vessels are scheduled for delivery in 2024, with GTT providing design and associated engineering services.

Also in September, GTT and naval architecture and engineering firm Deltamarin revealed they had been granted Approval in Principle by ABS for a new LNG-fuelled Aframax tanker design. Working closely with GTT, Deltamarin studied various arrangements to find the optimised size and placement for the Aframax's LNG containment system.

The AiP certifies that the onboard integration of the fuel tank solution is technically feasible and compliant for an LNG-fueled tanker, meeting IMO's environmental regulations until 2030. It is said to offer a 20% reduction in CO_2 emissions compared to HFO. It is also said to offer increased autonomy without reducing the cargo volume.

Philippe Berterottière, GTT chairman and CEO says: "This new design further demonstrates GTT's ambition to innovate and support the maritime industry in facing the challenges of the energy transition. With Deltamarin and ABS, we are very proud to be able to offer a new LNG-fueled tanker solution that is more respectful of the environment and without making any compromise on cargo."

OPINION

MARITIME FUEL AND OTHER SUBSIDIES: WIND UP OR WIND UP?

By **Gavin Allwright,** Secretary General, International Windship Association

SOURCE: YARA MARINE TECHNOLOGIES

Recent announcements on fuel subsidies have, for me, brought to the fore issues surrounding the way subsidies are introduced and their impacts on the decarbonisation pathway's they take us down in the shipping industry. My economics professor always hammered on that subsidies indicated market failures and should always be a temporary, last resort if you believed markets could deliver a level playing field. That always led to an energetic debate and one that is picking up steam in the industry, though currently solely through the lens of the pros and cons of imposing carbon levies.

Maritime subsidies come in many forms; direct ones are obvious such as tax exemptions on fuel, favourable tonnage tax regimes, R&D funds, tax credits for investments or subsidies to hold down the cost of employing seafarers. Indirect subsidies come in the way of support for maritime clusters, port infrastructure development, training etc. These are relatively transparent (though accurate data is often hard to find) and many nations deliver these.

These distort the shipping market to an extent, but the few billions spent here are quite peripheral in the grand scheme of things, and the strategic nature of shipping and heavy capex burden is a justification for these in many people's minds, though the question of their effectiveness is still an open one.

The far more impactful subsidies are the indirect, externalised ones around fossil fuels. The externalisation of climate costs and the decarbonisation agenda is fuelling the debate that is currently raging in the industry. But are we seeing the whole picture? The external costs of our current fuel mix also extend to hundreds of billions per year in health costs and lost productivity, pollution issues and the security costs of securing fuel reserves along with the opportunity costs of not investing these resources in productive areas of the economy.

There are numerous estimates around the levels of subsidy for fossil fuels, but let's go with the median estimate made by the IMF at US$4.3 trillion on worldwide energy use equivalent to between US$200-300 per tonne of oil, a not insignificant amount and one that doesn't include security cost estimates, the full lifecycle assessment of fuels, opportunity costs or the longer-term climate impacts, but a useful indicator nonetheless. With the shipping industry consuming 300 million tonnes of fuel per year, this is a very substantial amount, and the carbon levies being proposed from the EU Emissions Trading System (US$180/tonne) to Trafigura's proposal (US$750-900/tonne) bear this out by factoring in the climate impact alone at a high level.

In recent weeks, we have seen calls to subsidise alternative fuel development in the UK for example, with Blue Hydrogen. Now, I don't single out any alternative fuel in particular, but this one has been making the news and the discussion here bears out some of the contradictions. The argument goes that existing fossil fuels are very cheap and available but new fuels face extremely high barriers to entry costs and thus new subsidies will be required to make them cost competitive.

OK so far, however most alternative fuels will likely be derived from fossil fuel over the coming two decades and that fossil fuels themselves are extremely heavily subsidised and have been so for the last century or more. Thus, the energy sector is effectively needing subsidies to compete against its own existing heavily subsidised product line.

The answer is to precisely assess the impacts of all energy sources and then remove all subsidies, while

assisting new technologies and fuels to a degree with the barriers to entry that a century of fossil fuel subsidies have created. Is that likely to change anytime soon? Well, the introduction of a carbon levy would go some way to balancing the playing field and one that is ring fenced and brought back into the industry in way of grants and low-cost loans for the installation of decarbonising technologies, as we saw with the Norwegian NOx fund, would magnify that impact. Few would dispute the need for R&D support and many would also agree with support for installations, but both of these also fall foul of the question of who pays and where the proceeds are spent. Developing nations rightly point out they will be expected to pay high prices for fuel but almost all R&D and technology developers come from developed countries, another subsidy quandary.

This all brings me to my favourite subject, direct wind propulsion and how primary renewable energy fits into this equation. Wind propulsion systems can of course benefit from R&D subsidies and subsidised installation costs but currently receive far less than alternative fuel support, even though it has the potential to deliver up to a third of the fleet energy requirement by 2050s. It is a zero-emissions energy source that is free and non-commoditised, delivered without the need for infrastructure, production, transport, storage or exploration subsidies. So, if other energy sources are receiving subsidies for these, how do you level that playing field?

On subsidies gone awry (but in wind's favour), in the late 19th century, in an effort to challenge British maritime dominance, many countries paid ship building tonnage bounties to encourage steam and steel. France though paid high bounties for sailing vessel building too, and also introduced operational bounties paid per 1,000 nautical miles sailed. This led to fewer steamships being built and sail cargo captains taking more circuitous routes to claim the maximum bounty available, ending with a depleted treasury and delaying the transition to steam.

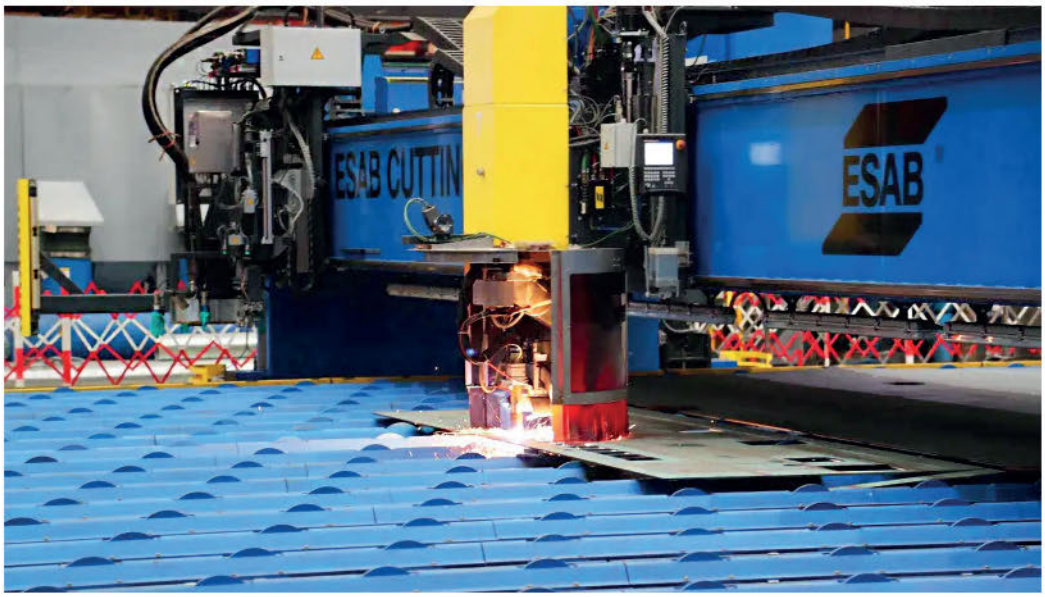
So, should shipping companies adopting wind propulsion be handed bags of money equivalent to the subsidies deployed elsewhere? I am sure there would be few to turn that down, but is it likely? Carbon levies will help redress the balance but a fair, equitable distribution of proceeds to all propulsion energy sources will be required. If we created a ship-based energy market where each energy source was paid per kWh with technology companies leasing their technologies to the ship platform that could be an interesting longer-term solution.

In the meantime, whenever we hear the word 'subsidy' we should pause and reflect on the market 'failure' that is exposing and question whether these remedies are both effective and will promote an 'energy-centric' transition rather than a narrower, and more costly 'fuel-centric' decarbonisation pathway. Winding up subsidies across the board or ensuring subsidies level up all energy sources, including 'Wind Up'. ■

SHIPBUILDING TECHNOLOGY

GUANGZHOU SHIPYARD INTERNATIONAL'S THIN PLATE BLOCK ASSEMBLY LINE COMPLETED

By **Ship Economy & Trade**



GUANGZHOU SHIPYARD INTERNATIONAL 'S SHEET BLOCK ASSEMBLY LINE

On 28 June, the newly-built thin plate block assembly line of Guangzhou Shipyard International Co., Ltd. (GSI), a subsidiary of China Shipbuilding Corporation Limited, was completed for the commencement of production trials. The production line has a total area of about 45,000m^2, a total length of 390m, and comprises of two workshops. The entire assembly line is equivalent to a giant ship hull 'thin plate segment printer', which can print 2.6 thin plate segments per day.

On the afternoon of 29 June, the inspection-free workshop for sheet-segment construction was officially inaugurated. In the future, some thin plate sections of COSCO Shipping's ro-ro cargo vessels will be built in this workshop to further improve the independent quality management level of the manufacturing department, improve product quality and production efficiency, and provide a good demonstration for subsequent efforts to obtain more inspection-free work.

The assembly line's high degree of automation has subverted the popular perception of traditional hull segmentation production. Steel plates go in one end and are segmented out the other. Only about 50 people are needed to make the entire production line operate.

Why build a thin plate segmented assembly line?

The construction of the thin-plate segmented assembly line is mainly intended to meet the construction needs of high-end ship products such as GSI's luxury ro-ro passenger ships and small and medium-sized luxury cruise ships. Because this type of ship has a huge superstructure, a large number of thin plates of only 3-4mm are usually used for construction, in order to reduce the ship's own weight, increase speed and reduce its centre of gravity. GSI's investment in the the thin-plate block assembly line is intended to meet the requirements for high-quality development and realise the transformation and upgrading of ship products.

Features

The entire thin-plate segmentation line consists of a segment line, one profile steel line, and two segment lines, which are respectively equipped with a series of advanced equipment such as laser composite welding and welding stations, longitudinal assembly welding stations, and robot welding stations. According to on-site operators, the equipment on these workstations are almost like human organs, all with automatic sensing functions. When the equipment is working, it can synchronously transmit all kinds of 'perceived information' to the control system and form a visual animation. The staff can easily control the entire assembly line for production by issuing instructions in the information management and control system.

In addition, the high degree of automation of each station on the production line can subvert people's

cognition of traditional segmented production. For example, in a robot welding station, only the segmented 3D model that needs to be welded needs to be imported, and the system can automatically determine the weld. According to the requirements, the welding process parameters are matched and the robot welding program is created. The robot runs autonomously according to the welding program until the products are completely welded.

A further benefit is avoiding deformation of the thin plate. Reducing the deformation of sheet segments during the production process is one of the difficulties that need to be solved in the construction of this assembly line. So how does this assembly line reduce the deformation of a 3-4mm sheet during the process of making segments? Making thin plate segments on such a production line is equivalent to incubating an egg and the key is to minimise the stress and deformation of steel during thermal processing such as welding.

For these complex process requirements, the designer has fully considered the timing. For example, when milling the welded joints of the panel, the gap of the welded joints should be less than 0.5mm to ensure that the joints are heated evenly during welding. The rib welding station is also equipped with a special shaping device, which can minimise the degree of freedom of the workpiece during welding, thereby reducing the deformation. At the same time, the transfer of the segmented sheet between each station is carried out by rollers, almost like abacus beads, to ensure that the sheet is uniformly stressed at multiple points and avoid bumps.

Customised production is economical and easy to implement. The production line is contracted by the Shanghai Shipbuilding Technology Research Institute under the auspices of China Shipbuilding Corporation. It is divided into two parts: domestic and imported stations. The luxury cruise production line for advanced domestic shipbuilding enterprises are designed and combined with the production characteristics of GSI.

GSI has also set up a working group for optimising processes, which has conducted special research and continuous improvement in terms of reducing costs. To further reduce construction costs, GSI's Planning and Construction Support Department dispatched a team to undertake on-site construction management work by itself. The steel structure of the workshop is also all produced by Yonglian Company, a subsidiary of Guangzhou Shipyard International. ■

A version of this article was originally published in the Chinese publication 'Ship Economy and Trade'.

NETHERLANDS

RESOLVING UNCERTAINTIES IN CONTAINER SAFETY

By **Sophie Collingwood**

Container ships have changed dramatically in the last 10 years; vessels are growing exponentially bigger and tiers higher. It's impossible to discuss the sector without recalling safety concerns, especially in light of the recent incidents where a collective of around 3,000 containers were lost from multiple ships during a single winter season on the Pacific.

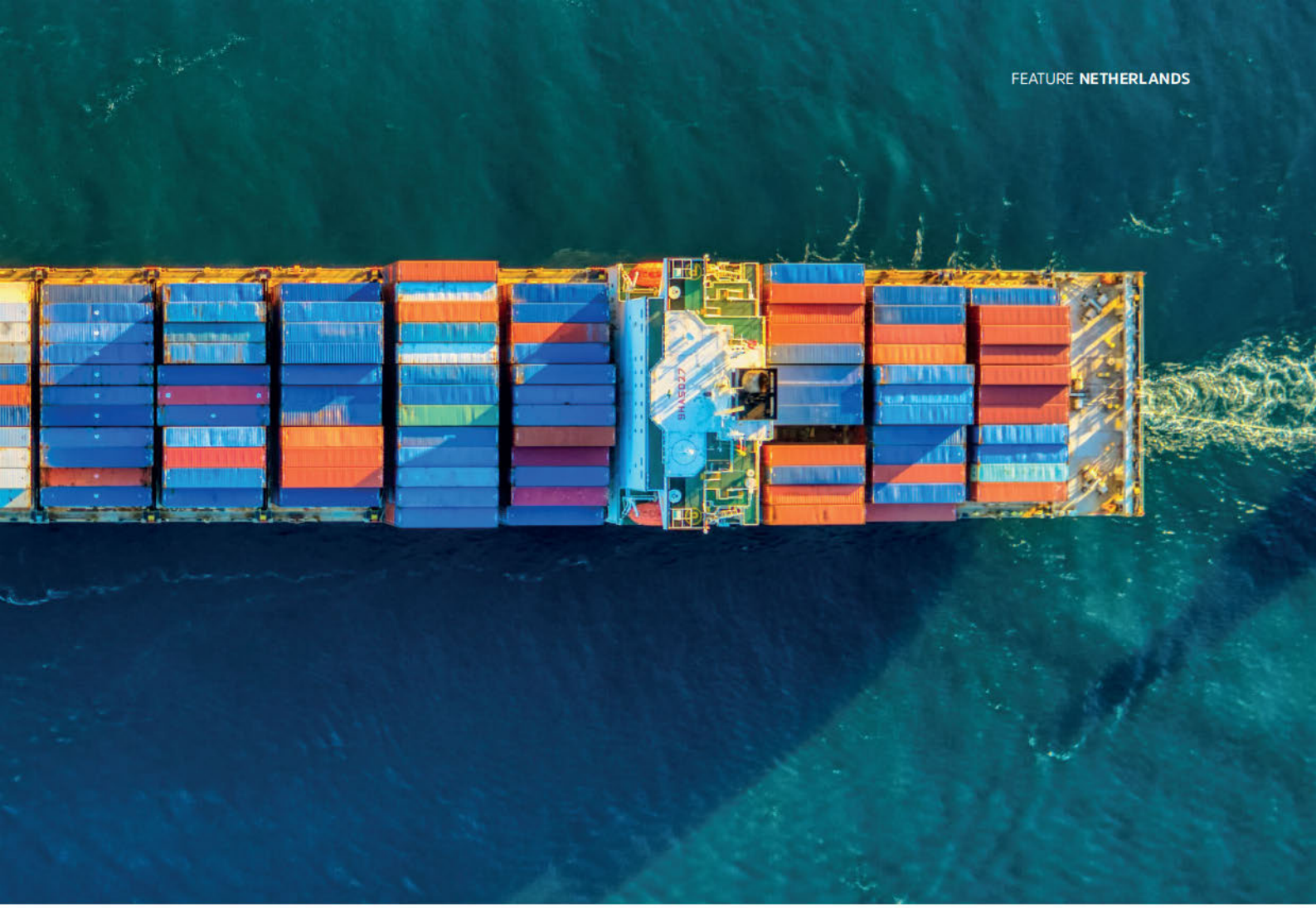
With too many large-scale incidents occurring to be considered one-off mistakes, the question remains: how can truly safe operations be reached? A recent joint industry project (JIP) launched by the Maritime Research Institute Netherlands (MARIN) in July 2021, known as TopTier, seeks to research and restore fidelity in the safety of the current container ship fleet.

Lashings at sea

Container safety is not a new topic for MARIN. Just 10 years ago, the company headed Lashing@Sea, a JIP which mainly concentrated on improving lashing systems to avoid failure and increase efficiency. Although Jos Koning, senior project manager for TopTier, and previously Lashings@Sea, tells *The Naval Architect* that some progress was seen as a result of recommendations made by the JIP, he notes that ultimately most emerged as optional recommendations.

Making limit calculations by using container weightings taken prior to loading, rather than numbers filled out weeks previously, was one such recommendation made. "This was picked up by IMO and has been implemented in the verified gross mass (VGM) requirement. It suggests that the weight is measured and verified, but in fact it's not such a strict requirement in the end and no one is sure of how good an effect it has had," says Koning.

TopTier follows on from the research undertaken in Lashings@Sea, but Koning explains that it is an emerging concern over systematic issues that is driving the project overall: "Over recent years, there have been a number of



SOURCE: CAMERON VENTI (UNSPLASH)

incidents which are different from previous events, in the fact that it appears as though the amount of damage that occurred on ships was so big that it suggests the design limitations of the cargo arrangements were, and maybe still could be, systematically exceeded." The challenge, Koning says, is for TopTier to search out any potential systematic loopholes in the current container framework and figure out a way to close them.

Uncertainties in safety

A complex issue calls for a comprehensive approach and, during its kick-off meeting, the JIP identified six main aspects to address in order to meet the project's primary goal; restore fidelity in the safety of container ships.

The first, minimising uncertainties relating to a vessel's planned stow configuration: inaccurate container weights, their stowage locations and how this affects safety margins. The second, concentrating on the uncertainty in the strength limitations of containers and equipment used and for the third and fourth aspects, TopTier will consider the uncertainty of motions and quality of the calculation design models. "In the stowing process, calculations are used to determine the expected maximum loads under worst case assumed operational weather conditions. What we will do in the project is evaluate if the models that are used for those steps are actually lining up what is occurring on those large ships."

A significant part of TopTier's investigations concentrates on these technical issues, aiming to recommend on dealing with the effects of extreme motions, high GM, hull girder flexibility, flexibility of containers and lashing gear components, high stack dynamics, and more. Koning points out that many of these aspects are presently not yet included in the securing procedures primarily because they have only become of higher importance over the last decade.

"Ships sailing with these high GMs, for instance. That's something which is related to the increase of the ship designs. Ships are definitely a lot wider than they used to be and sometimes operate in part load when they are not so heavy, and so the centre of gravity and centre of buoyancy are behaving such that they are becoming incredibly stable."

He continues: "That may sound really positive, but a very stable ship also wants to be upright against inclined wave surfaces, which means it will respond very strongly to waves. That's an affect which has come in line with the increase of ship dimensions, and there is not a lot of statistics on that yet."

Modern ships operate in a way that implies a very large variation of operational conditions, in the GM, in the sailing area where they are operating, and Koning comments that this makes it very hard to determine the extreme motions envelope that are the basis of operational stowage and securing calculations. The JIP aims to tackle these aspects by investigating and providing updated statistics for the modern generation and operation of ULCS's.

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TOPTIER PROJECT IS SUPPORTED BY THREE NATIONAL AUTHORITIES, THE WORLD SHIPPING COUNCIL AND INCLUDES PARTNERS THROUGHOUT THE INDUSTRY TO PERFORM THE REQUIRED RESEACH AND DEVELOPMENTS.

Down to the crew

Operational factors with feedback to the crew is the fifth aspect on the agenda. Crew on board are expected to avoid extreme conditions, severe pounding and synchronous or parametric rolling as these can trigger 'high loads'. But Koning highlights that currently crew members may not have enough reliable data to act upon: At some point the risk of excessive loads becomes too high and crew action as speed or heading adjustments are needed to stay inside safe load envelopes.

"They base their decisions on good seamanship but do not have extensive feedback on the load ratio of the cargo arrangement. It is really hard to get an intuitive feel for the acceptable level of stress imposed on a collection of 24,000+ containers on a laden vessel of 400m and 60m wide, sailing in bad weather, at nightime. Its incredible to picture that, and I dont think it is realistic to just put that on the plate of the crew. The question is if the limit which is assumed in the design models lines up with operational reality that is faced by crews in the real ocean.

"We want to provide feedback for the crews so they can get better insight in how much of the design loads, which were taken in calculation models, is actually already being taken on by the ship in that current situation and what the estimated risk is that, in a short or longer term, they might exceed those limitations. Not based on just feeling, but on measured information from the ships motions and the documented limitations of the equipment and the actual configuration of the loading system on the deck," he explains.

Regulation challenges

The sixth and final aspect, Koning stresses, is key to putting all previous research areas into action: "All those five that I mentioned are things that we expect will improve the situation, but in the end they will just be technical options that you can provide to operators and ship crews. Unless they are implemented practically onboard and operated in the daily operations, they will not have a broad effect on general safety. You only need one operator that does not comply with those recommendations for conditions to remain unsafe, because general safety is not effected by a single ship but by all ships."

As such, the sixth aspect's objective is to find a way to update the regulatory framework to ensure minimum requirements on these different aspects that are acceptable for authorities, for class and for the carriers, and that has a systematic improving effect on safety.

However, Koning admits that regulations may be the most challenging of all the aspects TopTier seeks to address and implicate. "But we will be doing those discussions in co-operations with national authorities, class society and support from the carriers, so all the relevant input at least is there, but it will be a challenging task. I think it may be the challenging task in the project. But that's where the actual impact will come from. Otherwise it would all just remain optional," he adds.

A missing link

The TopTier project already has numerous project partners and Koning notes that this was an intentional move by MARIN to broaden its scope beyond the national authorities, carrier companies, class societies and lashing gear manufacturers as involved in Lashing@Sea. "At the start of project we contacted all the same partners as before, but we knew that in order to investigate it in total we would need support also from a wider group. So now involvement is extended and for instance also includes branch organisations such as the World Shipping Council, P&I International Group and BIC; they have played a very important role involving industry in the project."

Despite this, Koning points out that shoreside operations, a crucial party involved in the container industry, is still missing: "Container safety sounds like a maritime problem, but it's not really just a maritime problem, it's a problem that starts already when a ship is loaded or planned to be loaded – that means onshore."

The next stages

TopTier's first project stage is due to report by end of November, by which point Koning hopes the JIP can cluster together typical types of incidents and circumstances: "to see if there is a phenomena standing out that we should focus on more in particular and, if we have that, then what we want to lay out at that time is the more detailed plans for the coming year." ■

SOUTH KOREA

SOUTH KOREA PLANS FOR A HYDROGEN-BASED FUTURE

By **Richard Halfhide**

Like many nations, South Korea is putting its faith in hydrogen to meet its future energy demands, but for a country that prides itself on being at the forefront of technology that means more than simply following the crowd. In January 2019, the Korean government published its Hydrogen Energy Roadmap, which outlines its goal of becoming the world's leading hydrogen economy. The following year, its National Assembly ratified this with the Hydrogen Law – Hydrogen Economy Promotion and Hydrogen Safety Management Law, the first legal framework of its kind anywhere in the world.

Unsurprisingly, maritime takes a central role in those plans, both in terms of hydrogen-based fuel solutions for shipping and the transportation of hydrogen to Korea for wider applications. The Korean government hopes to eventually stimulate investment in local production, however even at maturity it's anticipated that at least half of hydrogen demand will still need to be met by imports.

In October last year, classification society the Korean Register of Shipping (KR) granted the first Approval in Principle (AiP) for a large liquid hydrogen carrier design developed by Hyundai subsidiaries Korea Shipbuilding & Offshore Engineering (KSOE) and its shipyard Hyundai Mipo Dockyard (HMD). The 20,000m³ vessel, which is being developed in partnership with operator Hyundai Glovis as well the Liberian registry, will include double-walled vacuum-insulated tanks to store the hydrogen, while an electrical propulsion system powered by hydrogen fuel cells would utilise boil-off gas.

KR tells *TNA* that it is also working with Daewoo Shipbuilding & Marine Engineering (DSME), Samsung Heavy Industries (SHI) and KSOE on a separate hydrogen carrier project to import green hydrogen from overseas. In addition, KR is currently engaged in type approval for a ship fuel cell system developed by an undisclosed manufacturer. It has also been making efforts to contribute to meeting Korea's Nationally Determined Contribution to the Paris Agreement goals by developing hydrogen technologies for the marine industry.

Hydrogen storage and handling

Dr. Chun Kang-Woo of KR's Green Ship Technology team explains that hydrogen containment onboard ships is generally divided into either high-pressure gas storage or cryogenic liquid storage, depending on the purpose and operating distance of the vessel. High-pressure storage, which compresses the hydrogen to around 250bar or higher within a pressurised container, is currently the more mature technology.

High-pressure containers are essential components in the design of such ships, and these must be capable of controlling the rising temperatures caused by hydrogen charging as well as precautions to protect against natural hydrogen leakage from the wall of the container. "Such measures are widely applied to land vehicles and there are already cases of such applications on some small ships at sea for government-led research and pilot projects," says Kang-Woo.

The fuel supply systems from the pressure containers to the fuel systems (be it an internal combustion engine or fuel cell) is a relatively simple setup consisting of pressure control regulators, filters and valves and suitable for small ships. However, high-pressure hydrogen can cause some brittleness in metal materials, hence there is a preference for Type IV (polymer based) containment systems.

KSOE, HMD, HYUNDAI GLOVIS, KR AND THE LIBERIAN INTERNATIONAL SHIP & CORPORATE REGISTRY (LISCR) SIGNED THE AIP FOR A 20,000M³ HYDROGEN CARRIER LAST YEAR. SOURCE: KSOE/LISCR

But for larger capacity transportation and storage liquid hydrogen, which has a higher volumetric density, is a more viable option. Its storage temperature of -250°C is much lower than that of LNG (-83°C), making it necessary to develop and apply new techniques to address issues such as heat insulation, materials selection and boil-off.

Land based liquid hydrogen storage facilities consist of primary barriers in direct contact with liquid hydrogen, as well as insulation and secondary layers that are directly exposed to the outside. "Storing liquid hydrogen on ships and using it as fuel is still in the research stage, but it is expected that a similar structure will be needed," says Kang-Woo.

"Research into IMO Type-B and Type-C containment tanks, which can be commercially produced while maintaining insulation performance and offering the least chance of leaked hydrogen in the hull, is actively underway. Hydrogen fuel supply systems are expected to be developed to meet the requirements of fuel consumers with large ships, but the supply systems should be subject to stricter safety standards than LNG."

International standards

Earlier this year, KR and KSOE signed an MoU to develop the first international standards for hydrogen ships. Kang-Woo says that it is part of a range of hydrogen safety standard development projects KR currently has in the works.

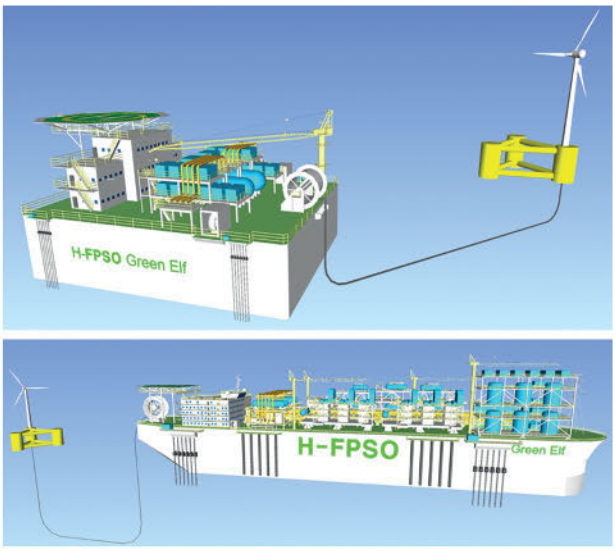
He explains: "A draft safety standard for hydrogen ships was developed first, and based on this, hydrogen fuelled ships and ships which are carrying liquified hydrogen in bulk are being designed. The completed designs will be modified/complemented through risk analysis, explosion, and structural safety analysis, which will contribute to the process of revising the original standards. The contents of this study and safety standards (proposal) will be submitted to IMO at the end of 2022 or early 2023 to share the experience and knowledge of the Republic of Korea and to contribute to the overall decarbonisation of international shipping."

Kang-Woo adds that in June also developed its 'Rules/ Guidance of Ships using Low-flashpoint fuels (ammonia)', to cover the functional and safety related requirements for ammonia propulsion ships. These are intended to reduce trial and error in the design and construction and inspection of ammonia powered vessels and based on IMO's existing IGF Code for low-flashpoint fuels.

Scaling up

Both hydrogen and ammonia present significant challenges in scaling up the technologies to make them suitable for larger vessels but ammonia, which has an energy density of 15.6MJ/litre compared to 9.1MJ/litre (or 5.6MJ/litre for compressed hydrogen at 70MPa) is generally considered the more viable option. But Kang-Woo says that if the technology can be developed it is expected that a liquid hydrogen-based fuel cell propulsion system with a high energy density will eventually be possible.

He adds: "The main barrier to future alternative fuel and reduction technologies for green ships, including green hydrogen, is economic feasibility. Previously, economic feasibility for these technologies was based on the cost of applying the relevant technology and the benefit of fuel saving costs. However, if market based measures including emission trading systems are introduced, then the reduction of GHG technologies could be added as a benefit, supporting the economic feasibility of these technologies still further and promoting the application of future green ship technology."



THE DEMONSTRATION HYDROGEN FPSO COULD BE OPERATIONAL BY AS EARLY AS NEXT YEAR. SOURCE: KOREA MARITIME & OCEAN UNIVERSITY

Hydrogen FPSO

Notwithstanding the ships themselves, Korea is also starting to explore the possibilities for producing its own decarbonised fuels. In August, KR was announced as one of the members of a private-public consortium that has been launched to a floating offshore plant using wind power to produce hydrogen. The consortium, which also includes Korea Maritime & Ocean University (KOMU) and DSME hopes to build a 1.0megawatt pilot plant in 2022, upscaling this to a gigawatt-class plant in 2030.

"KR is working to develop a P2G-based (power-to-gas) FPSO covering the entire cycle from green hydrogen to utilisation," Kang-Woo says of the project. "The goal is to produce green hydrogen using renewable energy and an offshore SMR [Small Modular Reactor] nuclear power plant based on the PTG system which can serve as the main energy source of the future energy mix grid."

The SMR, which is being developed by the engineering wing of the state utility company, KEPCO E&C, is a block-type pressurised water reactor, an alternative to traditional light-water reactors based around modular technology that require less on-site construction. Such solutions are increasingly seen as a possible means of ramping up hydrogen production beyond the capacity limitations of renewable energy.

"KR is also conducting feasibility studies, undertaking research and development to contribute to the creation of new industries for demonstrable greenhouse gas reduction and carbon-neutral fuels," he concludes. ■

SAFETY

THE *GOLDEN RAY* CAPSIZING: HUMAN ERROR OR FLAWED DESIGN?

By **Richard Halfhide**

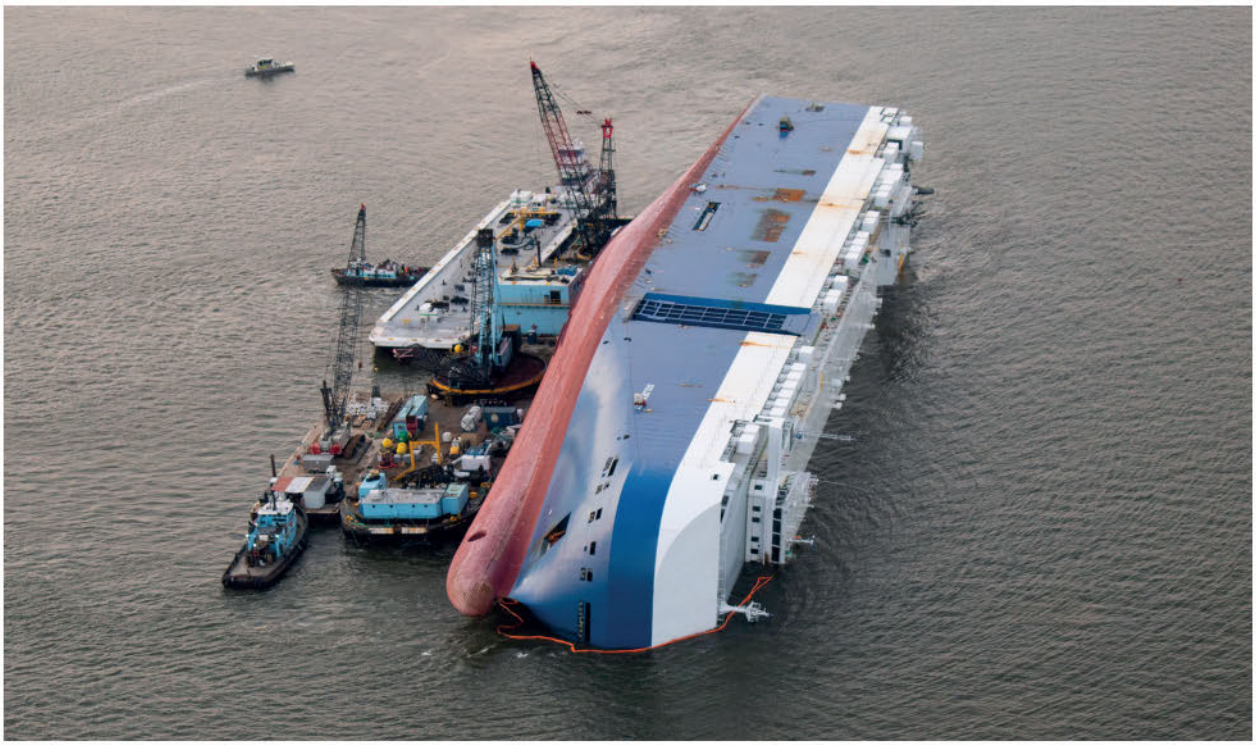


FIG 1: THE CAPSIZED *GOLDEN RAY* IN ST. SIMONS SOUND, GEORGIA, PICTURED IN OCTOBER 2019. SOURCE: SHUTTERSTOCK

Vessel traffic at Georgia's Port of Brunswick, located in the southeast corner of the US state, is dominated by roll-on/roll-off (ro-ro) ships, and these are largely vehicle carriers. Ford, General Motors and Mercedes all use Brunswick for their exports, while it receives imports from the likes of Volvo and Mitsubishi. It would be fair to say that the pilots that navigate these ships out from the Colonel's Island Terminal, towards the East River that leads to the Atlantic, are well accustomed to their behaviour.

On 8 September 2019, at around 0100 Eastern Daylight Time, the 200m vehicle carrier *Golden Ray*, flagged to the Marshall Islands and owned/operated by Hyundai Glovis, was being piloted on such a trip when, as it turned starboard, it began to heel quickly to port. The pilot and master quickly issued commands to counteract the heeling, but to no avail, and in less than a minute it had heeled to about 60°, enough to cause water to flood through a portside pilot door on deck 5 which had been kept open in anticipation of the pilot's imminent departure. Within minutes the vessel had settled at an angle of 90°.

The US Coast Guard (USCG) arrived shortly afterwards and quickly rescued the pilot and 19 of the 23 crew onboard, however four of the engineering crew remained trapped in the flooded engine room until the following evening, when it was finally possible to cut a hole into the ship's hull. Thankfully, although two crew received serious injuries, there were no fatalities. The same could not be said for the financial cost; in addition to the US$62.5 million value of the vessel, there was a further US$142 million in lost cargo and the ongoing salvage operation has so far cost in excess of US$800 million.

Although Covid was undoubtedly a factor, the two-year wait for the publication of the National Transportation Safety Board's (NTSB) report into the investigation has been a source of frustration for many. Last year, a public hearing into the accident listened to powerful testimonies from the of the crew who had narrowly escaped with their lives, yet it has taken until now for any formal conclusions to enter the public domain.

Findings

The NTSB investigation examined potential safety issues such as weather, transfer of ballast and fuel, propulsion and steering systems, shifting of cargo, possible obstructions in the shipping channel, and a fire which broke out in the cargo hold after the heeling, and

found that none of these could be deemed responsible. Rather, the vessel capsized because *Golden Ray* lacked sufficient righting energy to counter the heeling caused by the starboard turn. The reason being that at its time of departure *Golden Ray* did not meet international stability standards and postaccident analyses concluded the vessel was heeling between 0.1 and 1.8m, well below the GM of 2.45 that had supposedly been entered by the first officer into the LOADCOM stability calculation computer.

Moreover, the USCG's Marine Safety Centre (MSC) found that even this figure fell short of the minimum GM of 2.54m, and that this was some 30% higher than the GM that was specified by *Golden Ray*'s Trim and Stability (T&S) booklet. The MSC also determined the vessel's KG was 4% above the maximum permitted by the T&S booklet. In effect, *Golden Ray* was some 1,492tonnes short of the level specified by IMO's 2008 Intact Stability (IS) Code. During the Brunswick call, 265 KIA Forté and Hyundai Accent vehicles were offloaded from decks 11 and 12, while 359 heavier KIA Telluride sport utility vehicles were loaded on decks 5, 11, and 12 (a net increase of approx. 373tonnes), but the chief said he had concluded the vehicles could be accommodated and still meet stability requirements.

Golden Ray's LOADCOM computer sustained water damage that made it impossible to extract data for the purposes of the investigation, meaning that it was impossible to know the exact loading condition (specific tank levels, cargo weights and locations, and draft) the chief officer had used for the stability calculations. The officer declined to participate in the investigation process after his initial post-accident interview, but the report found there must have been errors in his recording of the ballast tank level data, which in turn led to his incorrect calculation of the vessel's stability.

Although there was a facility to automatically transfer ballast tank data from the Integrated Monitoring, Alarm, and Control System (IMACS) – which made it possible to see the vessel's power management system, tank-level indications, anti-heeling and loading programs, and the engine monitoring and automation features – the chief officer said that he had instead overseen the tank level markings and personally observed and recorded the draft markings, then manually entered the IMACS data for the ballast, fuels, fresh water and cargo weight into the LOADCOM. The IMACS also included a GM measurement program that automatically transfers ballast to heel the vessel up to 1° to either side that he chose not to use. However, for reasons that remain unclear, he chose not to utilise this feature.

Safety management system

The chief officer, who had joined *Golden Ray* about six months before, had been at sea for 13 years, 10 of which had been at his present rank. However, his experience training in using the LOADCOM was limited to a few hours on-the-job training by the ship's former chief officer. There was no formal training program for the software.

Curiously perhaps, the calculation of stability is something left entirely to the chief officer and there is no specific requirement within SOLAS for those figures to be checked by another member of crew and it was this "single point of failure" that was the key to the accident, in the NTSB's opinion. The Safety Management System (SMS) implemented by G-Marine Service Co, the Hyundai Glovis subsidiary responsible for *Golden Ray*'s technical management, stipulates that the master has "to be satisfied that the ship has sufficient stability at all times", but neither the nor any junior officers attempted to verify the chief officer's calculation prior to the voyage, or the two preceding it (which were also found to have erroneous stability calculations).

The master was also obliged to provide a departure report, including the GM and draft, for the operator's fleet management team, which might also have flagged a problem, yet this had not been sent at the time of the accident because the vessel was deemed to be in a "standby situation" prior to the pilot's disembarkation.

NTSB does highlight that "the master had many responsibilities to get the vessel in and out of port, and

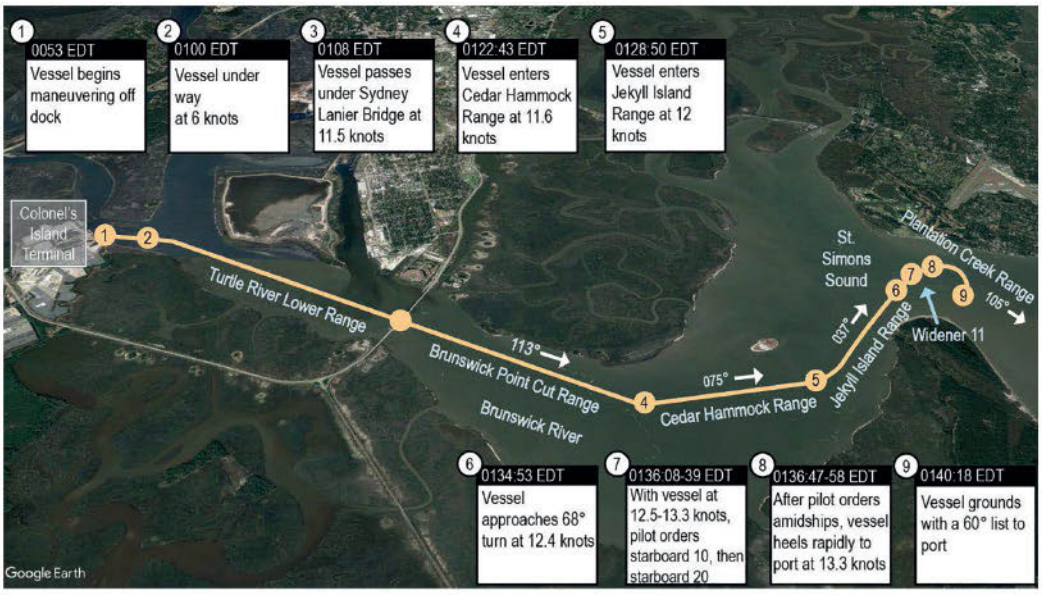


FIG 2. *GOLDEN RAY*'S TRANSIT AFTER IT DEPARTED THE COLONEL'S ISLAND TERMINAL AT THE PORT OF BRUNSWICK. SOURCE: USCG

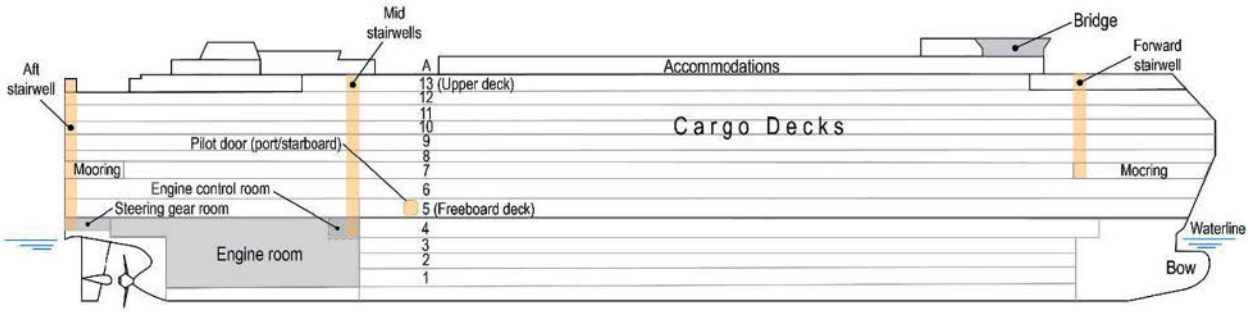


FIG 3. *GOLDEN RAY* GENERAL ARRANGEMENT. SOURCE: HYUNDAI MIPO DOCKYARD

the five-hour turnaround time at Brunswick demanded focus and distribution of duties. In this case, the accident master had been on the vessel only 10 days and had not sailed on the *Golden Ray* or a vessel of the same class before". Moreover, because the Brunswick port call had brought only a small change (4%) increase in cargo weight, the report surmises there may have been less concern about the impact on stability.

Had *Golden Ray*'s stability not been critically undermined, it is unlikely the open pilot door would have led to flooding. Ordinarily, as the ship's freeboard deck, it would also have been watertight, however analysis of the IMACS data by NTSB also found that the doors to two additional portside stairwells were open at the time of the accident and had been for almost two hours prior to the incident. This was in contravention of the operators Arrival/Departure Checklist as outlined in the SMS and led in turn to the flooding of the engine room.

Questions

Any investigation report must, by definition, focus on objective facts, but while the NTSB's work has been commended for its thoroughness, it raises a number of questions about the design and operation of vehicle carriers. Given that intact stability, or lack thereof, has been cited in previous comparatively recent vehicle carrier incidents such January 2015's listing and deliberate grounding of *Höegh Osaka*, and the 2016 listing of *Modern Express*, why are vehicle carriers proving such a problematic segment?

It's a matter which is currently being discussed by RINA's IMO Committee. Regular *TNA* contributor Dennis Barber, a former mariner and member of the committee, says that while the report appears to largely attribute blame to the first officer and SMS there remain a number of matters not covered by the report. He thinks that while extensive reference is made to the LOADCOM and T&S booklet, no consideration appears to have been given to whether free surface movement in the ballast tanks may have exacerbated the problem.

Barber says: "When you pump out a ballast tank you can never completely empty it, you are always left with what are called the strippings. Those strippings could cause a lot of free surface in addition to the higher centre of gravity, but no stability booklet ever considers this, so when the ship has to turn sharply there is a lot of free surface movement."

Placing sole responsibility on the first officer for stability calculations is, adds Barber, a longstanding problem with all ship types and unless the officer has the wherewithal to request either the master or

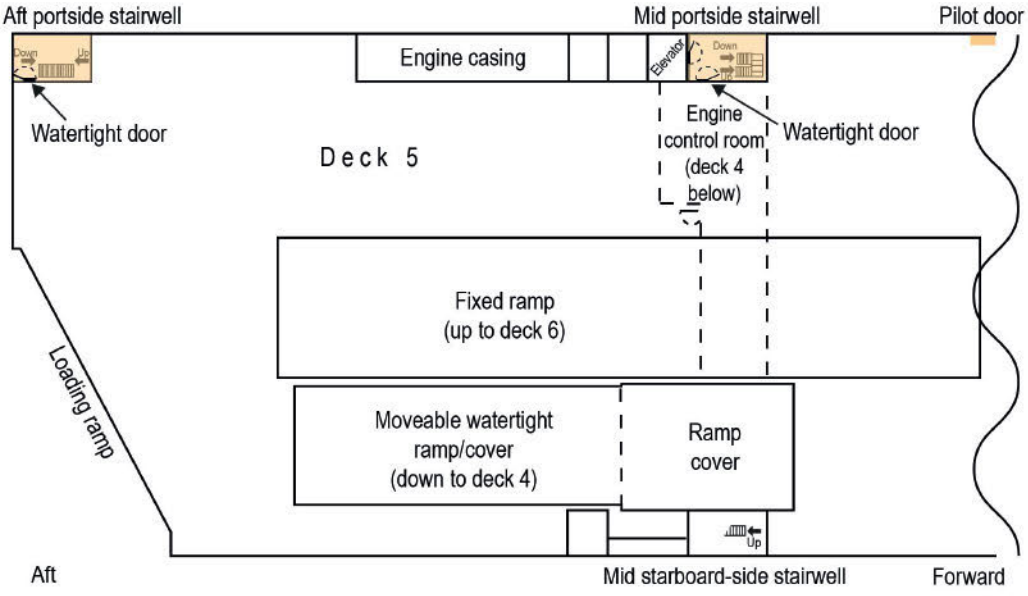
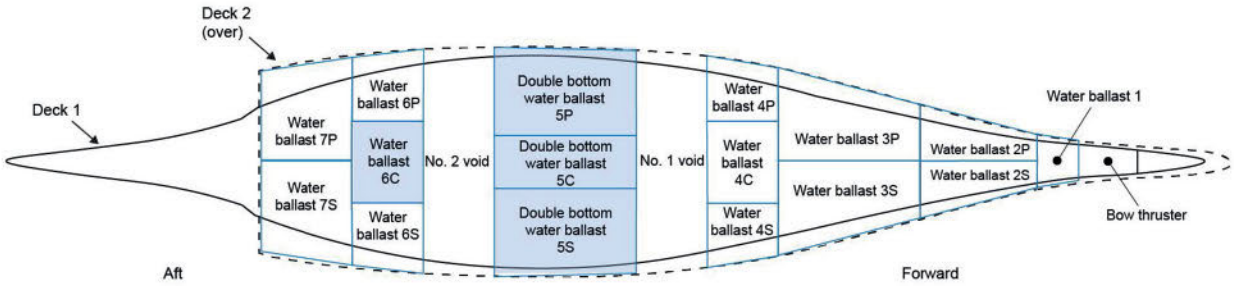


FIG 4. OVERHEAD VIEW OF THE AFT PORTION OF DECK 5. SOURCE: HYUNDAI MIPO DOCKYARD



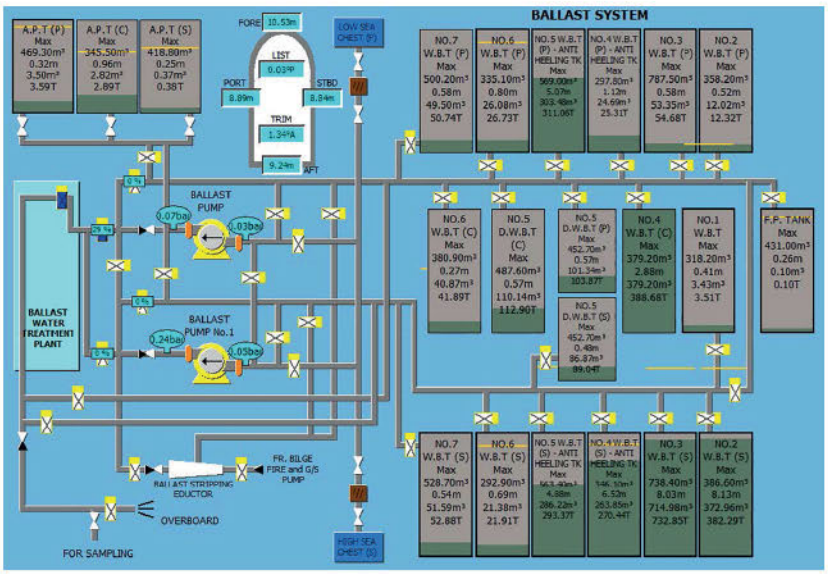


FIG 5. GA FOR THE BALLAST TANKS LOCATIONS (TOP) AND THE IMACS DATA FOR THEIR LOADING CONDITION PRIOR TO DEPARTURE. SOURCES: HYUNDAI MIPO DOCKYARD AND USCG

second officer verify those numbers they will often go unchecked. Ironically, just a few months after the *Golden Ray* accident, the amendment SOLAS II-1/20 came into effect, which states: "... on completion of loading of the ship and prior to its departure, the master shall determine the ship's trim and stability and also ascertain and record that the ship is upright and in compliance with stability criteria in relevant regulations."

Prior to this the requirement had only applied to passenger, not cargo, ships.

Another factor not specifically addressed in the report is why the pilot door couldn't be located in a watertight cofferdam, such as a stairwell, rather than opening directly into a cargo deck, which would have contained the flooding. "If you've got something that's going to breach the watertight integrity then you really should think about where the water is going to go. My suspicion is they're stowing cargo right up to that door and [the designers] decided a door would cut out too much cargo space," says Barber. However, the NTSB fails to raise this matter in its findings.

Yet while a more safety-conscious design might have prevented a more serious incident, the prevailing question remains why an experienced officer would have chosen not to ensure *Golden Ray* was adequately ballasted before departure? Without his own testimony we can, of course, only speculate. However, speaking on his 'What Is Going On in Shipping?' YouTube channel Sal Mercogliano, former mariner and adjunct professor at the US Merchant Marine Academy, suggests that the officer may have deliberately input inaccurate data into the LOADCOM:

"[The first officer] wanted to show he was at eight feet when he was leaving port because he didn't want to load ballast while he was in port... If you ballast pierside in Brunswick you're putting a lot of [turbid water] through your ballast water treatment plant... this water has to be treated and it costs money. The reason I think the chief mate didn't input [the IMACS data] in the computer is he's trying to save money for the company," says Mercogliano.

In short, rather than load additional water when he should, Mercogliano surmises the first officer had hedged his bets with the intention of loading blue water once *Golden Ray* was out in the ocean, with disastrous consequences. Whether this was something that had been risked on a regular basis, or how regularly such habits are repeated across vessels and fleets is impossible to say.

A year before the *Golden Ray* accident, in 2018, the US Transport Research Board published a review into vessel stability that included a particular focus on ro-ro vehicle carriers. It noted that: "the potential for risk arising from human error in regulatory compliance cannot be neglected and should factor into assessments of regulatory content, design, and effectiveness". Perhaps, in the strictest definition of the term, 'human error' shouldn't extend to deliberate deviations, but we might also need to ensure commercial pressures aren't having a negative influence on decision making, both in design and operation. ■

CAD/CAM

3D MODELS: A TECHNOLOGY ISLAND IN SHIP DESIGN OR A CENTRAL PIECE FOR SHIPBUILDING PROJECT DATA?

By **Ludmila Seppälä**, CADMATIC

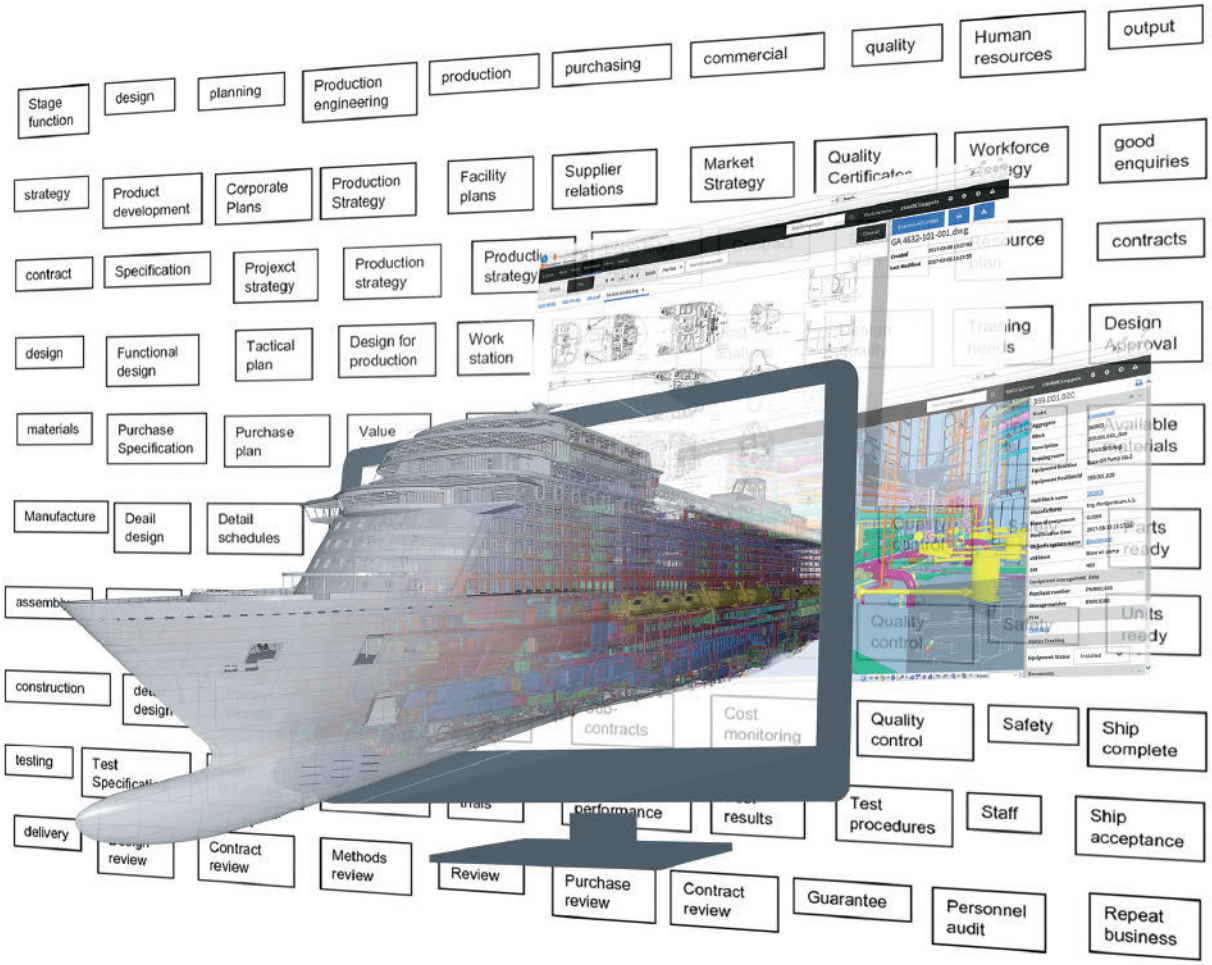


FIG. 1: SHIPBUILDING ACTIVITY MAP: STAGES OF ACTIVITIES VS. FUNCTIONS AND 3D MODEL USE. SOURCE: CADMATIC / BRUCE, G. (SHIPBUILDING MANAGEMENT (2021)

Shipbuilding has used 3D models for several decades. The contemporary design and building process relies heavily on 3D modelling as an engineering tool; it enables high-quality production data, facilitates project review, eases change management, and more. However, recent interest in Digital Twins and related expectations for digital shipbuilding raise questions about the use of 3D models.

What is the potential value of using the same 3D model throughout the whole shipbuilding management process? How can the complexities of the same 3D model be managed for changing purposes throughout the ship's life cycle?

In an ideal world, the 3D model is created incrementally, starting from the concept stage of the shipbuilding project. It is enhanced with details and used to extract production data; it may serve as a basis for marketing materials and rendered visualisation – including AR/VR/XR – and contain converted or raw 3D laser-scanned data. The same 3D model or a or filtered model can be used later for maintenance, repair, operation, training and retrofit purposes. It can become a digital twin that lives its digital life alongside the actual vessel.

The focus of shipbuilding design solutions on the 3D model might be too narrow: the 3D model is a 'technology island' similar to an 'automation island' in the production process. Many technological advancements focus on creating 3D models – from basic design to detailed design and production. Each stage of the shipbuilding process often focuses only on its own outcomes, such as

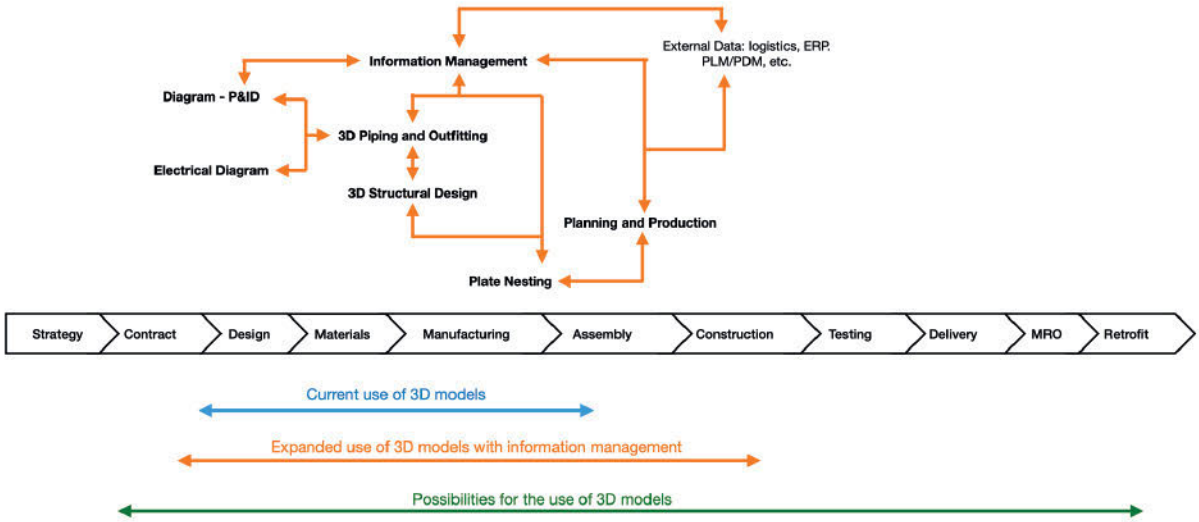


FIG 2: CAP: 3D MODEL USE IN SHIPBUILDING TIMELINE – CURRENT, EXTENDED, AND POSSIBLE

hull design or piping and outfitting, and related outputs. Typically, only neighbouring disciplines and project stages are covered, leaving gaps or ignoring the overall strategy and integration of the digital thread. For example, a model created for basic design and class approval is often not used for detailed design purposes.

While each gap can be addressed individually, the overall PLM approach is still novel for shipbuilding. The expectation is that PLM can potentially resolve most of these inconsistencies. However, a typical PLM solution originates from mechanical CAD models with significantly fewer parts and less complexity. It only brings the automated approach of splitting the 3D model into parts and managing information about each piece independently.

This article explores the typical uses of the 3D model in the shipbuilding cycle from the concept and contract stages to operation. It outlines specific use cases and explores the future possibilities of using 3D models in shipbuilding management

3D model and shipbuilding management activities

It is a relatively novel approach to use the 3D model throughout the entire shipbuilding process, albeit a commonly used way of designing highly complex ships. The use of 2D drawings has become increasingly outdated, and the order of creation has turned to the extraction of 2D drawings from 3D models, and not 3D modelling according to 2D documentation. In recent years, there have been significant shifts that were enabled by new computing technology and comprehensive access to 3D manipulation, making it possible to avoid 2D documents. Examples of these include direct interfaces with CNC machines, welding robots and cobots, new options to submit 3D models for class approvals, and more.

All these uses of the 3D model are different. In some cases, the 3D model comes as an engineering model, and the visual representation only visualises calculated data, such as in the case of 3D fairing or surface definition.

In the case of 3D detailed design, it manages the arrangement complexities in crowded 3D spaces. It allows users to resolve conflicts in 3D arrangement, select the correct materials, and provides a common place for all disciplines to connect – align equipment with foundations, electrical cables with motor connections, etc.

Software providers embed an extremely high level of knowledge in modern CAD software and 3D modelling. As a result, in the final stages of 3D modelling, a complete model is available that includes all disciplines, accurate geometrical information, topological and parametrical connections, a significant amount of meta-data, and links with 2D outputs for change management. At this stage, the focus of attention often shifts from design to production, assembly, and construction, and the 3D model remains an extra item or attachment to the project documentation package.

Fig.2 illustrates the typical use of the 3D model in CAD against the timeline of the overall shipbuilding management process. The period of 3D model use is somewhat restricted to design and partially includes construction. Typically, it is limited and fragmented. For example, it is possible to have several 3D models for different purposes or several models that were created in different design software packages. Specialised tools for calculations may have been used or several subcontractors responsible for only a limited part of the design may also have been involved.

Fig. 3 gives several example cases for use of 3D models at shipyards, based on experience CADMATIC has accumulated through everyday interactions with the yards. These illustrate the extended use of 3D models and do not include obvious scenarios, such as using the 3D model for collaboration design or production information purposes.

Boost for communication

The use of 3D models facilitates communication within shipyards, and between the shipyard and subcontractors and shipyard groups. Instead of a paper- or email-based information flow, the engineering office and shipyard

can use 3D model mark-ups and interfaces to VR/AR/XR applications. 3D models, which often include 3D laser-scanned data, are a more realistic representation of the ship than 2D documentation, project structures, or data tables.

It was long accepted that the lack of technology prevented effective manipulation of 3D models due to heavy GPU requirements and the lack of VR developments. However, these constraints are in the past; current technologies enable 3D visualisation on powerful workstations and tablets and XR devices, such as VR headsets or MS Hololens, with the possibility to manipulate 3D models in mixed reality and align 3D models with real objects.

In recent years, much progress has been made in the use of 3D models in almost every ship design stage and beyond. A general conclusion is that the use of 3D models significantly enhances communication for all parties involved and serves as a more natural means of communication than old-fashioned 2D drawings and data sheets. Understanding a work breakdown structure based on a list of components or installation schedules is challenging. The same task is greatly eased when it can be visualised with colours inside the 3D model and interacted with in a live setting.

Traditionally, shipbuilding CAD 3D models were locked inside ship design packages, required skills to navigate, and were otherwise available only for designers or for project review at most. However, with mature IT supporting a large amount of 3D data in recent years, it became possible to provide ship models for inspection on demand. In addition, it became possible to liberate 3D shipbuilding data and use significantly lighter and cheaper devices than specialised CAD desktops or virtual reality caves.

3D models in VR have been used for shipowner review, design validation, and production support. The 3D model can remain as an extra item in the package that contains project information, including documentation, data from production and construction, and all related notes. These packages of information data about the same project will be different for the use of design collaboration, class approval, shipyard production workshops or shipowner. Alternatively, it can effectively serve as a natural entry point for information searches and to open linked data stored in other systems.

Manufacturing and installation instructions can be visualised on mobile or wearable devices, thereby replacing paper drawings in the approval and production stage. Furthermore, direct data from the 3D model, such as geometrical representation, metadata, BOM, and workshop information is provided online to installation teams on site. At the same time, the outfitting part installation status can be added for progress following and as feedback to the design team.

Interaction with 3D data distinctively differentiates the digital era – the first attempts to standardise drawings aimed to improve readability and production quality. For the data-native generation, this poses unnatural limitations. Instead of a static snapshot, people prefer to obtain data on demand and then manipulate it.

Integration with planning and manufacturing execution systems

For 3D evaluation, monitoring progress, and checking the parts and materials, shipyards can integrate the 3D model with PLM/PDM or ERP systems. Linked documents and system parts, including dimensional drawings and piping parts, provide a rich context when they are efficiently visualised as separate parts and as an integral part of the vessels' 3D model. In addition, a 3D model linked to task planning at the detailed work breakdown level, kitting packages, and BOM visualises planning, retrieval of tasks (welding, grinding, painting), and resource planning.

Integrating the 3D model with planning and manufacturing execution systems helps visualise the scheduling status of parts and blocks with color-coding, adding a visual aspect to work scheduling and progress monitoring. It also provides context for each work task by relating it to the overall production process and background data. Resource management systems are often focused on narrow tasks and reporting processes, leaving workshop staff without a direct link to the product they are producing and a significant amount of design and production-generated information.

Linking materials, fittings, and equipment with their digital counterparts in a 3D model provides additional benefits for integration. For work preparation and planning, the 3D model can be integrated with work planning systems and ERP for work package kitting visualisation and shipyard resource management. Any item can be found in the

Boost for communication	Integration of information flows	Platform for Digital Twin
• Communication within shipyard and shipyard networks • Project review and handover • Visualisation of installation instructions and replacement of paper drawings	• Integration with ERP, PLM/PDM, planning systems, and Manufacturing Execution System (MES) • Integration with work packages and component tracking	• Consolidating shipbulding management information with 3D dashboard

FIG 3: MAIN USE CASE SCENARIOS FOR EXTENDED USE OF 3D MODELS IN SHIPBUILDING

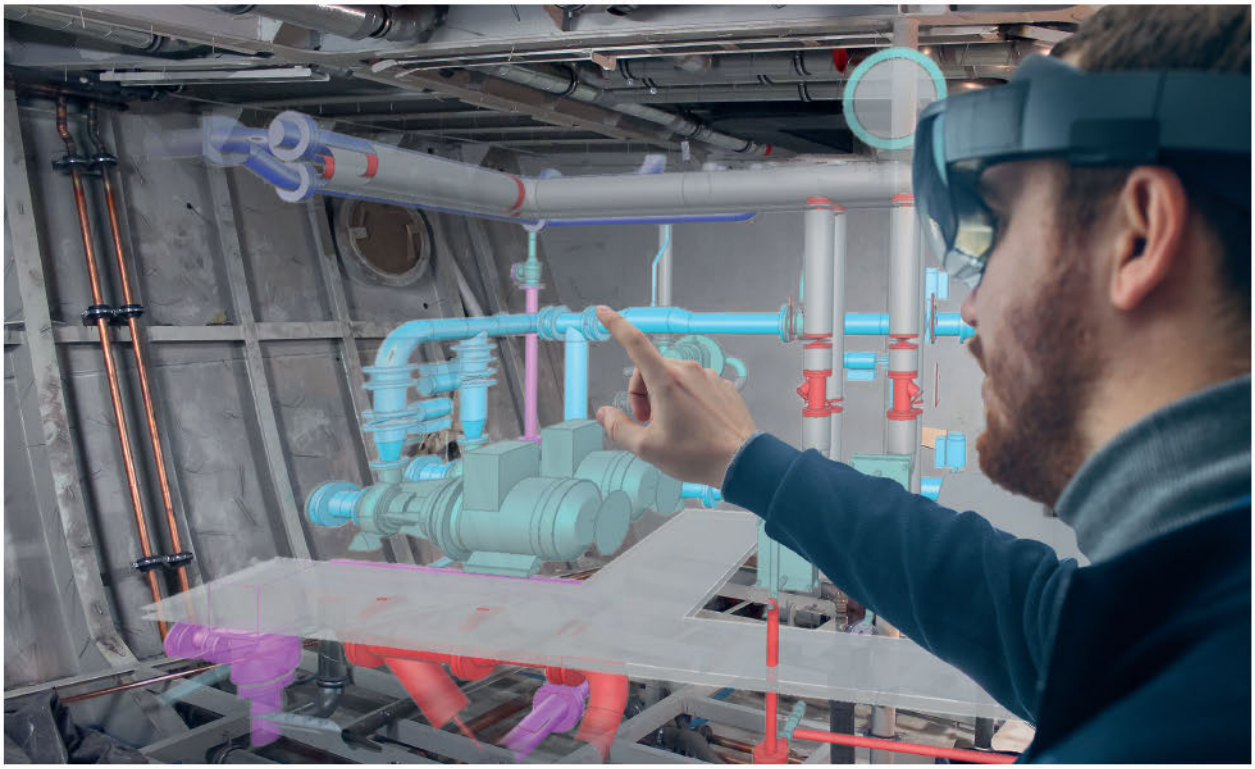


FIG 4: EXAMPLE OF USING A 3D MODEL IN CADMATIC ESHARE FOR MS HOLOLENS AT A PRODUCTION SITE

digital model using RFID or QR codes as well as all related data from integrated systems – attributes, drawings, and instructions accessed on site. The shipyard can benefit from integrating 3D models with production systems, such as nesting and assembly controls. The hull production statuses for cutting, bending/pre-assembly, approval, and section assembly are visualised and monitored using a 3D model on a suitable device.

Platform for Digital Twin

Consolidating shipbuilding management information on a 3D dashboard and using the 3D model as a natural interface have considerable potential in shipbuilding. The discussion about the advantages and uses of the 3D model has, on the one hand, been an ongoing debate over the last decade, and on the other, has provided a new perspective on continuity in the shipbuilding process and the blurring of borders between design stages and even disciplines.

Traditionally, ship design software has stored data that originated in the design stages and extended slightly towards the production stage. Decades ago, 3D browsers aimed to fill this gap, at least partially, by providing the possibility to review 3D models outside CAD. This approach was expanded recently with information management systems that serve as a platform for consolidating 3D data and for providing smart functionality to access data needed for different stages and purposes.

The primary use cases of this access were presented in the previous sections. However, one question needs special attention – how to store and access all the data that comprises the Digital Twin. If one considers this question purely from a PLM perspective, the answer will be as simple as storing any 3D models, such as the basic design model, detailed design model, production model with geometrical data for each object, etc., alongside other documentation drawings, schedules etc. A PLM system would provide a secure vault for 3D model storage, which would diminish the use of 3D data. Alternatively, using a shipbuilding-specific information management platform and supporting incremental creation of the 3D model and its use would boost digital shipbuilding.

Combining several 3D models and converting 3D models between different formats help to facilitate a one-model approach. It helps to consolidate 3D data in one platform and supports the approach based on a "universal" digital twin, in contrast with a specialized digital model for each use case.

Conclusions

The single source of truth is an attractive analogy and a trap at the same time. It provides the illusion of a central access point for all up-to-date data. The contemporary reality at shipyards is far from the ideal situation with a myriad of specialised systems, interfaces, and data storage methods used in different departments. A step that would provide unification is the expansion of the use of the 3D model, thereby ensuring support for specific needs of each discipline and shipbuilding process stage.

The use of 3D models would boost communication and integration without compromising shipbuilding's specific purposes. Hopefully, in the future, 3D models will become a landscape instead of an island, and 3D technology will support the whole shipbuilding cycle rather than segmented stages.

This article is an abridged version of a paper presented at the 2021 COMPIT conference. ■

LNG/LPG

COATINGS – AN INTEGRAL AND UNIQUE ASPECT OF LNG CARRIER DESIGN

By **Carl Barnes**, general manager – marine consulting, Safinah Group, and
Keith Hutchinson, senior consultant – whole ship design, Safinah Group

FIG. 1: A CONVENTIONAL SIZED MEMBRANE-TYPE LNG CARRIER. SOURCE: SHUTTERSTOCK/MIKE MAREEN

LNG is now an area of significant focus as a replacement for bunker fuel for ships [1], being arguably the current 'transitory' marine fuel of choice in the shipping industries' journey to zero carbon fuels later this century. In addition, it is also growing in interest as a clean energy source onshore, which is fuelling demand further. The main LNG export countries include Qatar, Australia, Malaysia, United States of America (USA), Russia, Indonesia, Algeria, Nigeria and United Arab Emirates (UAE) with import regions including Japan, South Korea, China, India and Europe. Transporting LNG globally via pipelines is obviously not practical and therefore the only viable method is via LNG Carriers (LNGCs), utilising specially insulated tanks.

The oceangoing transhipment of LNG can be traced back over six decades to late 1950's, when the *MS Methane Pioneer*, a former Second World War built cargo ship, was converted to transport 5,088m^3 LNG from the USA across the Atlantic Ocean to the UK. The first two purpose-built LNGCs, the 27,400m^3 *SS Methane Princess* and *SS Methane Progress*, were built in the UK in the early 1960s for shipping LNG from Algeria. The LNGC fleet has been growing significantly over the past few decades, and as of September 2021 the fleet surpassed 660 ships representing approximately 100 million m^3 of LNG transport capacity. This is an increase in ship numbers of more than 40% from 2010 levels. As of the end of July 2021, the global orderbook stood at 171 ships equating to 25.7 million m^3 total capacity, with year-to-date delivery rates significantly higher than last year's [2].

As a consequence of the fact that LNGCs carry a cryogenic hydrocarbon cargo, and therefore require bespoke containment and cargo systems etc., they are by definition extremely specialised ships and therefore complex to both design and construct. Hence, there are only a small number of shipbuilders with the required specialised capability to build such ships. Due to their complexity and typically long build times, they represent a significant investment for any prospective owner compared to other cargo ship types of similar dimensions – such as tankers, bulk carriers, and even container ships etc. As of July 2021, the newbuilding price for a conventional sized 170,000m^3 LNGC, of typically LPP 280m x B 45m x D 26m x T 12m, was in the region of US$195 million. As of the end of September 2021, the total value of the conventional LNGC fleet, existing and on order, was estimated at more than US$87,000 million [3].

With such a significant investment required for an LNGC, the average ship trading lifetime expectation can be typically 30 years and possibly up to 40 years. However, due to the recent rapid growth of the fleet, the average age of LNGCs is relatively low as only approximately half of the existing fleet is over 10 years old.

Corrosion prevention

Coatings play a critical role in protecting the integrity and maintaining the value of the LNGC throughout its trading lifetime. With the required prolonged trading life, one of the key requirements of the coating system is to provide long term corrosion protection. Of particular importance are areas such as the water ballast tanks as these are

obviously critical to the structural integrity and operation of the ship and which, due to their structural etc. complexity are difficult and costly to repair and maintain.

Choosing a high performance proven anticorrosive primer is vital in maintaining the capital value of an LNGC whilst also maintaining its integrity and operational safety.

Typically, a pure epoxy anticorrosive primer, pigmented with aluminium flake, should be considered. The lamellar (plate like) shape of the aluminium pigmentation helps to provide increased barrier properties to the coating by reducing the rate of water and oxygen transport through the coating. Glass flake and mica pigments will also provide these barrier properties. However, the use of aluminium flake is advantageous if the coating is damaged and therefore exposing the steel substrate as the aluminium pigmentation reacts with the hydroxide ions produced at the cathode in the corrosion cell (area of damage), hence, reducing the pH at the coating-steel interface and therefore decreasing the rate of cathodic disbonding (under-film corrosion).

High performance anticorrosive coatings will also help control future maintenance costs and limit the downtime in undertaking expensive and time-consuming repairs to water ballast tank coatings (Fig. 2), which will obviously have a significant impact on chartering opportunities and hence overall trading. Corrosion in water ballast tanks has been found to significantly increase after 10-15 years in service, which is therefore particularly relevant to LNGCs due to their long trading lifetime discussed above.

Fouling control at newbuilding

Fouling control requirements for a LNGC commences at the new building stage before the ship even undertakes trials and enters service. This is a direct consequence of the bespoke and specialised cargo containment system which must be utilised in order to carry the cryogenic LNG. All such containment systems are extremely complex and, especially for the membrane systems, are time consuming to install and test which is typically undertaken following the main erection sequence and therefore afloat after launch. Hence, the fitting out period can be 12 to 18 months. This is significantly longer than other similar sized ship types such as tankers, bulk carriers and container ships etc., which typically will have fitting out periods of no more than three to four months.

FIG 2: WATER BALLAST TANKERS ARE COMPLEX STRUCTURES

During this fitting out period the LNGC will be moored and hence static alongside the outfit quay with a significant area of the hull exposed to a high fouling challenge. Such fouling conditions are found in the coastal waters around major South Korean newbuild shipyards who are responsible for constructing the majority of conventional sized LNGCs.

The fouling control products applied to the underwater hull for fouling protection once the LNGC enters service are obviously designed to work under dynamic conditions, not to provide fouling protection under the extended static conditions of the fitting out period. The underwater hull therefore requires specific fouling protection whist the LNGC is fitting out, this is in addition to the fouling control system designed for when the LNGC enters service under dynamic conditions. The solution chosen for the fitting out period will directly depend on the choice made for the in-service fouling control system. Essentially, there are three main types of fouling control technology available for LNGCs whilst in service, these are as follows:

1. Biocide free Foul Release Coatings:
These products, typically based on a silicone matrix, are characterised by their low surface energy and elastomeric nature which, along with water flow when the ship is underway, prevents and / or removes fouling.

During the extended static period when the LNGC is fitting out, regular underwater cleaning is required to keep the underwater hull clean from fouling growth. As these systems are silicone-based care must be taken to ensure the cleaning methods used do not scratch and damage the coating as this will degrade the performance of the product once the ship enters service.

2. Biocide containing Foul Release Coatings:
Recently, a different approach has been adopted which incorporates a biocide into the foul release formulation. This approach is claimed to reduce the problems associated with slime attachment and hence provides improved performance under extended static periods. However, cleaning is still required for the extended static period during fitting out.

3. Biocidal antifouling coatings:
A biocidal antifouling coating comprises a soluble, or partly soluble, resin system that contains a mixture of biocide(s) effective against a broad range of fouling organisms. These products are designed to dissolve or 'polish' away over time, delivering the biocide under dynamic conditions. However, these are not designed to function under extended static periods and will

FIG 3: HEAVY BARNACLE FOULING

eventually foul during the long fitting out period encountered by LNGCs.

Unlike foul release coatings, cleaning is not really a viable option for biocidal antifouling coatings for several reasons. Cleaning will inevitably deplete the thickness of the antifouling system each time it is undertaken, which is undesirable as these products are applied at a specific thickness which is directly related to the design speed and activity profile of the ship in question. Furthermore, as these products have no foul release properties, any fouling that does attach will adhere to the hull and be significantly more difficult to remove compared to foul release systems. This is specifically relevant for barnacle fouling Fig. 3), as after a period of time the barnacle shell will cut through the coating and eventually penetrate to the steel substrate. At this point, removal via underwater cleaning is not possible without significantly damaging the antifouling coatings, tie coat and anticorrosive coating.

Therefore, the solution is to apply an extra coat of antifouling as the final coat, which is specifically designed to protect against fouling during fitting out. Typically, these fitting out antifouling products are specifically designed to polish rapidly under static conditions and / or may contain biocides that specifically target barnacle fouling. The fitting out antifouling will likely be almost polished away at the end of the fitting out period, therefore exposing the main antifouling system for when the LNGC enters service.

Whilst these technologies are the typically used options for fouling control, new and innovative fouling control technologies continue to be developed, such as polishing systems which are biocide free to other methods that utilise ultraviolet (UV) lights, ultrasonics and hull aeration. Performance under static conditions is clearly an area that would benefit from further advancements in fouling control.

The settlement of marine species on the hull of an LNGC will not only result in significant economic penalties but also the potential to cause environmental damage. Accumulation of biofouling on the hull leads to the following:

- An increase in hull roughness, which has a direct impact on fuel consumption and consequently the emission of air pollutants – which the International Maritime Organisation (IMO) has adopted regulations to address;
- Increased risk of translocating non-native, potentially invasive, species.

The most significant financial penalty for the shipping industry is the increase in fuel consumption due to the adverse effects on hydrodynamic performance of the hull, as shown in Table 1.

Typically for a contemporary conventional sized LNGC, consuming 100 tonnes per day of fuel with a 70% activity profile, the annual fuel bill will be approximately US$11 million, assuming operations on liquid fuel at an average price of US$440 per tonne. Hence, hull fouling, particularly calcareous animal fouling, will have significant consequences on the operational costs and emissions.

Therefore, along with anticorrosion protection, fouling control is a vital requirement for a LNGC in order to minimise fuel consumption, reduce engine wear and ensure on time scheduled arrival at the destination port. For these reasons careful consideration should be taken when specifying the fouling control scheme and the following factors should be accurately identified before making any choices:

- Trading route, including typical port locations;
- Ship activity / speed;
- Expected locations of extended static periods;
- In service period, i.e. time between drydock e.g. three years, five years;
- Historical fouling control product performance on similar trades / ship types;
- The potential for hull cleaning / grooming in service;
- Hull performance expectations.

Summary and conclusions

Careful selection of the underwater hull and anticorrosive coatings for LNGCs will have a significant positive impact on both preserving the fabric of such an expensive asset and also providing optimal in-service performance.

Whilst the cost for coating an LNGC is minimal compared to the overall procurement cost, typically

Hull condition	Additional shaft power to sustain speed
Freshly applied coating	0%
Deteriorated coating or thin slime	9%
Heavy slime	19%
Small calcareous fouling or macroalgae	33%
Medium calcareous fouling	52%
Heavy calcareous fouling	84%

TABLE 1: ROUGHNESS AND FOULING PENALTIES – ADAPTED FROM [4]

only representing between 2% and 3% of the ship's value, the benefit delivered by the coatings is clearly significant. Informed product selection is vital to ensure optimal protection and performance throughout a trading lifetime that may extend to 40 years.

Given the wide range of anti-corrosion and fouling prevention products and technologies available in the market today, it is critical that a robust and effective selection process is utilised to ensure the selected coatings are those best suited to both the new-build and in service needs of a specific LNGC. ■

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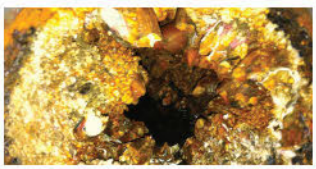

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