The ultimate Jones Act dry cargo carrier: An innovative LNG fueled container RO-RO vessel

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SUMMARY

Designed by Wärtsilä Ship Design (WSD) for Crowley Maritime (CM) and currently contracted with, and soon under construction at Vision Technology Halter Marine shipyard (VTHM) in Pascagoula, Mississippi. This paper presents the concept design and highlights key activities and processes undertaken during the development of a Panamax, LNG fueled and high speed container RO-RO vessel, the first of which will be christened "El Coqui". This innovative craft of engineering was designed with the purpose and business growth in mind and following a specific trade pattern and operational profile. It will be capable to carry conventional 20ft, and 40ft containers, as well as the special 45ft and 53ft wide body high cube containers specific for the American market, simultaneously with a Ro-Ro capacity in excess of 350 private cars (US size). When built, these will be among the very first LNG powered, American flagged, container Ro-Ro ships operating between Jacksonville, Florida and San Juan, Puerto Rico on a weekly rotational basis.

NOMENCLATURE

CAPEX	CAPital EXpenditure
CFD	Computational Fluid Dynamics
CO2	Carbon Dioxide
DF	Dual Fuel
DFOC	Daily Fuel Oil Consumption
ECA	Emission Controlled Area
EEDI	Energy Efficiency Design Index
FGSS	Fuel Gas Supply System
FPP	Fixed Pitch Propeller
GHR	Gas Handling Room
GM	Metacentric Height
GVU	Gas Valve Unit
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
MARPOL	MARitime POLution Convention
MCR	Maximum Continuous Rating
MGO	Marine Gas Oil
NG	Natural Gas
NOX	Nitrogen Oxides
OPEX	OPerating EXpense
SFOC	Specific Fuel Oil Consumption
SOX	Sulphur Oxides
TCS	Tank Connection Space
ULSMGO	Ultra Low Sulphur MGO
USCG	United States Coast Guard

ABSTRACT

The coming into force of the newly established ECAs on the Eastern and Western seaboards of the USA combined with the low price of LNG has raised the interest of US based ship owners to explore the options of LNG as fuel for their new or existing fleet employed on the protected Jones Act trade routes.

1. A MODERN APPROACH IN THE DESIGN OF MERCHANT VESSELS

1.1 PHILOSOPHY

The design of ships seems to have been far less complicated back in the days when the shipping used to be simple with less regulatory bodies and instruments, and when too few seem to have cared about the fuel consumption and the impact of shipping on the environment. Arguably, each period in time has instruments and measures to deal with its respective challenges, and the benefits derived from today's sophisticated design tools would have probably made the design of earlier ships a child's play some decades ago. Remarkably still, even nowadays the shipping industry does not always take advantage in full of all the powerful tools at our disposal nor does it always apply the best standards.

The design and operation of ships has evolved throughout time, and continues to develop in each segment. As more statistical data and experience is accumulated the more reliable models can be construed to help improve the safety and reliability of marine structures. These analytic models are part of the mechanisms that are driving the development of new rules and regulations and stimulate the need for new technologies in order to cope with the increasingly demanding requirements.

Ship design is the art of intelligent compromise in choosing the vessel configuration that correctly balances the operational profile and trading route, with the cargo carrying capacity and performance at sea. Functionality with the capability to operate efficiently and sustainable in a dynamic, current and future business environment, and more recently…it also has to take into account and mitigate the impact on the environment.

The mechanism is simple: the Buyer wants the best product at lowest cost, while the Builder wants the highest returns with the least costs. An independent designer's task is never easy for it has to satisfy Buyer's requirements to the design and to deal commercially with the Builder.

Like in any other engineering field, the evolution of ship design is rooted in statistics from built ships, and thus a "proven" design tends to get far more traction than a "new" design.
Depending on the context (e.g. from Classification Societies point of view, etc) the interpretation can be quite different, but for this paper a "proven" design means that a number of vessels or at least one was built following a particular design. Whilst a "new" design indicates that no vessel is yet built and afloat, and thus not able to validate the engineering calculated and predicted performance.

A "proven" design provides increased commercial and operational safety the more vessels of similar type are in operation. The new series of vessels that are constructed based on a "proven" design get periodical updates due to a number of reasons:

- new technology
- new regulatory framework,
- new requirements from the Buyer
- construction sequence alterations by Builder.

Arguably, one drawback of "proven" designs is that it tends to limit the amount of innovation in a design by recycling, for instance by maintaining the hull shape and the structure for the sake of keeping the design and construction cost low.

There is far more to the story than just this, but to illustrate, traditionally, merchant vessels (including most of the current world fleet) have been designed for "worldwide operations" in an attempt to build operational flexibility into the vessel, and also to increase the "re-sale" value of a vessel. An FPP with a 2-stroke diesel engine (direct drive) is perhaps the most economical and widely employed propulsion configuration in merchant ships. At the same time it restricts the desired flexibility especially for hull shapes designed for "service speed" at one of the design or scantling draught which is typically the contractual Technical Performance Guarantee (TPG) between the Builder and the Buyer. Ironically, the contractual TPG for speed is for a draught condition and engine power that is very seldom reached in operation when in fact a merchant vessel, throughout its lifecycle, is more likely to experience a wide range of draughts and speeds.

Comparing the performance of similar ships is not always easy especially with incomplete information. For the untrained reader it is easy to fall on the misconception that the vessel with the highest cargo capacity and the highest speed for the lowest fuel consumption is the best without ensuring thoroughly that the performance figures are presented consistently for the same condition. Good observation of the maximum capacity and performance of certain merchant vessel should ensure that:

- DWT is consistent with service speed on scantling draught
- engine margin (about 10-15%) and sea margin(about 10-20%) are specified for service speed performance consistent with the scantling draught
- for the calculation of dfoc, (any) applied tolerance on the engine supplier's published sfoc figures should be indicated, and the sfoc must be consistent with the specified engine rating for the service speed at scantling draught.

The total installed engine power alone is not enough to judge the required power for propulsion nor is saying anything about the minimum electric power demand.

With the ever increasing price of fuel and manning costs, design of ships should rather focus on efficiency and higher degree of automation. Choosing the right design is a pressing matter that nowadays is made "simple" by the regulations and the dynamics of world's economy.
The optimum ship for a certain enterprise is likely to be the result of a tailored solution (i.e. design) for a particular trade route and with the intended purpose in mind. The equipment selection should be based on the required performance and efficiency for the vessel, and ultimately the best design is the one that generates the best Internal Rate of Return (IRR) over the lifecycle of the vessel.

Nonetheless, at some point we will have to accept that a technological peak has been reached for a certain product. For instance for a certain vessel type and size, with a certain draught and speed, and in particular sailing conditions there is little left anyone can do to improve the efficiency of that particular design (or vessel). The Aframax tankers and Handymax bulkers are examples of designs that are at a high degree of optimization and while more could be done, one has to question the economics of such an undertaking..

The new efficiency and environmental focused regulations are a game changer. The international regulatory framework is strengthening, and the amendment to MARPOL Annex VI on EEDI is worth noting in this respect as representing the first international climate change treaty provisions to be formally adopted since the Kyoto Protocol in 1997, and the first ever globally binding instrument introducing energy efficiency regulations for an international industry sector.

Sustainability and ethics should be considered in terms of society as a whole and not only simply as relating to the environment. It should in agreement and with the understanding that economics, environmental health and human well-being are interconnected and interdependent. The future actions on which to build and secure our future society should be based on the precautionary principle, sustainable development principle, 'polluter pays' principle and with equitable distribution of benefits internationally and inter-generationally.

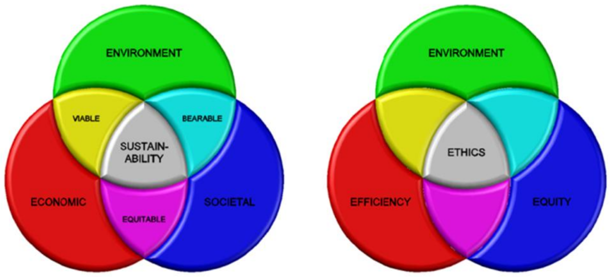

Figure 1: Sustainability diagram: triple bottom line effect (left), the 'four Es' of sustainable development (right) Source: Roland Clift, CES (2010)

1.2 METHODOLOGY

The perfect vessel would be able to carry everything, everywhere, at any time, and all at a gentle exhale of captain pipe's smoke blown into the sails. Unfortunately, there is no such thing as the perfect "one size fits all" type of vessel, but there can be a solution that given a set of certain (ship owner) requirements can qualify as the best for a particular trade route.

The shipping industry is very traditional in nature and this can be observed also in the design similarities of vessels that are being built. Different designers that are given the same design criteria and efficiency requirements are likely to come up with very similar designs both in terms of layout and performance. This is not about "re-inventing the wheel", but notable difference could be seen if the designers would start with a blank sheet of paper and a sharp pen.

The fundamental science of materials looks at their structure and properties, where a material's structure determines its properties, and then the properties determine the applications for which it can be used.

Processing → Structure → Properties → Application

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Concept design → Specification → Purpose

In a similar way, the modern approach or otherwise the normal engineering practice approach in ship design is to:

- understand how and where the vessel will be operated, for which purpose and for how long i.e. the "application" for the vessel
- generate a descriptive list of qualitative and quantitative requirements by prioritizing the "must have" over "nice to have" features and parameters i.e. the "properties" or specification of the vessel.

Further, there is a complex process involved in altering the "structure" or otherwise to develop a concept vessel according to the "properties" required for the intended "application". This is an exercise that requires expert knowledge and understanding about:

- the vessel's operational profile and trading route i.e. to understand the "application"
- the vessel type and the technologies (with their pros and cons) required to be implemented in order to meet the specification i.e. to understand the "properties"
- how each choice of technology integrates into the vessel, and how it affects the construction and operation of the vessel i.e. to make the best trade-offs between the vessel's requirements to change the design with minimum impact on the final vessel performance and economics.

The success of a concept design relies on effective dialog and communication between all relevant stakeholders starting with the ship owners, operators, builders, equipment suppliers and last but not least the designer who has the task to integrate all equipment and systems in an ergonomic and functional layout.

A new design in the same vessel class and size will likely offer better efficiency through hull lines optimisation (by using CFD) and by selecting the optimum propulsion configuration for a particular operational profile and lifecycle – as a minimum. The overall performance can also be upgraded by adopting a non-standard (or not so common) layout configuration of the vessel. For instance, deckhouse accommodation forward eliminates the forward visibility constrains on capacity for a container vessel.

In terms of the newly established ECAs, an efficient design or vessel indicates that the vessel was or needs to be designed specifically for the purpose in a particular trading pattern, basically reducing the flexibility and limiting the re-sale possibility outside that operational area.

At WSD we strive to deliver the best optimum tailored engineering solutions (i.e. ship design) that match and enhance our customers' dynamic business environment.

WSD specializes in highly cost-efficient standard and non-standard merchant vessel types. Wärtsilä's in-depth expertise, experience, and high level of innovation are utilized to provide added value to customers' businesses. The knowledge of the customer's operational needs is an essential element in Wärtsilä's ability to provide design solutions tailored to complement the evolution of specialized ships to carry various types of cargo. Innovation is a hallmark of WSD, with special emphasis given to fuel consumption, cargo handling, and crew safety, to ensure cost-effective operations and the best possible return on investment.

2. INTRODUCTION

The CRV2400 WB container RO-RO vessel is designed by WSD. The basic design is in progress, and the construction is scheduled to start soon at VTHM facilities in Pascagoula, MS, US.

This is the first in class vessels with dual fuel propulsion, built to Jones Act and to operate along the East and West seaboards of the USA.

Figure 2: WSD CRV2400 WB. Source: Wärtsilä

3. CM'S PUERTO RICO LINER SERVICE FLEET RENEWAL PROGRAM

The US Mainland to Puerto Rico is the largest domestic (Jones Act) liner trade, where CM owns the largest share through the North Atlantic (NAL) and South Atlantic (SAL) lanes.

The current fleet employed by CM on the SAL route consists of 4x 730 and 2x 580 triple deck RO-RO barges towed by Invader Class Tugs sailing three times per week from Jacksonville, FL and once per week from Pennsauken, NJ. The fleet is part of a very extensive logistics train where any downtimes have dire consequences.

The fleet age, the new regulations and the increasing business potential were the main drivers for CM looking ahead of its competition and beyond the currently employed shipping practices to write down the requirements for a new fleet of vessels. These ships would also strengthen the bond with the company's values and culture of environmental stewardship in providing world class services.

CM's main objectives for and with the new flagships are:

- replace the current aged fleet's carrying capacity while accounting for business growth
- reliability in service
- LNG as primary fuel
- halve the round trip voyage
- very efficient vessels, but with fuel consumption secondary to speed
- "environmental friendly" in operation

Figure 3: US Jones Act trade. Source: Crowley Maritime

4. A MODERN APPROACH IN THE DESIGN OF WSD2400 WB

4.1 PROJECT CONCEPTION

In February 2012, Wärtsilä Ship Design had received an inquiry for a very high spec'd container RO-RO vessel for Crowley Maritime.

If in Europe ship owners were cautiously experimenting with LNG capacities in range of few hundred cubic metres, in the 'Far West', Crowley was talking business inquiring for a vessel that would soon show a capacity demand of few thousand cubic metres.

The Ship Building Contract (SBC) could have been signed before the summer of 2012, but given the novelty of the design linked to rules uncertainty, readiness of technology and lack of (built) references, CM wanted to ensure that all possible foreseeable risks are mitigated before the SBC which in effect lead to the preliminary risk assessment and model testing having been completed by the time the contract was signed in December 2013.

First contact		SBC		First Delivery
Feb-12	→	Dec-13	→	May-17

4.2 MAIN PARTICULARS

LOA	:	219.50m
B	:	32.24m
D	:	18.00m
T_s	:	10.00m
DWT_s	:	26,000t
V_s		22kts (@ 90% MCR, +15% SM)
M/E	:	1x 26,160kW (8S70 ME-GI)
A/E	:	3x 1,800kW (9L28/32 DF)
LNG tanks	:	3x 770m3 (IMO Type C, double st.st. barrier, vacuum insulated)
Container layout		
Deck	:	20ft/40ft/45ft/53ft
Hold	:	40ft/45ft/53ft

Four (4) car decks arranged in the RO-RO superstructure with anti-clockwise loading/unloading.

4.3 OPERATIONAL PROFILE

Five (5) representative operational profiles corresponding to same number of trading routes have been analysed with corresponding duration and speeds and at various operating modes, with and without cargo.

The most representative (i.e. demanding) operational profile was selected for the purpose of sizing the cargo capacity and layout, the propulsion configuration, the LNG tanks and Fuel Gas Supply System (FGSS), as well as the level of redundancy the vessel would need for uninterrupted service on any of the trade route, including Alaska.

4.4 APPLICABLE RULES AND REGULATIONS

In the upcoming years more stringent requirements for the environmental compliance can be traced in the shipping industry. This makes it extremely important to identify the combination of those requirements which need to be applied to the vessel in order to match the operational requirements and to ensure full regulatory compliance.

In addition to the existing in-force regulations (not within the scope of this paper) the focus has shifted to the upcoming IMO regulations, mainly MARPOL ANNEX VI, which is aiming to reduce NO_x, SO_x, CO_2 and PM compounds from the ship emissions. New limits with higher requirements for NO_x emissions (Tier III) will be effective from 2016 and, higher limits for SO_x emissions from 2015 in ECA areas, and a global sulphur cap from 2020 onwards.

In the initial design phase, the operational profile requirements of the vessel and its future area of operation(s) are very important as it defines the regulatory boundary for which the vessel needs to be designed.

In terms of choice of technology, (Wärtsilä) internal analyses on the availability and feasibility of one technology over another have shown that environmental and efficient should be a primary target focus when designing the vessel. From the ship owner’s perspective, retaining and enhancing the market share and competitiveness is the key factor when adopting new technologies.

In addition, part of the MARPOL Annex VI, the resolution MEPC 203(62) prescribes requirements for the compliance with CO2 emissions. It introduces the EEDI that calculates assumed CO2 output per tonne-mile. The calculated EEDI for the present vessel shows full compliance with the requirements for vessels with building contract placed between 2015 and 2020.

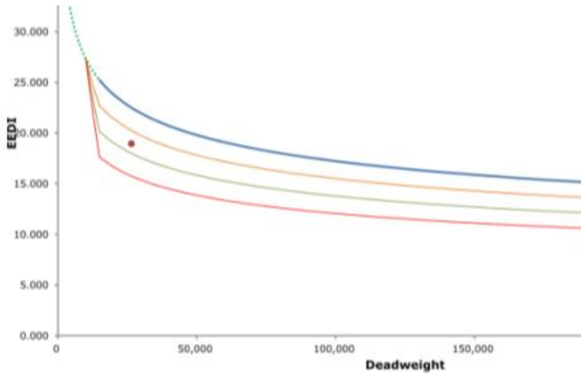

Figure 4: WSD CRV2400 WB Attained EEDI. Source: Wärtsilä

4.5 CLASS NOTATION

The Classification Society selected by CM for this vessel is DNV (presently DNVGL) with the following class notation:

DNV +1A1 General Cargo Carrier, CONTAINER, RO/RO, NAUTICUS (Newbuilding), GAS FUELED, DG-P, BIS, TMON, BWM-T, E0, NAUT-OC, CLEAN

1A1	Assigned to ships with hull, machinery, systems and equipment found shall be in compliance with applicable DNV rule requirements
General Cargo Carrier	Arranged for lift on/lift off cargo handling and intended for carriage of general dry cargoes
CONTAINER	Arranged for carriage of containers
RO/RO	Arranged for carriage of cars
NAUTICUS	Vessels based on finite element calculations
GAS FUELED	Gas engine installations

DG-P	Arranged for carriage of dangerous goods in packaged form
BIS	Built for in-water survey of ship's bottom and related items
TMON	Tail shaft monitoring
BWM-T	BW management system complying with the Ballast Water Convention (BWM/CONF/36). Ballast water treatment method
E0	Unattended machinery space
NAUT-OC	Enhanced nautical safety
CLEAN	Requirements for controlling and limiting operational emissions and discharges

4.6 FLAG

The vessel will be classed by DNV under the Alternate Compliance Program (ACP). After delivery from a US shipyard, the vessel will be manned by US crew in US waters. Amongst others, the USCG has retained the task to review and approve the FGSS together with DNV based on the current IMO requirements and the USCG Policy Letter CG-521 No. 01-12 April 19, 2012.

4.7 HULL FORM OPTIMISATION

At first, well-known statistical methods have been used to evaluate the preliminary required effective and delivered power and to size the propulsion plant accordingly.

An existing reference (1800 TEU container vessel) hull lines was used as the starting point in the initial hull form development process. Driven by the hydrodynamic aspects due to arrangement of cars and containers, the hull lines have been amended by making fuller aft body in the upper part of the hull. The main changes have been performed to enable adequate flow of vehicles in and out of the aft RO-RO superstructure through a single lane stern quarter ramp arranged on Portside.

LNG is a very space demanding fuel option, and minimizing the capacity of LNG bunkers can be done by reducing the operational range, or best by improving the efficiency of the design. Today's state-of-art tools for hull lines optimisation employ the use of CFD.

For the CRV2400, CFD was used to evaluate the effective power however in combination with optimization algorithms (through Friendship Systems) which allow certain modification of the hull shape in the predefined areas in order to find the optimum solution where optimisation parameter would reach its maximum value. Due to the complexity and time-consuming process for the viscous-based CFD including rotating propeller (numerical propulsion test) it was decided to use resistance as target for the optimisation. Thrust deduction factor, being still unknown parameter, was carefully considered by using data available from the model tests.

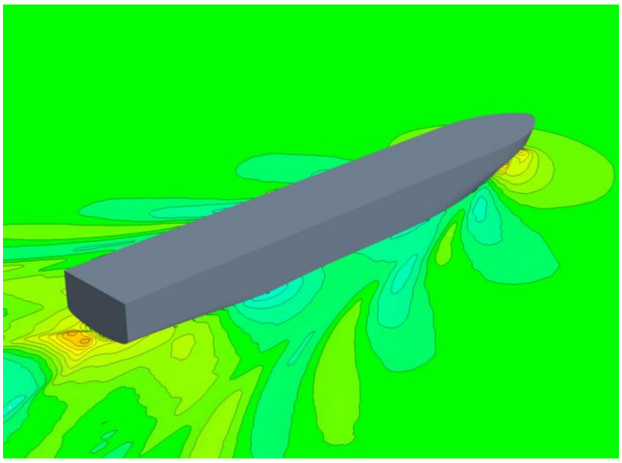

Figure 5: Pressure distribution and wave profile.
Source: Wärtsilä

All major technical constrains and characteristics, including speed, DWT, cargo arrangement, size and position of the LNG tanks were considered during optimisation.

Due to the specific requirements of the operational profile CFD optimisation of the hull form was based on the weighted combination of speeds and drafts.
This resulted in less pronounced shape of the bulb, giving somewhat less effective performance on the maximum draft but better performance at intermediate drafts. Corresponding weighting was derived from the future operational profiles. Later, the vessel's performance has been confirmed by model tests within 1% deviation in results from the CFD predictions.

4.8 MODEL TESTS

An extensive model tests program has been ordered at MARIN testing facility in the Netherlands to assess the future vessel characteristics, and the following tests have been conducted:

- Resistance and self-propulsion tests for the complete set of the drafts
- Wake measurements tests
- Open water tests with stock and design propeller
- Maneuvering tests
- Extensive sea-keeping tests

Very slender hulls in specific operational conditions are subject to parametric rolling. For this reason, the CRV2400 WB has had additional sea keeping tests performed to understand and map the field of occurrence, and to ensure adequate mitigation measures.

Further, numerical simulations were performed with the optimized hull and a suitable Energy Saving Device (ESD) solution to identify any potential fuel saving benefit from installing such device. Finally, Wärtsilä

EnergoPac solution has been selected and successfully tested at MARIN.

Due to the combination of the twisted leading edge of the rudder and transition bulb it was possible to reduce the drag and eliminate strong vortex behind propeller.

Comparison results have shown that about 2% of power reduction can be expected when using EnergoPac solution.

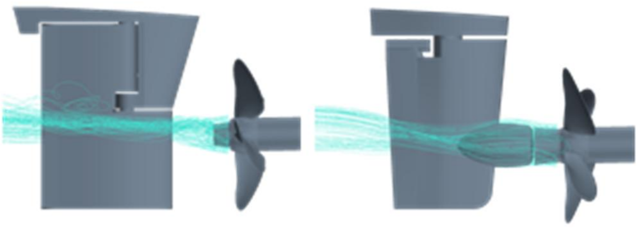

Figure 6: Conventional rudder vs. Energopac.
Source: Wärtsilä

5. MACHINERY

The requirement to design a Vessel which is powered by environmental friendly technology played the key role during the project development.

Besides the challenges derived from combining the RO-RO and the container vessel capability, the gas system and its associated equipment was the major driver constraining the vessel's arrangement and the overall concept. A number of different machinery configuration options were investigated in order to find the optimum between CM's operational requirements and vessel delivery.

Based on the various options developed by WSD for CM's, the final decision was for single-screw propulsion with 2-stroke low speed dual fuel High Pressure (HP) main engine and 4-stroke medium speed Dual Fuel (DF) auxiliary engines from MAN Diesel & Turbo (MAN), and FGSS including LNG tanks from TGE Marine Gas Engineering (TGE).
Amongst others, the Otto cycle DF options has not been selected due to the higher natural gas consumption which meant less endurance for the same LNG bunker tanks size – already at their maximum allowable within the agreed reserved space i.e. below C/H No.4.
While both Wärtsilä and MAN are striving hard to improve the consumption on both natural gas and pilot fuel, an interesting finding is that above about 85%MCR, the 2-stroke Low Pressure (LP) engine used for this project showed better overall energy consumption.

The main machinery and fuelling system equipment can be summarized as follows:

- Main engine, 1x 8S70ME-C8.2-GI
- Auxiliary engines, 3 x 9L28/32 DF
- LNG containment system, 3 x 770m^3
- Tank Connection Space (TCS)
- Pump room and compressor room or Gas Handling Room (GHR)
- HP FGSS to main engine
- LP FGSS to auxiliary engines
- Gas Valve Unit (GVU)
- Bunkering station
- Ventilation mast

5.1 ENGINE ROOM DESIGN

The entire engine room and all the systems relating to the DF system are designed according to the Inherently Safe Engine Room concept, which in practice means that double wall piping is applied where routed through engine room (incl. enclosed spaces).

The Vessel is propelled by a single low speed 2-stroke dual fuel MAN engine located aft.

Three (3) medium speed 4-stroke DF engines were selected to provide electrical power generation, and arranged in the engine room. Only the emergency generator set is fueled only by ULSMGO.

The LNG is supplied to the main engine at high pressure (abt. 300 bar) and to the auxiliary engines at low pressure (abt. 4 bar). The three (3) LNG tanks are meant to feed both HP and LP systems.

The HP and LP gas auxiliary equipment is placed in the GHR which is located on Portside, just aft of E/R bulkhead (see 5.3).

The gas supply line in the engine room to the DF engines is designed with ventilated double-wall piping and gas detectors for emergency shutdown. The purpose of the outer pipe shielding is to prevent gas outflow to the machinery spaces in the event of rupture of the inner gas pipe. Hence the annular space as well as spaces around valves, flanges etc. are equipped with separate mechanical ventilation (30ch/hr) from a non-hazardous area (outside engine room).

All gas related piping is of stainless steel.

Permanently installed gas detectors are fitted in the TCS, Tank Hold Space (THS), in all ducts around gas pipes, in engine rooms, ventilation trunks, compressor rooms, and other enclosed spaces containing gas piping or other gas equipment.

The exhaust system is designed and built sloping upwards in order to avoid formations of gas fuel pockets in the system.

5.2 LNG TANKS AND ENDURANCE

The capacity of LNG tanks is optimised for the specific Vessel's operational profile.

A round trip is considered for the following combination:

- southbound route (JAX-PR): fully loaded with reefers, maximum load on generating sets
- northbound route (PR-JAX): as ballast with empty containers, minimum load on generating sets

It follows that LNG tanks are sized for bunkering every two (2) round trips as per CM's requirements. This equals to 6,000nm, which represent the maximum mentioned distance between the five (5) analysed scenarios. The attained endurance is based on service speed of 21.0 knots and 15% sea margin, both on laden and ballast draught.

The resulting required capacity was abt. 2,310 m^3 split in three LNG Type C tanks to fit into the assigned THS.

The LNG tanks are designed with double barrier containment, vacuum insulated and abt. 4 bars operating pressure.

The outer shell is made of stainless steel as well as the TCS which is considered the secondary barrier to LNG piping/nozzles. This makes the THS a gas safe area.

5.2 (a) LNG tanks location

Numerous loops were made in order to find the optimum combination between LNG tanks position and cargo holds setup with respect to minimization of the bending moments, cargo loss and stability considerations.

In the final stage, the LNG tanks length/diameter ratio was constrained by:

- The distance from shell specified both by IMO and USCG guidelines. The tanks were located well within B/5 from ship side and B/15 above the bottom. The distances are measured from the primary barrier i.e. inner stainless steel tank diameter.
- Minimum inspection space between tanks
- Required foundations space
- Length of two (2) 53 ft optimized holds
- Height of two (2) high cube containers.

As most suitable location, the LNG tanks were arranged in an enclosed compartment below Cargo Hold (C/H) No.4 within its complete length on top of double bottom extending at the same level as in, and forward of the engine room.

The engine room and C/H No.3 (dangerous goods) are considered high fire risk spaces. Consequently, the tanks have been located 900 mm away from these bulkheads, each bulkhead having A60 insulation towards the THS.

No LNG/NG equipment or LNG pipe works is anywhere less than 800 mm from the ship side.

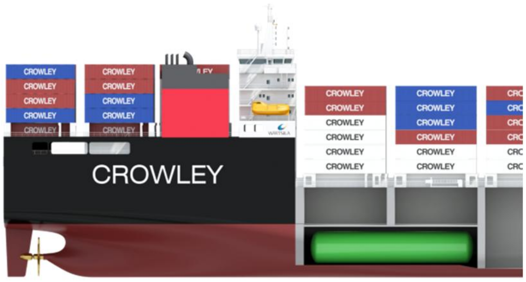

Figure 7: Location of LNG tanks. Source: Wärtsilä

Additional protection was ensured by a double hull, i.e. ballast water and MGO stored in the wing tanks extending along the complete length of the hold where the LNG tanks are located.

In order to protect the LNG tanks from accidental drop (container), a reinforced deck structure acting as the bottom of C/H No.4 is arranged on top of THS, separating the compartment from the container hold above.

5.3 FUEL GAS SUPPLY SYSTEM

The main engine is fed by HP gas system (300bar), the auxiliary engines by low pressure system (abt.4bar).

The LNG is brought to 300 bar gas by the HP LNG vaporizer and HP Fuel Gas Heater.

This kind of installation implies the need of having compressors as well as separation tank and booster pumps in a GHR, hence in an enclosed and separate compartment.

The solution does not create major Class or Flag State safety concerns when applied on ships which do not carry cargo on deck (as for example LNG carriers, tankers, bulkers). However, on a container vessel where cargo is carried both above and under weather deck, this results to be very demanding design task, even more with the aft RO-RO superstructure further limiting the options.

Hence the separate compartment containing the gas system was considered as pump/compressor room. USCG required such defined compartment to be located above the freeboard deck. From USCG point of view, this requirement could be met by achieving the same level of safety with an alternate arrangement.

Given the vessel layout constrains, the space was located within the engine room area and below freeboard deck, on Portside aft of engine room bulkhead. Complete segregation from E/R was ensured by means of continuous gas tight bulkhead fitted with a 900mm cofferdam, extending from double bottom along the complete E/R height.

In this way the GHR, containing the main gas supply equipment for the engines, was also located next to the THS. This was received well as it minimizes the LNG piping running through the vessel and consequently reducing the risks of cryogenic leaks.

All the connections on the LNG tanks, including the double block and bleed arrangements segregating the bunkering stations, are located in the TCS welded onto the aft dish end of each LNG tank.

5.3 (a) FGSS operational principle

From the TCS the LNG is sent to the pump room for gas handling. Two (2) HP pumps each at 100% capacity are installed in the pump room to supply the main engine (one pump running at the time). The engine requires pressurised gas at a maximum pressure of abt. 300 bar.

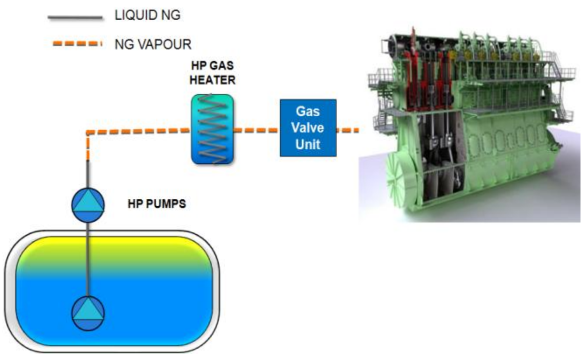

Figure 8: Main engine MAN & TGE HP FGSS

The LP system is arranged to feed the auxiliary engines.

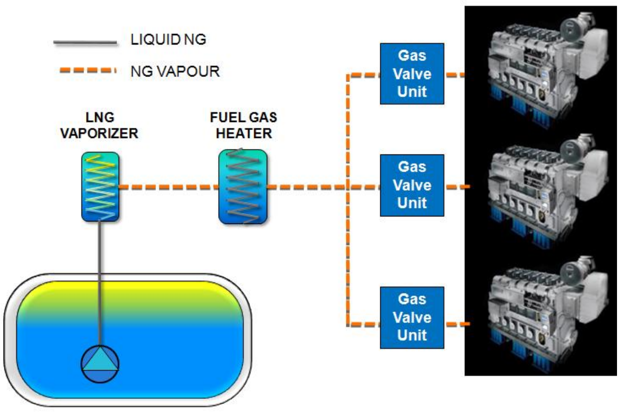

Figure 9: Auxiliary engines MAN/TGE LP FGSS

The GVUs (one per engine) are arranged in two separate gastight compartments, one dedicated to the HP system and the second for the LP system, both in proximity of the DF engines.

The pump room containing the LNG handling equipment is designed to withstand leakages from the cryogenic liquid system and therefore enclosed in a separate stainless spill space.

5.3 (b) Bunkering station

The bunker stations are located in the RO-Ro superstructure on each ship's side on main deck in a semi-enclosed space allowing the Vessel to berth and bunker on either side. The lines are sized for a bunkering rate of 350m^3/hr with the intention to fully bunker the tanks in less than 8 hours, and are physically separated or structurally shielded from accommodation, cargo / working deck and control stations. Additionally, the ship's structure is protected during bunkering operations by means of water curtain system, besides drip trays fitted below liquid gas bunkering connections and where leakage may occur.
The bunkering stations are segregated one from each other, and the systems are designed to enable simultaneous cargo and bunkering operations.

5.3 (c) Ventilation

In certain situations during normal operation of a DF-engine, as well as due to possible faults, there is a need to safely ventilate the fuel gas piping. Special considerations are accounted, as ventilation of hazardous spaces should be separate from that used for the ventilation of non-hazardous spaces and electric fan motors should not be located in ventilation ducts.

Effective mechanical ventilation system of the under pressure type, providing a ventilation capacity of at least 30 air changes per hour was provided for the GHR, TCS, GVU Rooms and the double wall annular space

Another important aspect was the location of the ventilation mast. Due to the container handling operations virtually along all exposed decks of the Vessel, satisfying the minimum height from any working deck (6 m) and distance from any opening to machinery or accommodation spaces (10 m) ended in being very difficult to position. Hence as the only acceptable spot, both from operational and Class perspective, was to rise the mast above the deckhouse on Starboard, well away from any shore crane interference.

6. STRUCTURE AND STABILITY

The main challenge when checking the stability of the vessel was to find the balance between reasonable GM value, trim restrictions, amount of ballast used during voyage and strength limitation coming from the high bending moment. The task turned out to be even more complicated when different combinations of container types (standard, high cube) and sizes (40ft, 45ft and 53ft) had to be calculated.

The requirement of having longer holds suitable for accommodating 45ft and 53ft containers and large heavy aft body (RO-RO space with container stacks on top) played the major role both in Vessel's arrangement and structural configuration, bringing to the Vessel an uneven lightship weight distribution.

Normally for the calculation purposes homogeneous weight is taken into account for all containers.
A homogeneously loaded vessel does not feature major deviations from hull stresses present in conventional containerships. Nevertheless, as operational requirement, it was needed to optimise the ship for very specific loading scenario:

- 40/45ft containers: 23 t/unit
- 53ft containers: 16 t/unit

Such loading can be beneficial in respect to an even trim of the vessel, which was among the requirements for the Vessel when calling Jacksonville harbour where due to harbour restrictions, at 10.0m scantling draught the vessel is not allowed any trim. Hence the trim aft, which possibly could contribute to lower the hull stresses was not permitted.

High hogging moment appeared as a result of light 53ft containers, prescribed to be carried in the central part of the vessel. At the same time with accommodation located semi-aft it was a need to load more heavy containers in the aft part. Supported by the maximum buoyancy in the middle area of the hull and very little buoyancy in the aft part bending moment had raised considerably. Finally the balance between optimised structural arrangement of the midship section able to withstand required bending moment, maximum number of containers loaded in the predefined way and minimised ballast capacity has been found.

Moreover a number of iterations were made in order to find the optimum combination between LNG tanks position and cargo holds setup with respect to minimizing the bending moments.

The implications on the arrangement listed above led to extensive hogging and higher bending moments, abt.35% higher than the standard Rule values.

Therefore, optimisation of midship section and all structural members was needed from the very beginning of the project development phase, prior to start with Class drawings.

The accuracy of the weight distribution resulted to be critical in this specific design as well as LSW influences directly the DWT and the related penalties; hence structure was modelled in NUPAS for verification purposes. In this way detailed weight monitoring was established from the very beginning of the project.

Such extensive naval architecture investigations prior to Contract signing reduces the risks.

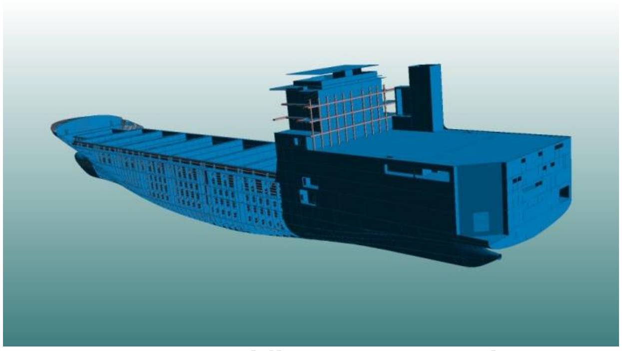

Figure 10: NUPAS modelling. Source: Wärtsilä

6.1 (a) Freeboard and additional loading capability

The Tween Deck at 13,800 mm a.B.L. was assigned as freeboard deck instead of the continuous main deck at 18,000mm a.B.L. As consequence, a complete superstructure from AP to FP was accounted into the calculation resulting in a sufficient freeboard to allow a maximum vessel draft of abt. 11.0 m.
Additional investigations were carried out in order to identify the required draft to have all the container slots filled at the most unfavourable condition.
The above was achieved at a slightly higher draft and the damage stability was met with minor subdivision modifications.
An increase in scantling draft did not affect the structural characteristics of the midship, as the bending moments were still in range of the design ones (which superseded the Rule values).
Nonetheless, as of today CM didn't pursued the option to increase the vessel's draught.

7. CONCLUSIONS

The development of CRV2400 WB is a very rewarding experience that reaches across the globe, where has been a very good co-operation and trust within the development team (WSD, CM and VTHM).

Nonetheless, the project is equally challenging and the pressure is high on all the stakeholders as this is a very important "first of its kind" project for most, even more for the shipping industry itself.

For this project, WSD has a very professional and dedicated team mainly located in Poland and Norway which is working very closely with VTHM and CM.

WSD is confident that it has the best people on the job to ensure that the design of the vessel meets all of the contractual requirements mirroring the initial inquiry set by CM, including enhancements that develop throughout the design and construction of a vessel.

Once successfully delivered from VTHM, the vessels will raise the bar for merchant shipping, not only for U.S. flagged ships, but globally.

Crowley is taking a bold step in bringing environmentally viable designs to market, and these vessels are only a part of the whole program. LNG bunkering facilities will be available in Jacksonville before the ship makes her maiden voyage ensuring uninterrupted supply of LNG as fuel and thus solving the perpetual “chicken and egg” issue that many ship owners are faced with today.

8. ACKNOWLEDGEMENTS

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