EV2 – NEW RESCUE BOAT POWERED BY LNG: POTENTIAL USE OF LNG AS AN ALTERNATIVE FUEL FOR THE MARITIME RESCUE FLEET

Deliverable D3.2 – Feasibility and Technological development study on an LNG-powered rescue boat

SASEMAR / ARMON

SOCIEDAD DE SALVAMENTO Y SEGURIDAD MARÍTIMA

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More Information

Public CORE LNGas HIVE reports and additional information related with the project execution and results are available through CORE LNGas Hive public website at **www.corelngashive.eu**

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1. INTRODUCTION

The Society of Salvage and Maritime Safety (hereinafter SASEMAR) and Shipyards ARMÓN, S.A. (hereinafter ARMON), are partners in the consortium formed for the development of the CORE LNGas hive Project. Both entities were designed for the development of the EV2 sub-activity "Rescue boat powered by LNG".

The main objectives to be achieve with this activity are focused, within the policy of reducing emissions from maritime transport, in developing an study about the use of Liquefied Natural Gas (LNG) as alternative fuel in anti-pollution and salvage vessels, since it is a viable alternative to the use of conventional fuels (MGO/MDO) more harmful to the environment from the point of view of emissions.

Based on it, the application of LNG as fuel in salvage vessels requires a technical analysis because of the particularities and the wide range of typologies that these ships actually give service in the coasts of the world. Within the present study an analysis of the state of the art in relation to the use of LNG will be carried out, as well as a study on the feasibility of using in both existing and new building SASEMAR fleet vessels. The global study to be developed along the project CORE LNGas HIVE will also include a monitoring on the latest technological developments in the use of LNG in ships in order to keep it up to the end of the EV2 sub-activity.

2. FEASIBILITY STUDY: GAS AS FUEL IN SASEMAR FLEET

The feasibility study for the use of Natural Gas as fuel in anti-pollution and salvage units is developed in the present section. The study considers the overall SASEMAR fleet and pretends to categorize the most suitable units to be upgraded (if any), such categorize is done by analysing each unit from a technical and operational point of view:

- Power requirements – engines
- Range requirements – LNG capacity
- LNG logistics chain
- LNG technology on-board integration

SASEMAR fleet is divided into the following ship categories:

- SALVAMARES: Fifty-five units with a range of total lengths between 15 and meters and beams between 3.80 and 5.60 meters. These are quick response rescue and salvage units with a certain towing capacity.
- GUARDAMARES: Four units (Calíope, Concepción Arenal, Polimnia and Talía) built in the 2008-2009 period, which are quick response vessels with towing capacity, with a size of 31 meters in length and 7 meters of breadth.
- OCEAN GOING TUGS: Seven units (María de Maeztu, María Pita, María Zambrano, Marta Mata, SAR Gavia, SAR Mastelero and SAR Mesana) delivered in the period of 2007-2010. They have a size of 39.7 meters in length and 12.50 meters of breadth.
- MULTIPURPOSE VESSELS CATEGORY 1: Two units (Luz de Mar y Miguel de Cervantes) built in 2004 with a length overall of 56 meters and a breadth of 15 meters. They can perform, among other functions, towing and anti-pollution Works, as well as rescue and salvage operations.
- MULTIPURPOSE VESSELS CATEGORY 2: These are two units (Clara Campoamor y Don Inda) built in the year 2002. They have a size of 80 meters in length and 18 meters of breadth, and are capable of develop a wide range of operational functions.

For all of them, different aspects of each block will be analysed, in order to make an analysis on the feasibility of its application in each vessel.

2.1. Initial Hypothesis

In order to carry out the present study, a series of requirements / hypotheses have been previously established, with the objective of enable, in this first phase of the feasibility analysis, calculations and estimates that allow reaching a series of conclusions that, in turn, will serve as a starting point for the later stages of the feasibility analysis. Fundamentally, these are the following:

- The starting requirement to begin the study is that in no case the use of LNG must imply a decrease in the operational performance capabilities in the vessel units under analysis. Fundamentally this aspect refers to the fact that total installed power and range reductions will not be contemplated, in order to improve the operational performance capabilities currently offered by the current SASEMAR units with the introduction of LNG as an alternative fuel.

Neither is there any limitation on the response time after a warning to any of the ships, beyond the usual ones.

- Regarding the configuration of the power plants it will be considered for all the cases a configuration based on dual-fuel engines, based on the range of powers currently installed.
- Once the different alternatives of dual-fuel engines for each type of vessel are selected, it will proceed to estimate the necessary volume of LNG to provide the different ships with 10%, 25% and 50% more range than the currently have working at 80% of the rated power. This would imply that once the equipment and system that allow the use of LNG as an alternative fuel are integrated, the vessels could operate for an additional time operating with LNG in any of the functions, thus benefiting from all the advantages that imply the use of this fuel for a percentage of the time of their normal operation. Additionally this alternative contemplates the entrance and exit from the port consuming LNG, which would reduce considerably the pollution in port zones.
- In relation to the equipment that are necessary to install on board to enable the use of LNG it will be considered the following in this phase of the study: Bunkering station, LNG tank, Tank Connection Space, Vent Mast, Gas Valve Unit (GVU) and dual-fuel engines. All of them constitute, in this phase of the study, the basic installation to analyse the feasibility on the integration of this technology in the anti-pollution and salvage vessels that are being studied.
- For the analysis of the regulatory aspects it will be used as reference rule the IGF Code, adopted by the IMO by resolution MSC.391(95) of 11 June 2015 and which becomes effective on 1 January 2017 for ships consuming gas and low-flashpoint fuels.

In each block of the present study where criteria for evaluating the feasibility on the implementation of LNG on-board as an alternative fuel are analysed, it will be finished with a conclusion based on the following colour code for the different types of vessels:

- **Green**: It is considered feasible to comply with the requirements imposed on a particular ship category.
- **Orange**: It is considered feasible to comply with the requirements imposed on a particular ship category, although with caveats and several risks of not meeting the requirements in a more exhaustive analysis which, if necessary, will take place in later stages of the sub-activity EV2, when the feasibility study is carried out in 2017
- **Red**: It is not considered feasible to comply with the requirements imposed on a particular ship category.

These criteria are applied on Table 23.

2.2. Use of LNG as an Alternative Fuel

The need to reduce the pollutant emissions in which society is nowadays immersed have a clear reflection in the international organizations responsible for ensuring respect for the environment. In relation to the maritime traffic, a series of criteria have been imposed that have been recently in force and will continue to be implemented over the next few years.

In October 2008 the International Maritime Organization adopted the normative MARPOL-Annex VI and the technical code of 2008, which came into force in July 1 2010. In that normative several changes where introduced, being one of the main changes de progressive reductions of the SOx and NOx emissions, introducing some areas where certain restrictions and emission control must be fulfilled. These extensions are the ECA zones (Emission Control Areas). In the ECA zone will be controlled the nitrogen oxides (NOx), sulphur oxides (SOx) and particles emissions (PM) from the vessels.

Annex VI of the MARPOL Convention regulates the emission into the atmosphere of gases from ships. In relation to the sulphur oxides the Rule 14 of the Annex VI establishes maximum limits on the content of those substances in marine fuels:

Outside the zones of limited SOx and suspended particles emissions	Inside the zones of limited SOx and suspended particles emissions
4.5 % m/m before January 1, 2012	1.5% m/m before July 1, 2010
3.5% m/m after January 1, 2012	1.0% m/m before July 1, 2010
0.5 % m/m after January 1, 2020	0.1% m/m before January 1, 2015

Table 1. Rule 14 Annex VI of MARPOL for the limitation of the content of sulphur in the fuels and date of entry into force. Source: IMO

Based on the above table, the limits of sulphur content in the fuels are subject to a series of staggered changes through the years that will come into force successively, which are defined in the following figure:

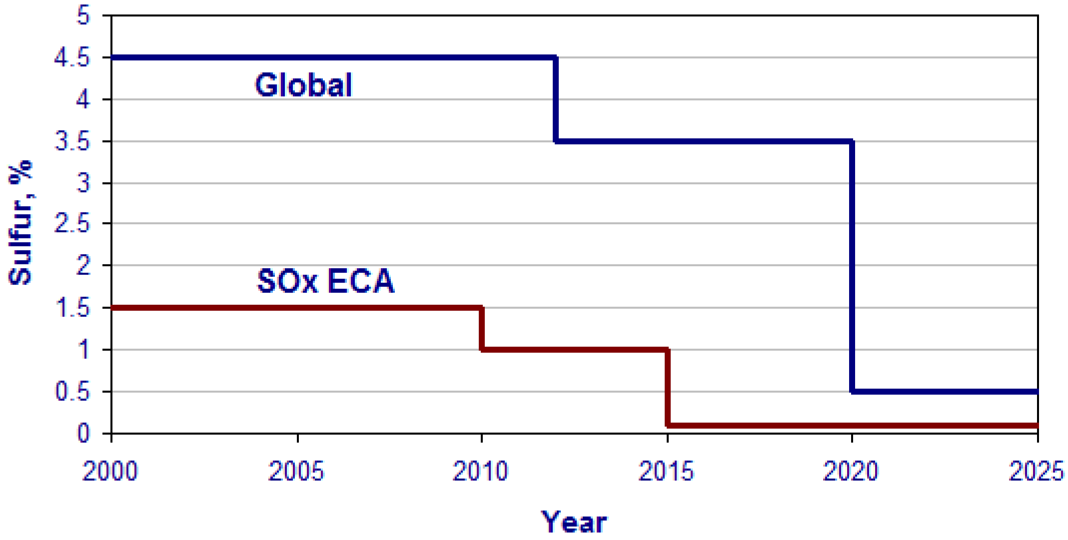


Figure 1 - Limit of the content of sulphur in the fuels and date of entry in force. Source: IMO

On the other hand, with regard to the emissions of NOx it have also been established certain emission limits for the new engines built after January 1 of 2011, in which has been named Tier II. Additionally level Tier III limits were defined, which will come into force for engines installed from 2016 and that will be applicable for vessel operating in ECA zones. For certain ship of small size established in rule 13.5.2 it is only applicable the Tier III level in the ECA zones of United States of America, so in the rest of ECA areas they may continue to apply Tier II level.

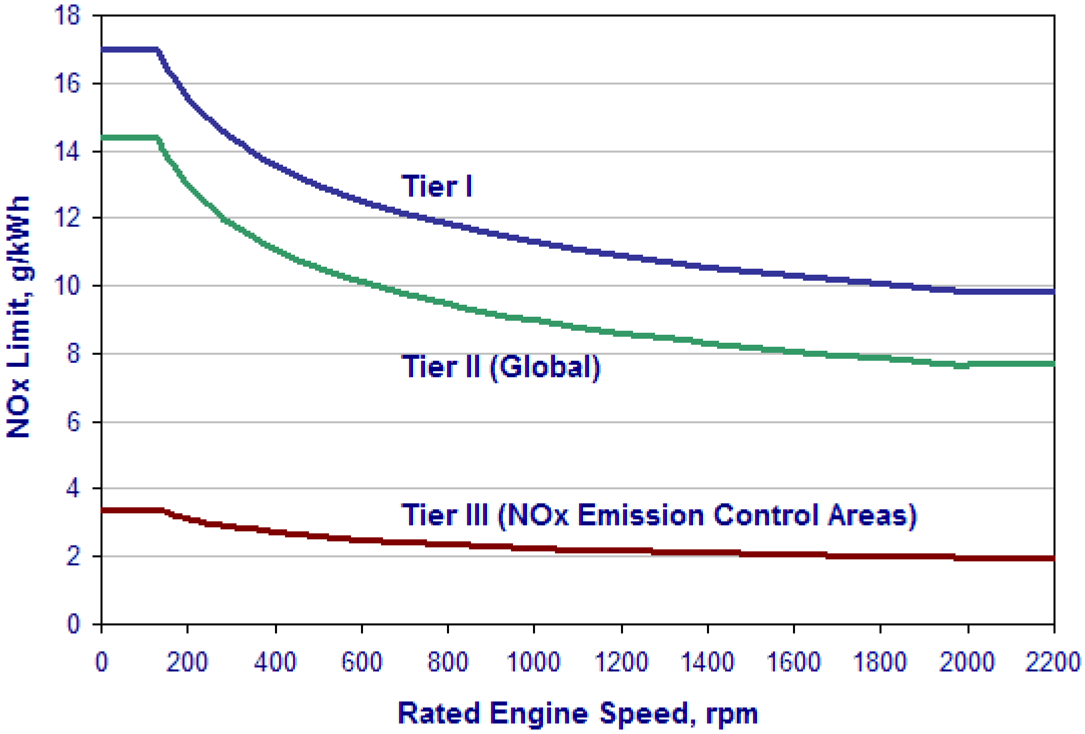


Figure 2. Limits of NOx emissions for marine engines. Source: IMO

As can be seen in the following picture, the use of LNG is an alternative solution to take into account due to its low emissions of NOx and greenhouse gases (CO_2), as well as his zero emissions of SOx and solid particles into the atmosphere.

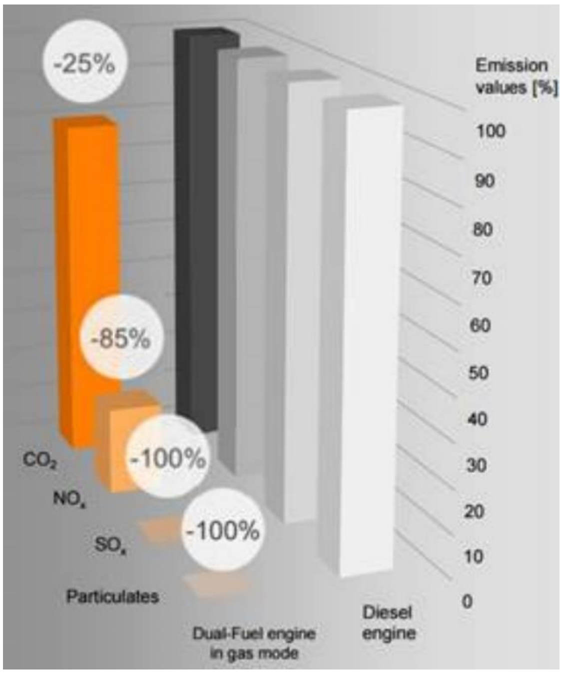
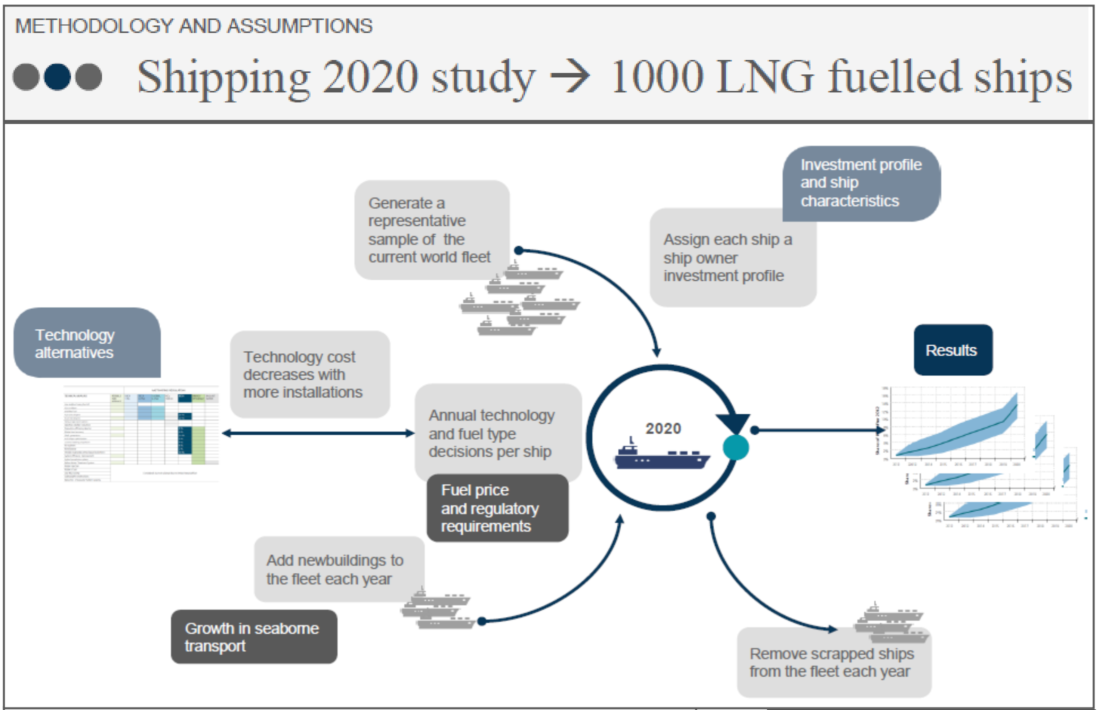
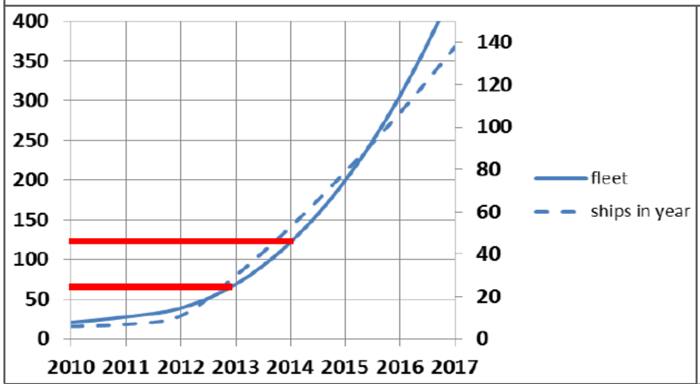


Figure 3. Reduction of the emissions of a dual-fuel engine running with natural gas respect to a conventional diesel motor. Source: Wärtsilä

In reference to the use of LNG as fuel in the naval industry, it should be pointed out that according to the Shipping 2020 study carried out by DNV-GL in 2012, it is estimated that by 2020 the marine fleets will consume in the world 7 million tons of LNG, representing an approximate number of 1,000 vessels propelled by this fuel, of which 2.2 million will correspond to Europe; while a market study prepared in 2011 by IHS CERA (an American entity specialized in consulting, on the energy market and the industrial tendencies, to governments and private entities) anticipates a market of LNG as marine fuel of 29 Mt/year from 2025, with a possible increase to 65 in the year 2030, representing the 22% of the bunkering market in the world. All this is showed in the following graphics and figures:





year	ships in year	fleet
2010	6	21
2011	7	28
2012	11	39
2013	30	69
2014	53	122
2015	79	200
2016	107	307
2017	138	445
2018	171	617
2019	207	823
2020	244	1068
2021	284	1351
2022	325	1676

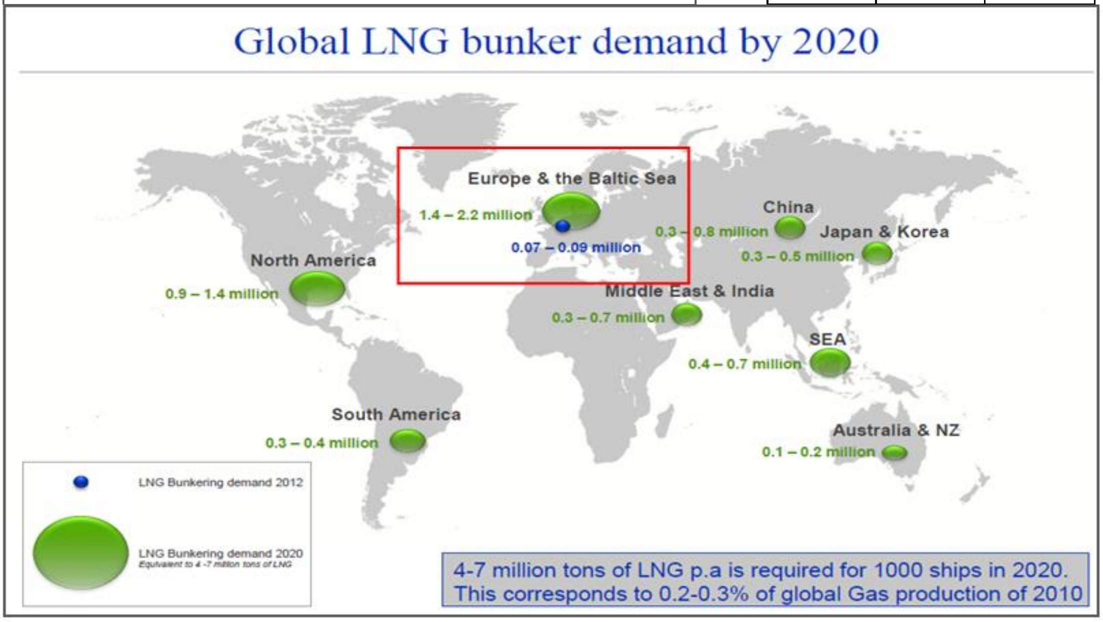


Figure 4. Tendencies in ships and LNG demand. Source: DNV

Considering the forecasts, there is and there will be a notable increase in orders for gas-powered ships, generating the need to supply according to the requirements of each zone.

Given this scenario, ship owners and ship operators are being forced to make a crucial decision when facing new ship orders. To do this, each case requires a detailed study of the different alternatives currently offered by the market, considering the advantages and disadvantages of each of them in order to adopt the most convenient solution.

The alternatives currently available that comply with the regulations for emissions are explained below. From these, four have been selected due to their higher level of development and deployment in ships and their current technical viability on the application on the ships of SASEMAR fleet:

- MGO + NOx emission reduction system (SCR) in ECA: The use of MGO may involve, depending of the zone of operation of the vessel, the utilization of NOx emission reduction systems. This systems are mostly based on the selective catalytic reduction technology (SCR), which reduces NOx emissions by using a catalyst, reaching a reduction of up to 95% allowing to comply with the most demanding regulations currently in force (Tier III level) and operate in any zone of the world.
  Based on it each engine must be equipped in its exhaust system an element of this type, being the rest of the installation common for the different alternatives that are described in this section.

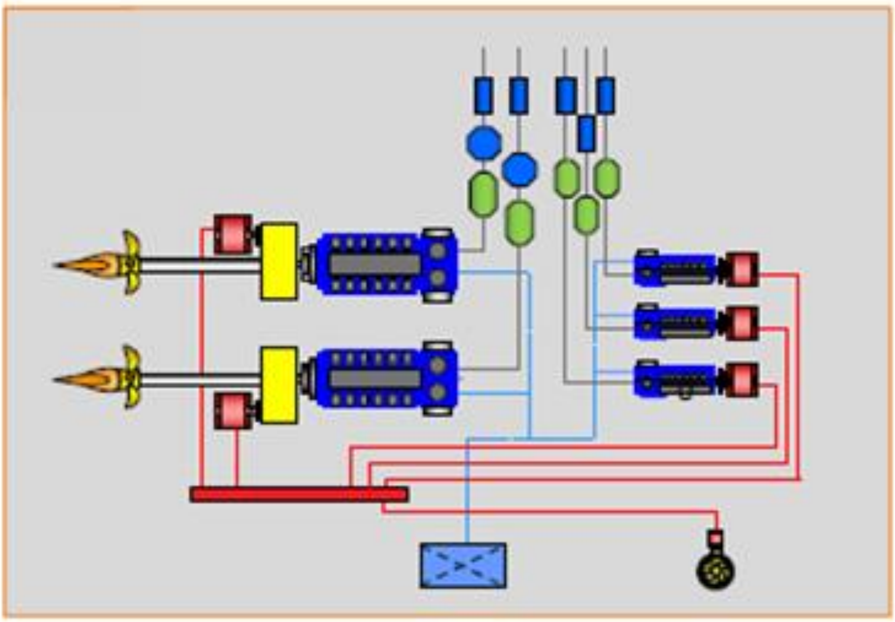


Figure 5. Scheme of a power plant for the use of MGO + SCR. Source: Wärtsilä

- HFO/MGO + emission reduction system (SCR and scrubber in HFO mode): This alternative provides the possibility of using HFO, which has a very significant impact on the reduction of operating costs of the ship, reducing in turn the emissions of sulphur practically to zero thanks to the system based on scrubbers. Operating with MGO the system will work as in the previous alternative using only the SCR system to comply with the Tier rules if being necessary. With the use of scrubbers the proportion of CO_2 does not decrease, in addition to generating new waste due to the use of this equipment that must be managed at the same time.

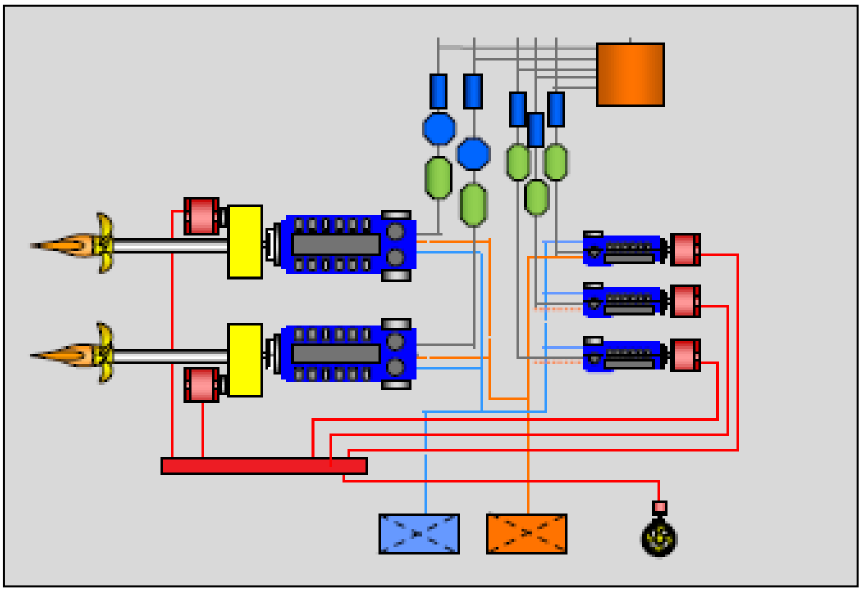


Figure 6. Scheme of the power plant for the use of HFO/MGO + Emission reduction systems (SCR/Scrubber). Source: Wärtsilä

- Use of LNG: The use of LNG on board can be introduced installing dual-fuel engines (DF): this type of engines has the possibility of operate with diverse types of fuel (HFO, MDO or LNG), offering longer service periods and longer component life than using only, for example, heavy fuels. With this type of configuration the installation of emission reduction systems can be avoided (SCR y scrubbers) as long as it is guaranteed that under any circumstance the vessels will not exceed the emissions limits established (two stroke high pressure engines do need additional equipment to comply with NOx), depending of the zone where they are navigating. An scheme of this configuration could be the following:

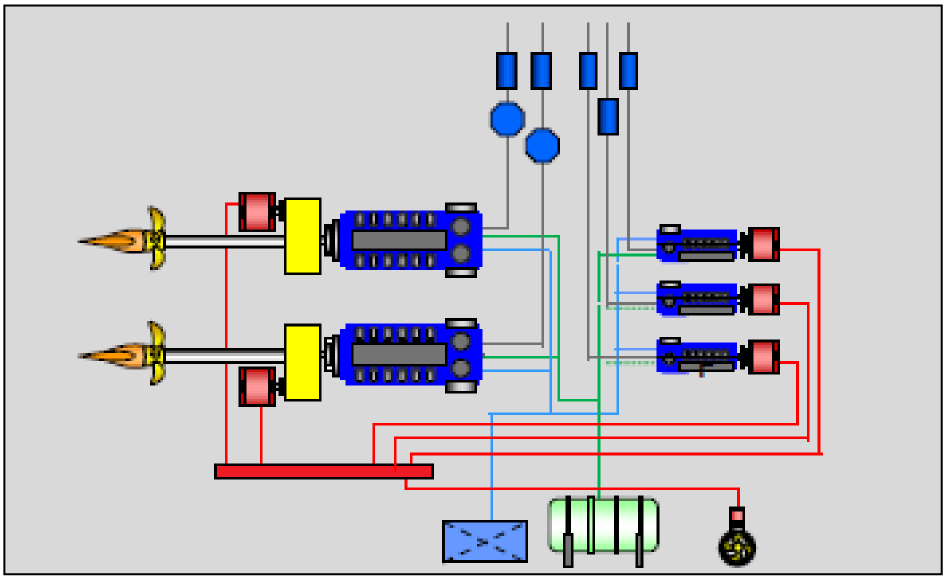


Figure 7. Scheme of the power plant for the use of liquid fuels and LNG. Source: Wärtislä

On the other hand, there is the option to opt for engines that only use gas as fuel. The combustion process of the gas-air mixture is generally in the Otto cycle, initiated by a spark plug. As main advantages are high energy efficiency, lower noise level and low pollutant emissions that comply with the IMO-Tier III levels in most engines of this type.
Based on it the option of install dual-fuel engines is considered as the most advantageous. In the following table are analysed the most important advantages/disadvantages of this configuration in comparison to the conventional technology:

Advantages	Disadvantages
• Do not require exhaust gas treatment: – No Scrubber – No SCR in general – No caustic soda/urea – No additional waste storage • Saving space and weight • Lower investment • Fuel selection flexibility • Intrinsic benefits of the LNG in terms of emissions	• Necessity to dispose a LNG intake on board (bunkering station) • Higher investment because of the higher number of equipment • Possible loss of space (to be evaluated in each case) • Refuelling time • Availability of refuelling pints in the port • Relation range/volume of LNG storage tanks • More frequent maintenance on a greater number of equipment • Regulatory requirements not compatible with compact vessel size

Table 2. Advantages and disadvantages on the use of dual-fuel engines.

Nowadays it seems that there is a clearly tendency in the market towards dual engine solution, due to the advantages it brings and the economy of use, this alternative is attractive from the point of view of ship owners and operators because it:

1. Complies with the emissions regulations
2. Usually uses a low pressure gas installation.
3. Provides flexibility in fuel usage: Natural Gas, MDO, MGO y HFO depending of the zone where the vessel is sailing, what finally have repercussions in a reduction of the operating cost depending on the operating profile.

2.3. Power Requirements

2.3.1 Current situation

The main characteristics of these ships whose viability is analysed in this document from the point of view of LNG utilization as an alternative fuel are summarized in the following table:

Vessel type	Length (m)	Breadth (m)	Depth (m)	Draught (m)	Bollard pull (tons)	Maximum speed (knots)	Fuel capacity (m^3)
SALVAMARES	15,0	3,8	1,1	0,8	---	30,0	2,0
	21,0	5,6	1,5	1,0	---	38,0	4,6
GUARDAMARES	31,0	7,5	3,35	1,34	20,0	27,0	18
TUG FOR HIGH-SEAS	40,0	12,5	5,8	4,8	60,0	13,0	315
MULTIPURPOSE VESSEL CAT. 1	56,0	15,0	7	5,9	128,5	15,8	588
MULTIPURPOSE VESSEL CAT. 2	80,0	18,0	8	6,6	228,0	17,5	1.520

Table 3. Summary of the operational characteristics of the vessels of SASEMAR fleet.

Taking as a frame of reference the European fleet dedicated to provide salvage, rescue and pollution control, the indicated ships correspond to the highest level regarding fleet modernity, thus incorporating the latest trends in design and applicable technology regarding to their types of ship and operational functions for which they have been designed and equipped.

In all the typologies of ships the power plants respond to conventional configurations based on engine-gearbox-propeller, independent auxiliary groups and, in the case of multipurpose vessels and ocean going tugs, PTOs coupled by gearboxes to the main engines in each of the two shaft lines they have.

In the following table are shown the characteristics of the main engines and the engines of the auxiliary group installed in each typology of the previous ships, through which they reach the speed and bollard pull performances indicated in the table above.

Main Engines				
Vessel type	**Model**	**nº**	**Unitary power (kW)**	**Total power (kW)**
SALVAMARES	CATERPILLAR 3412E (type 1)	2	1,044	2,088
	MTU 10V2000M92 (type 2)	2	1,015	2,030
GUARDAMARES	MTU 12V-4000M70	2	1,740	3,480
TUG FOR HIGH-SEAS	ABC 8DZC	2	1,872	3,744
MULTIPURPOSE VESSEL CAT. 1	MAK 8M32C	2	3,840	7,680
MULTIPURPOSE VESSEL CAT. 2	BERGEN DIESEL TYPE B32:40L8P	4	4,000	16,000

Table 4. Summary of the characteristics of the main engines of the SASEMAR fleet vessels.

Auxiliary Engines				
Vessel type	**Model**	**nº**	**Unitary power (kW)**	**Total power (kW)**
SALVAMARES	Cummins Onan MDKWB-5732263	1	6	6
	Cummins Onan 9.5 MDKM-5872D	1	7	7
GUARDAMARES	John Deere 6068TFM	2	89	178
TUG FOR HIGH-SEAS	VOLVO D9 MG-KC	2	239	478
MULTIPURPOSE VESSEL CAT. 1	CAT 3508-B	2	856	1,712
MULTIPURPOSE VESSEL CAT. 2	VOLVO PENTA Gen Set	2	1,500	3,000

Table 5. Summary of the characteristics of the auxiliary engines of the SASEMAR fleet vessels.

The objective of this first block of the study is to evaluate the possibility of having dual-fuel engines, capable of consume both conventional fuels (CF) and LNG, for substitute the main engines and the auxiliary groups of the different ships. All in order to provide the different units with an additional range to what they currently have, providing them with ability to consume LNG as alternative fuel during a certain time in all its operational profile.

2.3.2 Dual-fuel engines alternatives

Dual-fuel engines are those who are able to work with natural gas and liquid fuels heavy fuel oil or marine diesel oil for this study. This technology is not new since it has been used on gas vessels for a long time, in order to take advantage of the losses due to evaporation of the cargo that suffered the tanks of these ships during normal operation.

Nowadays the low prices of natural gas in addition to the regulatory restrictions on pollutant emissions in certain navigation areas have made this technology applicable to ships of all kinds, trying engine manufacturers to perfect the technology to comply with the emission requirements, also using the smallest amount of diesel possible keeping the efficiency. As for Dual fuel engine to operate with gas it is necessary a specific injection system and the change on the synchronization of the combustion and the proportion air-fuel. Although the dual-fuel technology could facilitate a transition to natural gas, the significantly higher cost of the natural gas engines and the actual lack of fuel supplying infrastructure will make the generalized change slow down.

Based on the power data of the main and auxiliary engines of the current SASEMAR fleet, it is proceed to search an engine with dual-fuel technology, allowing the consumption of conventional fuels and LNG. For these they have been analysed the currently available catalogue of the main manufacturers of dual-fuel marine engines, in particular of the following brands:

- ANGLO BELGIAN CORPORATION (ABC)
- CAT & MAK (CATERPILLAR POWER PLANTS)
- MAN DIESEL & TURBO
- MTU FRIEDRICHSHAFEN
- WÄRTSILÄ
- GUASCOR

The criterion of selection of engine alternatives with dual-fuel technology has been based on the search of marine units with equivalent power ranges with respect to the units currently installed in each type of vessel, in order not to vary the configuration of the power plants. The main characteristics of the engines, both for the case of the preselected main engines and the auxiliary groups are shown in the following table:

Main Engines (Selected Dual-fuel Alternatives)				
Vessel type	**Model**	**nº**	**Unitary power (kW)**	**Total power (kW)**
SALVAMARES	Wärtsilä 20DF 6L20DF	2	1,110	2,220
GUARDAMARES	ABC 12DZD	2	2,000	4,000
TUG FOR HIGH-SEAS	ABC 12DZD	2	2,000	4,000
MULTIPURPOSE VESSEL CAT. 1	Wärtsilä 34DF 8L34DF	2	4,000	8,000
MULTIPURPOSE VESSEL CAT. 2	Wärtsilä 34DF 8L34DF	4	4,000	16,000

Table 6. Summary of the characteristics of the selected dual-fuel alternatives for the main engines.

In relation with the engines associated to the auxiliary groups, the search for dual-fuel engine alternatives has yielded the following results:

Auxiliary Engines (Selected Dual-fuel Alternatives)				
Vessel Type	**MODEL**	**nº**	**Unitary power (kW)**	**Total power (kW)**
SALVAMARES	No alternatives found			
GUARDAMARES	No alternatives found			
TUG FOR HIGH-SEAS	No alternatives found			
MULTIPURPOSE VESSEL CAT. 1	Wärtsilä 20DF 6L20DF generating set	2	960	1,920
MULTIPURPOSE VESSEL CAT. 2	Wärtsilä 20DF 9L20DF generating set	2	1,440	2,880

Table 7. Summary of the characteristics of the selected dual-fuel alternatives for the auxiliary engines.

As can be seen in the table, for the SALVAMARES, GUARDAMARES and HIGH SEAS TUG cases, no marine engines with dual-fuel technology and a power equivalent to the ones that are currently installed have been found. For this reason, for this type of ships can only be considered within the study that the main engines will only be able to consume LNG.

In the case of MULTIPURPOSE VESSELS, the engine associated to the auxiliary group that has been found in the market with similar power, is the model WÄRTSILÄ 9L20DF, that has a power slightly lower than the groups currently installed, of the order of 40-60 kW. Taking into account that this difference is very small, it is considered convenient the selection of this WÄRTSILÄ model, instead of selecting a higher power group.

With all this and to conclude this point it follows that it seems viable the installation of dual-fuel technology both as main engines and auxiliary groups in the two categories of multipurpose vessels due to the configuration of their power plants and the possibilities offered by the market with respect to this type of engines. In the other side, dual-fuel alternatives have been found to integrate them as main engines in the categories SALVAMARES, GUARDAMARES and HIGH SEAS TUG, finding no dual-fuel alternatives to integrate them as auxiliary engines.

It must be taken into account that only the power of each of the engines currently installed has been used as selection criteria, although not considering other very important aspects for the integration of a new engine on a ship such as, among others, the nominal revolutions and the elements and auxiliary services needed for the running of the engine, which must be analysed in later phases of the study in order to ascertain the feasibility of its installation on the different vessels.

The following table summarizes the conclusions that have been reached in this first block, indicating also the alternatives found to replace the existing engines in each one of the ships by units that integrate the dual-fuel technology.

Power Requirements (Dual-fuel Engines Installation)		
Vessel type	Main engines	Auxiliary engines
SALVAMARES	Wärtsilä 20DF 6L20DF	No alternative found
GUARDAMARES	ABC 12DZD	No alternative found
TUG FOR HIGH-SEAS	ABC 12DZD	No alternative found
MULTIPURPOSE VESSEL CAT. 1	Wärtsilä 34DF 8L34DF	Wärtsilä 20DF 6L20DF generating set
MULTIPURPOSE VESSEL CAT. 2	Wärtsilä 34DF 8L34DF	WÄrtsilä 20DF 9L20DF generating set

Table 8. Feasibility analysis on the availability of dual-fuel alternatives.

2.4. Range Requirements

2.4.1 Current situation

The types of vessel studied have the following capacity of liquid fuel derived from petroleum and a range at the 80% of the installed power:

Vessel type	Fuel capacity (m^3)	Range at 80% of nominal power (miles)
SALVAMARES	2 and 4,6	300 / 400
GUARDAMARES	18	1,300
TUG FOR HIGH-SEAS	315	6,000
MULTIPURPOSE VESSEL CAT. 1	588	5,230
MULTIPURPOSE VESSEL CAT. 2	1,520	8,143

Table 9. Fuel capacity and range at the 80% of nominal power of the SASEMAR vessels

All of this based on the next table of consumption as a function on the power regime in which each unit is:

Vessel type	MULTIPURPOSE VESSEL CATEGORY 1		MULTIPURPOSE VESSEL CATEGORY 2		HIGH SEAS TUG		GUARDAMARES		SALVAMARES (21m)		SALVAMARES (15m)	
RPM%	V (kn)	Diesel Oil Consumption (l/h)	V (kn)	Diesel Oil Consumption (l/h)	V (kn)	Diesel Oil Consumption (l/h)	V (kn)	Diesel Oil Consumption (l/h)	V (kn)	Diesel Oil Consumption (l/h)	V (kn)	Diesel Oil Consumption (l/h)
100% RESCUE OPERATION	17.00	4,000.00	15.50	1,608.00	13.00	935.00	30.00	875.00	31.33	519.00	24.87	201.00
75%	14.00	2,500.00	12.00	960.00	10.00	445.00	23.30	572.50	25.03	412.50	18.47	132.80
50%	14.00	1,602.00	8.00	848.00	6.00	189.00	18.10	380.00	18.93	268.45	12.07	73.33
25%	5.20	630.00	5.00	475.00	3.29	131.29	9.20	135.00	9.85	80.00	7.93	34.00
SURVEILLANCE MODE	5.20	630.00	5.00	475.00	6.00	380.00	11.45	162.50	16.91	239.63	14.90	101.73

Table 10. Speed and consumes of the different types of ship in function of the main engines regime.

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2.4.2 Calculation of LNG capacity to achieve the required range

As indicated in the beginning of these document, for the calculation of the LNG needed capacity in each type of ship it will be evaluated in this section the possibility of increase the range of each type of vessel in 10%, 25% and 50% by the integration of the dual-fuel technology in the salvage and anti-pollution units, keeping therefore the actual capacity for liquid fuel derived from petroleum in each one of the units under study.

For this purpose it will be carried out a preliminary calculation of the volume of LNG to be stored on each vessel to have an additional range equivalent to the 10% of the conventional fuel range (CF) at 80% of the nominal power of the main engines and the generator groups, and in the same way two more cases equivalent to 25% and 50% of the range of conventional fuel, also to the 80% of the nominal power of the engines installed on board.

Since the characteristics of the installed engines are known by the data provided by the manufacturer, in first place it is calculated the conventional fuel consume for each motor at 80% of nominal power.

Vessel type	% Nominal power	Nº of engines	Unitary power (kW)	Total consumption, CF (l/h)
SALVAMARES (motorization type 1)	80%	2	1,044	392.80
SALVAMARES (motorization type 2)	80%	2	1,015	410.78
GUARDAMARES	80%	2	1,740	658.33
TUG FOR HIGH-SEAS	80%	2	1,872	680.09
MULTIPURPOSE VESSEL CAT. 1	80%	2	3,840	1,279.40
MULTIPURPOSE VESSEL CAT. 2	80%	4	4,000	2,770.82

Table 11. Calculation of the total consume of the main engines at 80% of nominal power.

In the case of the auxiliary groups, it is necessary consider that for some cases no alternative with dual-fuel technology have been found, so it can not be taken into account for the calculation of the LNG capacity. On the basis of this the following results are obtained:

Vessel type	% Nominal power	Nº of engines	Unitary power (kW)	Total consumption, CF (l/h)
SALVAMARES	*Not taken in account the consumption of the auxiliary groups in these types of ship for the calculation of the needed LNG volume, since there have not been found dual-fuel engines of equivalent power or their adaptation to the use of LNG.*			
GUARDAMARES				
TUG FOR HIGH-SEAS				
MULTIPURPOSE VESSEL CAT. 1	80%	2	768	177.09
MULTIPURPOSE VESSEL CAT. 2	80%	4	1,500	581.65

Table 12. Calculation of the total consume of the auxiliary engines at 80% of nominal power.

Therefore, the total consumes of conventional fuel of each tipology of ship in study, are the result of the sum of main and auxiliary engines consume:

Vessel type	Consumption, CL MMEE (l/h)	Consumption, CL AAEE (l/h)	Total consumption, CF (l/h)
SALVAMARES (motorization type 1)	392.80	n/a	392.80
SALVAMARES (motorization type 2)	410.78	n/a	410.78
GUARDAMARES	658.33	n/a	658.33
TUG FOR HIGH-SEAS	680.09	n/a	680.09
MULTIPURPOSE VESSEL CAT. 1	1,279.40	177.09	1,456.49
MULTIPURPOSE VESSEL CAT. 2	2,770.82	581.65	3,352.47

Table 13. Calculation of the total consume of fuel at 80% of nominal power.

Considering the volume of fuel which the different categories of ships currently have, it is determined below the range at 80% of nominal power of the installed engines in each case with the possibility of an adaptation to the dual-fuel technology:

Vessel type	Total consumption, CL (l/h)	Volume CF (l)	Range (h)
SALVAMARES (motorization type 1)	392.80	2,000	5.09
		4,600 [1]	11.71
SALVAMARES (motorization type 2)	410.78	2,000	4.87
		4,600	11.20
GUARDAMARES	658.33	18,000	27.34
TUG FOR HIGH-SEAS	680.09	315,000	463.18
MULTIPURPOSE VESSEL CAT. 1	1,456.49	588,000	403.71
MULTIPURPOSE VESSEL CAT. 2	3,352.47	1,520,000	453.40

Table 14. Conventional fuel range, in hours, at 80% of nominal power.

[1] The two types of motorizations (type1 and type 2) are studied for the volumes of storage of the SALVAMARES of 15 m (2 m^3) and 21 m (4,6 m^3).

Therefore, the requirements of range used for the calculation of the required volume of LNG are:

Vessel type	Range LNG (h) (10% CF)	Range LNG (h) (25% CF)	Range LNG (h) (50 % CF)
SALVAMARES (motorization type 1)	0.51	1.27	2.55
	1.17	2.93	5.86
SALVAMARES (motorization type 2)	0.49	1.22	2.43
	1.12	2.80	5.60
GUARDAMARES	2.73	6.84	13.67
TUG FOR HIGH-SEAS	46.32	115.80	231.59
MULTIPURPOSE VESSEL CAT. 1	40.37	100.92	201.86
MULTIPURPOSE VESSEL CAT. 2	45.34	113.35	226.70

Table 15. Calculation of the LNG range requirements.

For the calculation of the necessary volume of LNG to satisfy the range conditions determined in the previous table, firstly the LNG consumption must be calculated, taking into account the specific heat of the natural gas, the volumetric ratio between the LNG and the natural gas in gaseous state, the power of each engine and a regime of nominal power of the 80% in every case. Following this criteria, in the following tables are shown the data obtained for the main and auxiliary engines:

Vessel type	Dual-fuel engine type	nº	Unitary power (kW)	Total power (kW)	Natural gas engine consumption, ISO standard conditions[2] (m^3/h)
SALVAMARES (motorization type 1)	Wärtsilä 20DF 6L20DF	2	1,110	2,220	289.76
SALVAMARES (motorization type 2)	Wärtsilä 20DF 6L20DF	2	1,110	2,220	289.76
GUARDAMARES	ABC 12DZD	2	2,000	4,000	380.22
TUG FOR HIGH-SEAS	ABC 12DZD	2	2,000	4,000	380.22
MULTIPURPOSE VESSEL CAT. 1	Wärtsilä 34DF 8L34DF	2	4,000	8,000	931.89
MULTIPURPOSE VESSEL CAT. 2	Wärtsilä 34DF 8L34DF	4	4,000	16,000	931.89

Table 16. Calculation of the consumption of natural gas in the main engines.

[2] The ISO conditions correspond to T=25ºC and P=101.3 kPa.

Vessel type	Dual-fuel engine type	nº	Unitary power (kW)	Total power (kW)	Natural gas engine consumption, ISO standard conditions (m^3/h)
SALVAMARES	*Not taken in account the consumption of the auxiliary groups in these types of ship for the calculation of the needed LNG volume, since there have not been found dual-fuel engines of equivalent power or their adaptation to the use of LNG.*				
GUARDAMARES					
TUG FOR HIGH-SEAS					
MULTIPURPOSE VESSEL CAT. 1	Wärtsilä 20DF 9L20DF generating set	2	1,440	2,880	367.37
MULTIPURPOSE VESSEL CAT. 2	Wärtsilä 20DF 9L20DF generating set	2	1,440	2,880	367.37

Table 17. Calculation of the consumption of natural gas in the auxiliary groups.

In the above tables, the consumption of natural gas under standard ISO conditions corresponds to natural gas in the gaseous state, at 80% MCR. To know the natural gas in an equivalent liquid state, it is necessary to multiply these results by the ratio between the liquid and gaseous state of the natural gas, which is 1/600. Taking into account that the natural gas is stored in a liquid state, we must make this equivalence to know the volume that is necessary to dispose in the tanks.

Vessel type	Dual-fuel engine type	Natural gas engine consumption, ISO standard conditions (m^3/h)	Natural gas in liquid state engine consumption (m^3/h)	Nº of engines	Total consumption of LNG at 80% nominal power (m^3/h)
SALVAMARES (motorization type 1)	Wärtsilä 20DF 6L20DF	289.76	0.48	2	0.97
SALVAMARES (motorization type 2)	Wärtsilä 20DF 6L20DF	289.76	0.48	2	0.97
GUARDAMARES	ABC 12DZD	380.22	0.63	2	1.27
TUG FOR HIGH-SEAS	ABC 12DZD	380.22	0.63	2	1.27
MULTIPURPOSE VESSEL CAT. 1	Wärtsilä 34DF 8L34DF	931.89	1.55	2	3.11
MULTIPURPOSE VESSEL CAT. 2	Wärtsilä 34DF 8L34DF	931.89	1.55	4	6.21

Table 18. Calculation of the consumption of LNG of the main engines at 80% of nominal power (dual-fuel alternative).

Vessel type	Dual-fuel engine type	Natural gas engine consumption, ISO standard conditions (m^3/h)	Natural gas in liquid state engine consumption (m^3/h)	Nº of engines	Total consumption of LNG at 80% nominal power (m^3/h)
SALVAMARES	*Not taken in account the consumption of the auxiliary groups in these types of ship for the calculation of the needed LNG volume, since there have not been found dual-fuel engines of equivalent power or their adaptation to the use of LNG.*				
GUARDAMARES					
TUG FOR HIGH-SEAS					
MULTIPURPOSE VESSEL CAT. 1	Wärtsilä 20DF 9L20DF generating set	367.37	0.61	2	1.22
MULTIPURPOSE VESSEL CAT. 2	Wärtsilä 20DF 9L20DF generating set	367.37	0.61	2	1.22

Table 19. Calculation of the consumption of LNG of the auxiliary engines at 80% of nominal power (dual-fuel alternative).

With the consumption data obtained, and the range requirements for the three assumptions studied (10%, 25% and 50%), it is calculated the net volume of LNG that would be needed to be carried on board each units to comply with the requirement of increase the 10%, 25% and 50% of range with respect to the current capacities using conventional fuels, obtaining the following results shown in the table:

Vessel type	Total consumption of LNG at 80% nominal power (m^3/h)	LNG volume (m^3)		
		10 %	25 %	50 %
SALVAMARES (motorization type 1)	0.97	0.49	1.23	2.46
		1.13	2.83	5.66
SALVAMARES (motorization type 2)	0.97	0.47	1.18	2.35
		1.08	2.70	5.41
GUARDAMARES	1.27	3.47	8.67	17.33
HIGH SEAS TUG	1.27	58.70	146.76	293.52
MULTIPURPOSE CATEGORY 1	4.33	137.41	343.52	687.04
MULTIPURPOSE CATEGORY 2	7.44	337.200	843.00	1,686.00

Table 20. LNG capacity to reach an range increase of 10%, 25% and 50%.

Regarding the LNG volume values obtained it is considered as excessive the capacity resulting from the additional 50% of LNG range for all types of vessels. In the case of HIGH SEAS TUG and MULTIPURPOSE vessels (categories 1 and 2) even the capacity required for reach an increase of 25% of range is considered very high.

These aspects will be analysed in more detail in the item corresponding to the sizing of equipment, where the dimensions of an LNG tank are taken into account in relation to the necessary net volume of LNG, starting from the data obtained in this section. On the basis of all this, a summary table with the first viability results of this point is included below:

Vessel type	LNG net volume needed to increase a percentage the current range of each type of vessel (m^3)		
	10 %	25 %	50 %
SALVAMARES	0.49 / 1.13	1.18 / 2.83	2.35 / 5.66
GUARDAMARES	3.47	8.67	17.33
TUG FOR HIGH-SEAS	58.70	146.76	293.52
MULTIPURPOSE VESSEL CAT. 1	137.41	343.52	687.04
MULTIPURPOSE VESSEL CAT. 2	337.200	843.00	1,686.00

Table 21. Preliminary analysis of the feasibility of the installation of tanks for a certain increment of the currently range of the SASEMAR units.

2.5. LNG Logistics Chain (Response Time)

One of the most important aspects when assessing the viability of the use of natural gas on ships is the analysis of supplying alternatives within their areas of operation. Nowadays, there are four options regarding the supply of LNG to ships, the main aspects of each of them are briefly discussed below:

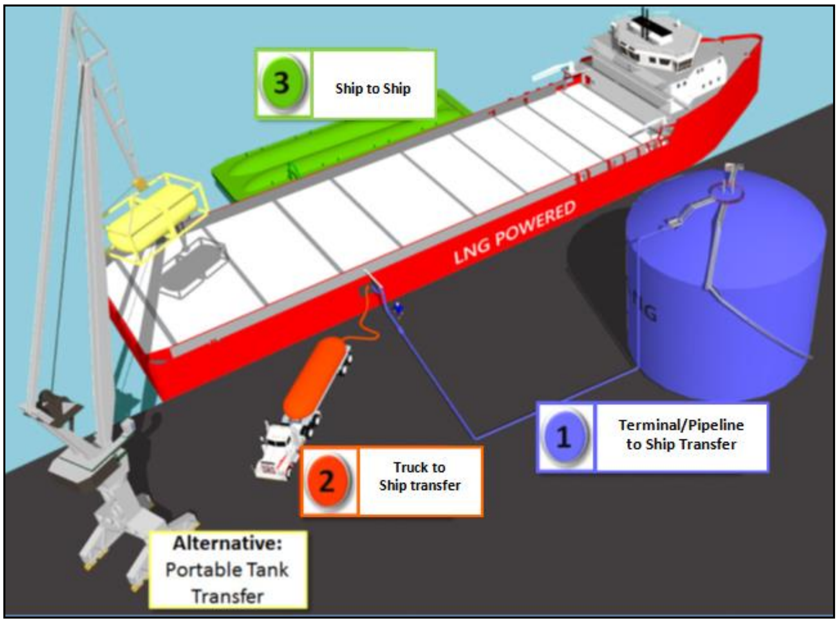


Figure 8. Current available options for carrying out the LNG bunkering operation on shisp. Source: Mobile LNG Pty Ltd (MLNG)

- Option 1: Supply by land bunkering - TPS ("Terminal/Pipeline to Ship Transfer"): The ships arrive at a shoreline facility designed to supply LNG as a fuel for ships. Fixed cranes and arms dedicated to bunkering are used for the management of fuel supply hoses, and their connection to the ship is made by the use of manifolds.
  It should be noted that the gas supply operation must comply with certain procedural and hazardous area regulations and can therefore significantly affect the normal operation of ships in port.
  The advantages of this method of supply compared to the other options lie in the availability and possibility of supplying large volumes of LNG, as well as a fast fuelling process. The main disadvantages are a high infrastructure cost, a dedicated area that obliges the ships to always dock in the same zone which can lead to problems of occupation of the pier or to move the vessel between two berths and also a detailed study of the hazardous zones in the dock.

- Option 2: Supply by tanker trucks - TST ("Truck Ship Transfer"): It simply consists of the use of a tanker truck. The mobile installation arrives at its location and through the use of hoses connects to the ship moored in the dock.

  Regarding the TPS operation, this option coincides with the limitations of the need to enter the port to perform the bunkering operation and the detailed study of the dangerous zones in the port.

  This option represents a great advantage as far as flexibility and operation costs and investment is concerned, however, this alternative represents a big problem in the capacity of the cisterns. This limitation has an increase in time when having to carry out the supply operation with more than one truck. On average, it is estimated that the time (compared to the supply at a land terminal) will increase in 2.5 hours, although of course it will depend on the volume of LNG that needs to be supplied.

Figure 9. Examples of TST LNG bunkering operations.

- Option 3: Supply by ship to ship - STS ("Ship to Ship"): It consists of carrying out the bunkering operation by a LNG supply vessel that is rigged to the ship to be supplied, thanks to this type of supply a vessel can perform the bunkering operation both in and out of port.

Figure 10. Examples of STS LNG bunkering operations.

The main limitation to apply this process is the lack of ships that actually realize these services in the coasts of Spain, although there are several ships under construction in Spanish shipyard that will solve this deficiency.

This way of supply has the advantage of providing a higher flexibility, allowing the supply of larger volumes of cargo than a tanker truck, and a high loading speed, in addition to allowing the possibility of supplying the fuel on the high seas without the need for the vessel to enter to port, which is a substantial operational advantage over other systems. The main disadvantages are that the supply vessel is very expensive and there may be supply limitations due to the position of the relative manifold of the two ships and the length.

- Option 4: Supply by standard containers - CTS ("Container to Ship"): There is a fourth alternative consisting of the use of standard LNG tanks that can be installed/uninstalled from ships in a fast a simple way. The process consists in replacing at the port the empty tank of the vessel with a previously filled one in a LNG terminal, for which is simply needed a simple crane that allows the handling of these containers.

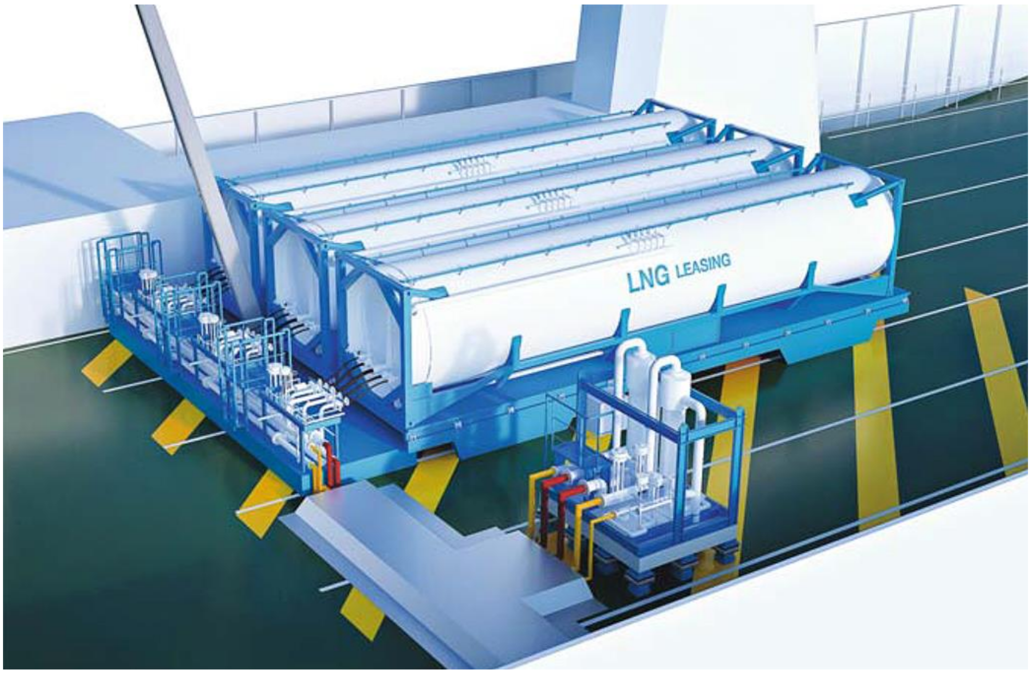


Figure 11. Standard tanks installed on deck.

Nowadays it does not exist infrastructure or companies in the Spanish ports that realizes this kind of bunkering services, and also it is necessary to enter in port in order to realize the operation as it happened in the options TPS and TST.
From the point of view of time for small volumes is considered an optimal solution since the supply process can be done in less than an hour and also the necessary means to dispose in port are very simple and economic once the infrastructure of logistics of standardized containers is created. The main drawbacks are that there are certain risks of impact on the movement of tanks as well as the connection/disconnection operation and the need to develop specific ship designs for this concept, since the LNG tankers as well as their connections to the distribution system, must be easily accessible from the outside in order to be able to perform the bunkering operation quickly and safely.

Below it can be seen a table summarizing the advantages and disadvantages of each of the available alternatives:

Way of supply	Advantages	Disadvantages
TPS (Terminal/Pipeline to Ship)	• Availability • Large volumes • Short time of fuel intake	• High infrastructure costs • Dedicated zone in the port • Need to move the ship between two docks • Detailed study of dangerous zones • Need to enter to port
TTS (Tanker Truck to Ship)	• Flexibility • Low infrastructure costs	• Small volumes • Increase of the bunkering operation time • Need to enter to port
STS (Ship To Ship)	• Flexibility • Large volumes • Short time of fuel intake without the need to enter to port	• High infrastructure costs • Possible limitations regarding the position of the manifold relative to both ships • Possible problems of manoeuvrability in the port
CTS (Container To Ship)	• Short time for small volumes • Low infrastructure costs	• Lack of actual infrastructure • Adaptation of the ship design • Risk of impact when moving the tanks and connect/disconnect the system • Need to install the tanks in accessible zones of the vessel

Table 22. Summary of the advantages and disadvantages of the different types of LNG bunkering processes.

2.5.1 Response time

The SASEMAR fleet is distributed throughout the entire coastal territory of Spain as indicated schematically in the following image:

Figure 12. Distribution of the SASEMAR units throughout the Spanish coasts.

The bunkering needs of these vessels are currently covered by the supply points distributed by the different ports, which allows to comply with the current service parameters imposed for each of the units.

In relation to the response times are immediate, i.e. when receiving the call of the rescue tower must start the engines and go immediately to the emergency point so that the fuel tanks must be prepared with sufficient foresight to respond immediately. In relation to the quick intervention units (SALVAMARES) the overnight time is established in approximately 20 minutes.

2.5.2 Available infrastructure in Spain

Currently in Spain the only option to reach all the base points where SASEMAR has ships is by tanker truck, which should be loaded in any of the 6 actually active plants and the consequent movement to the various vessels by road. Based on this data it has been elaborated the following graph where are shown all the units and the estimated response time that a truck could take from the consequent warning from the ship.

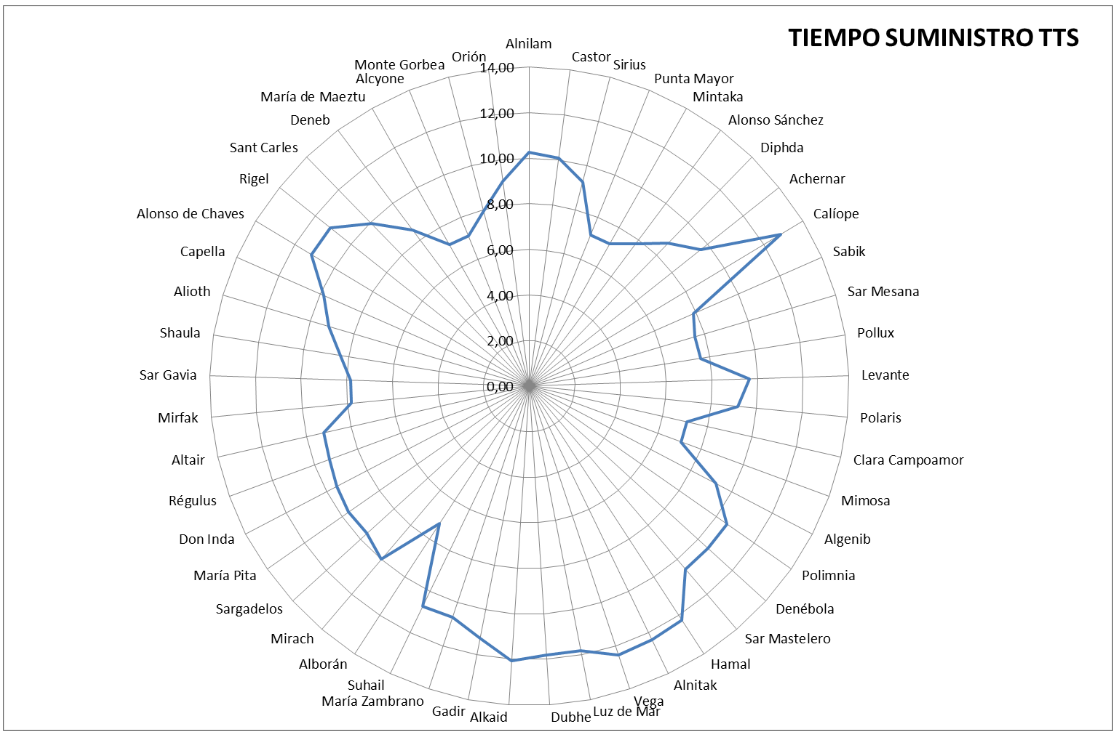


Figure 13. Units and the estimated response time that a truck could take from the consequent warning from the ship.

As a final conclusion to this section it is established the following viability analysis for each one of the typologies of vessels under study regarding each alternative for the bunkering realization, taking into account the present available infrastructure in Spain:

LNG bunkering supply requirements – Present logistics chain in Spain				
Vessel type	Supply by tanker trucks (TTS)	Supply by bunkering vessels (STS)	Supply by terminals or fixed supply points on land (TPS)	Supply by standard containers (CTS)
SALVAMARES				
GUARDAMARES				
TUG FOR HIGH-SEAS				
MULTIPURPOSE VESSEL CAT. 1				
MULTIPURPOSE VESSEL CAT. 2				

Table 23. Feasibility analysis on the bunkering alternatives regarding the vessel type. (See page 19).

2.6. LNG Technology Integration

2.6.1 Main equipment associated with the use of LNG in ships

The installation of a power plant with LNG as fuel makes it necessary to adapt the design of the ship to a specific set of needs, having to install equipment and arrange spaces that would not be necessary in case of a conventional propulsion.

A basic scheme of the layout of the main equipment that take part in the reception system (Bunkering Station "BS"), filling, treatment (Tank Connection Space "TCS" and Gas Valve Unit "GVU") and consumption by the LNG engine is shown below:

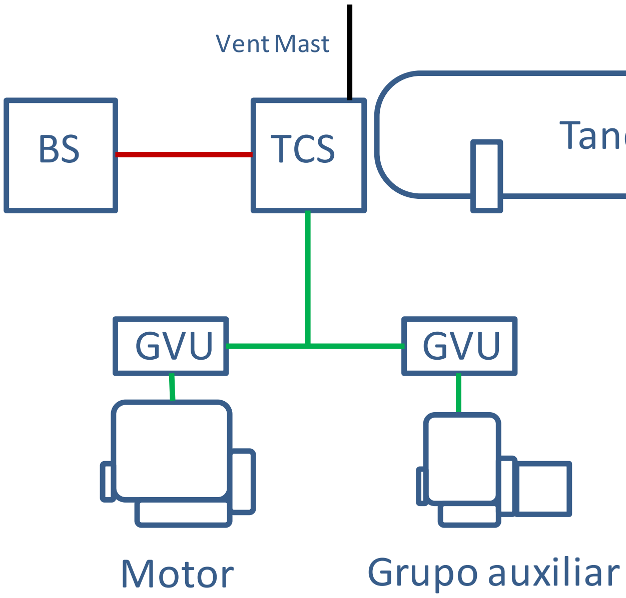


Figure 14. Basic scheme of the main equipment of the installation for the use of LNG on ships.

A more detailed scheme is shown below:

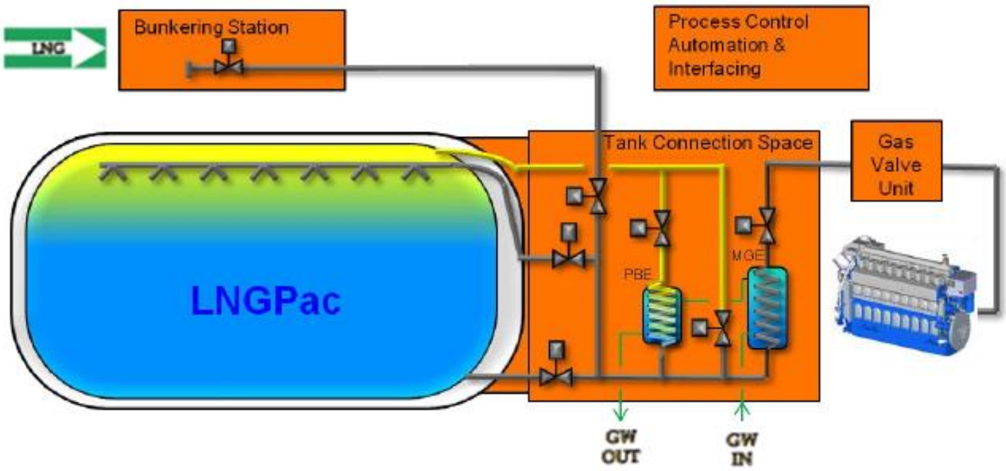


Figure 15. Scheme of the main equipment for the use of LNG on ships. Source: Wärtsilä

The storage tank is filled with LNG through the bunkering station. This LNG will be evaporated in the MGE (Main Gas Evaporator), located in the Tank Connection Space and lead to the engines for its fuelling, being the pressure controlled in the tank by the evaporator PBE (Pressure Build-up Evaporator). The evaporation of LNG is achieved by a system that works through a mixture of water and glycol (GW).

Below are briefly described the systems and main equipment of the LNG system, which includes the phases of reception, filling of tanks, processing and engine fuelling.

2.6.1.1 Tanks

There are different types of available tanks for the LNG storage on board ships, classified the types of systems defined by the IMO, which are shown below:

<u>Structural tanks</u>

Structural tanks are part of the structure of the vessel hull and are subjected in the same way as the adjacent structure of the ship to the effort imposed by the loads acting on it.

<u>Membrane tanks</u>

Membrane tanks are those that do not have self-support and are formed by a thin layer (membrane) to which, through the insulation, supports the adjacent structure of the hull. The membrane has been designed so that the thermal and other types of dilations and contractions are compensated without this imposing an excessive effort.

Semi membrane tanks

Semi membrane tanks are those that do not have self-support when containing cargo and are formed by a layer to some of whose parts support, through its insulation, the adjacent structure of the hull. Its rounded parts, that join said parts with the support, have been designed to also accept the thermal and any other types of dilations and contractions.

Independent tanks

Independent tanks are self-sustaining tanks that do not form part of the vessel hull and are not essential to the strength of the hull. Three types can be distinguished:

- Independent tanks type A: Those which are designed primary in accordance with recognized standards of classical methods of structural analysis of the ship. When these tanks consist mainly of flat surfaces (gravity tanks), the designed vapour pressure must be lower than 0.7 bar.
- Independent tanks type B: Those designed with the help of test models and advanced instruments and analytical methods to determine stress levels, fatigue strength and crack propagation characteristics. When these tanks are built mainly with flat surfaces (gravity tanks), the draft vapour pressure must be lower than 0.7 bar.
- Independent tanks type C: Also called pressure containers and whose vapour pressure is not lower than 2 bar.

Below is shown, schematically, the main advantages and disadvantages which are derived from the installation of each of these types of tanks:

Tank type	Advantages	Disadvantages
Structural	Maximum use of the cargo volume: Being tanks that are part of the hull structure, they adapt to the geometry of it and optimize the existing cargo volume.	Low design pressure: lower than 0.25 bar, although increasing the scantlings of the hull, could increase that value, always being kept lower than 0.7 bar. Boiling point of the cargo: The structural tanks may be used for the transport of products, if the boiling point of the cargo is not lower than -10 ºC.
Membrane or semi membrane	Maximum use of the cargo volume: Being tanks that are part of the hull structure, they adapt to the geometry of it and optimize the existing cargo volume.	Low design pressure: lower than 0.25 bar, although increasing the hull scantlings it could be increased, always keeping it under 0.7 bar.
Independent type A	Maximum use of the cargo volume: Can be adapted to the forms of the hull.	The design pressure must be kept lower than 0.7 bar The venting system is very voluminous due the low pressure that must be kept
Independent type B	Maximum use of the cargo volume: Can be adapted to the forms of the hull.	The design pressure must be kept lower than 0.7 bar The venting system is very voluminous due the low pressure that must be kept
Independent type C	Possibility of mounting outdoors without having to place it in a confined space: The same external structure of the tank that forms the secondary barrier with the inner chamber, is the structure that limits the tank from the ourside. Ability to withstand pressure increases: The rest of tanks work in pressure ranges below 0.7 bar, while types C allow higher pressures. No need of maintenance and no possibility of leaks	Poor use of space on board: This aspect is very important for ships carrying the tank integrated in the structure, as they allow to adapt to the geometry of the structure and optimize the use of cargo volume. Limitation of storage capacity: Nowadays, this type of tanks are manufactured in semi-series with a capacity range of up to 500-700 m^3, and working pressures up to 10 bar. The volume of the required space is between 3-4 times more than for the case of MGO or MDO

Table 24. Summary of advantages and disadvantages of the installation of tanks depending on the different types.

Based on the above, it is considered that the tank type C option is the best alternative for the vessels under study and it is the alternative that is being used nowadays in the projects of this type, this mainly due to the following causes:

- Due to their nature, they are small in size. The fact that this type C can be arranged both indoors and outdoors allows a great versatility and alternatives when designing a new construction or to make a transformation of a current unit.
- Taking into account that the stored LNG is going to be used only to self-consumption, and not to transport or provision as in the case of other type of vessels, the negative aspect of poor utilization of cargo capacity is not applicable in this situation, although space for the development of other functions is lost. For the same reason above, the advantage of the maximum utilization of the cargo in other types of tanks do not bring any positive aspect in this case.
- The type C tanks are capable of withstand pressure increases. This characteristic allows maintaining the tank with load and no consumption, while more than 15 days without significative boil-off generation.
- It is not necessary a high maintenance and there is no possibility of gas leaks, so it is a tanks whit a high safety factor.
- The storage tanks of type IMO C have double walls, vacuum insulation and perlite. The space between the double walls is where the insulation is arranged. Both the inside and the outside of the tank are made of stainless steel, and a vacuum safety device is provided on the outer plate to prevent any accumulation of pressure between the two plates. This vacuum system of the tank has two connections, one to provide vacuum and another to its measure.
-

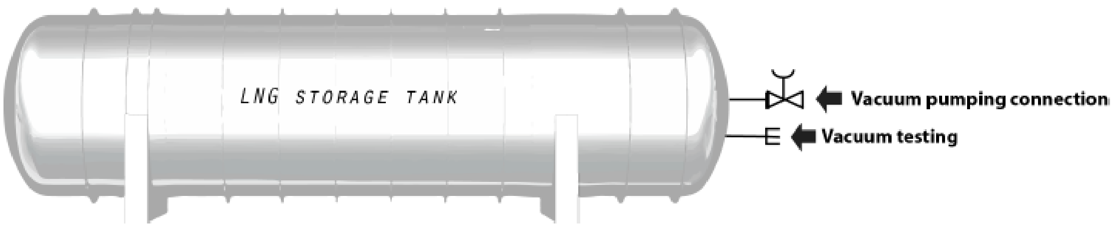


Figure 16. Scheme of the connexions for type C tanks.

In addition to the vacuum insulation, it can also be provided in this a polyurethane barrier.

- From the regulatory point of view, the requirements imposed by the different standards are much less demanding for this type of tanks since they inherently carry a higher level of safety and therefore a lower level of risk of accidents.
- Possibility of having custom tanks, adapting the designs to the available space in each unit, although of course this alternative would increase the cost with respect to designs of tanks of standard dimensions.

1.1.1.1. Tank connection space (TCS)

All equipment and systems for normal operation and LNG processing are installed inside the TCS. It is a closed, gas-tight enclosure, with independent ventilation from the other spaces, made of stainless steel, which acts as a second barrier in a way that prevents a possible LNG leak from affecting the hull of the vessel.

The equipment installed inside the TCS is designed to operate continuously and controlled remotely, so it is not necessary to access its interior under normal operating conditions. The main equipment housed inside this space are described below:

- Main Gas Evaporator (MGE): The main evaporator converts the LNG into gas, providing it to the Gas Valve Unit, which is located before the engine. In this unit, the LNG is vaporized and heated to a suitable temperature by the heat provided by a water-glycol mixture. This main evaporator works every time the engine consumes gas as fuel.

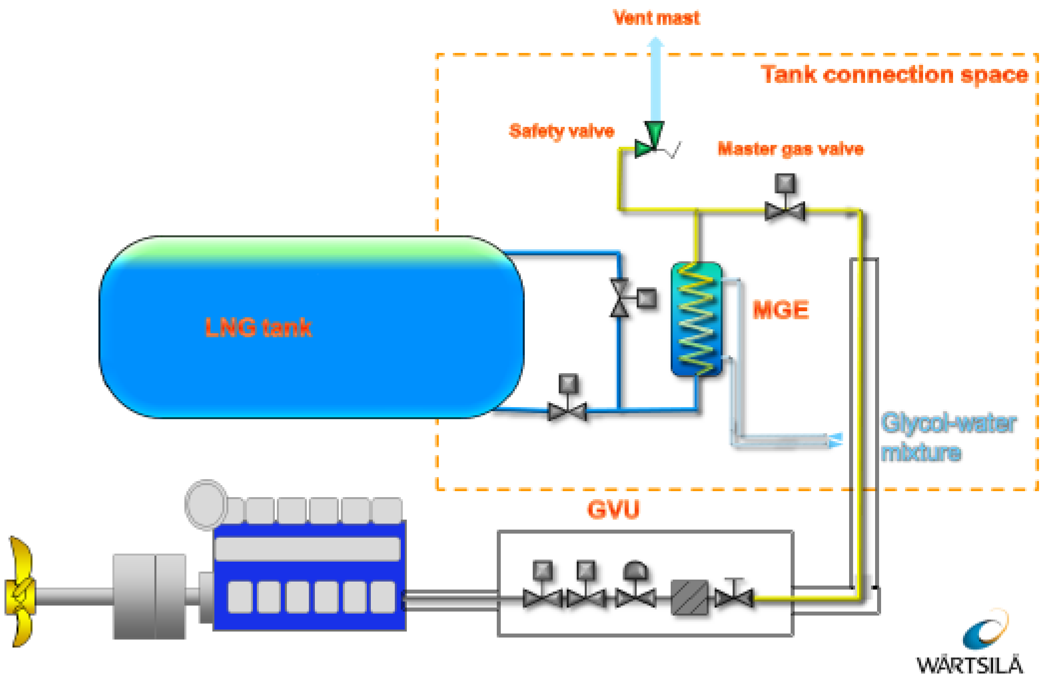


Figure 17. Main scheme of the operation of the Main Gas Evaporator (MGE). Source: Wärtsilä

The MGE receives LNG from the bottom of the storage tank, although gas from the top of the tank can also feed the engines through the MGE, in case the tank pressure is too high. The MGE system includes connections to the vent mast, and to the inert gas system, in addition to a pressure relief valve and temperature sensors.

- Pressure Build-up Evaporator (PBE): Its mission is to increase the pressure in the LNG tank to the optimum level, to compensate the loss of pressure suffered in the tank when supplying gas to the engines. This way the gas is always at the correct pressure to feed the motors, which must be at least 5 bars. Therefore, the PBE maintains the tank at the appropriate pressure by intermittently raising the pressure to compensate for the losses arising from the feed to the motors. As in the case of the MGE, in the PBE the LNG is heated by a water-glycol circuit that provides heat, resulting in the LNG vaporization. The vaporized natural gas is returned to the reservoir causing the pressure to increase.

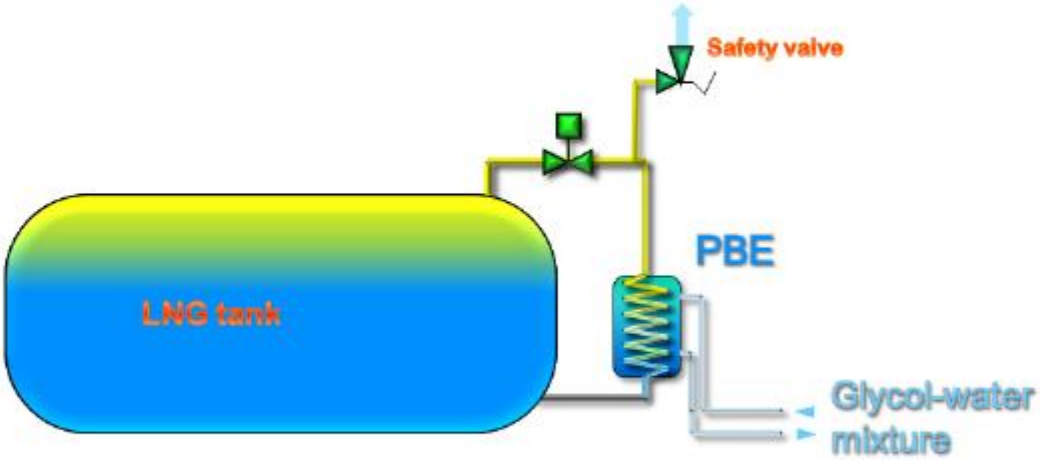


Figure 18. Main scheme of the operation of the Pressure Build-up Evaporator (PBE). Source: Wärtsilä

The PBE evaporator system includes the corresponding connections to the vent mast and the inertization system, and contains a pressure relief valve and sensors for the monitoring of the temperature.

- Glycol water mixture - Heating System: As previously mentioned, LNG is evaporated in the PBE and the MGE by a mixture of glycol, which provides heat. This heat supply system has circulating pumps, heat exchangers and expansion tank as its main components, as shown in the figure.

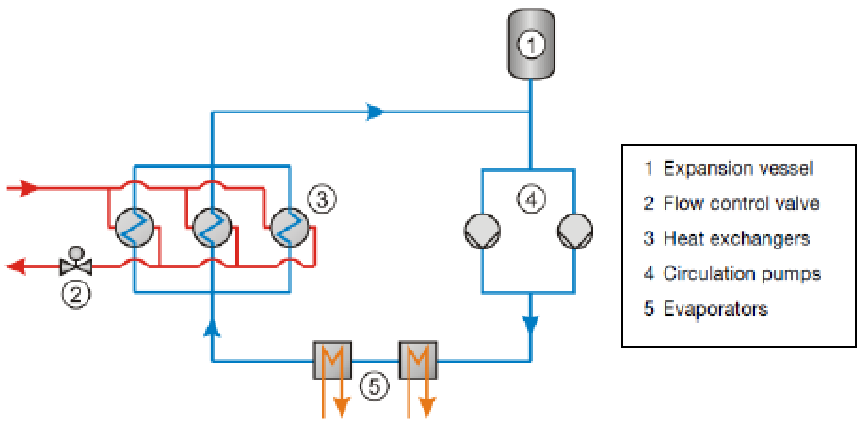


Figure 19. Main scheme of the operation of the LNG heating system. Source: Wärtsilä

1.1.1.2. Gas valve unit (GVU)

Before the gas is supplied to the engine, it passes through a set of equipment forming the GVU, so that the gas at the outlet of the TCS passes through this unit before it reaches the engine. The mission of the GVU is to adjust the gas pressure according to the load of the engine, so that it is supplied at all times with the gas at the correct pressure. To do this, the GVU pressure control valve is operated by the engine control system. This unit includes a gas pressure control valve, a series of blocking and drain valves, manual shut-off valve, connection to the inerting system, filters that prevent the gas supplied to the engine from impurities, ventilation valves, pressure transmitters, temperature transmitters, etc.

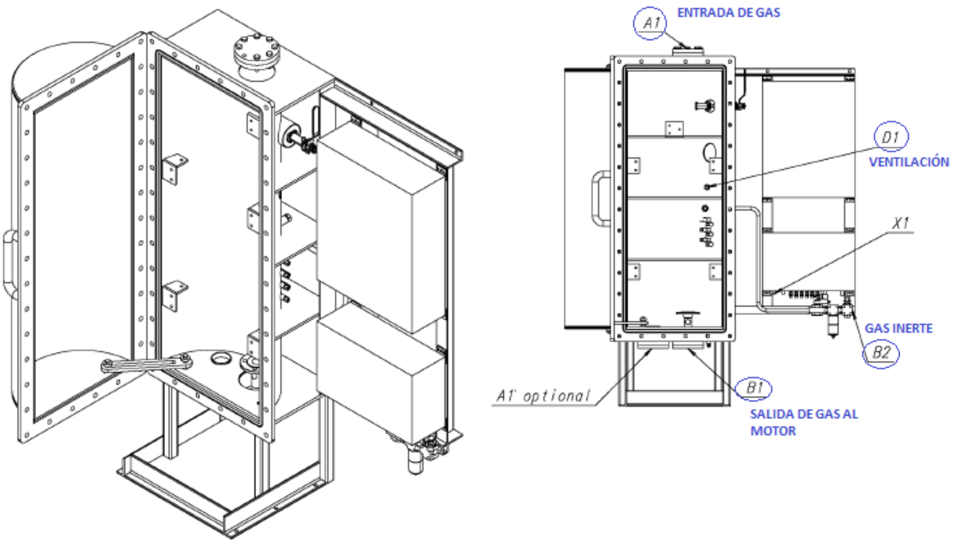


Figure 20. Configuration of the Gas Valve Unit (GVU).

It is required a GVU for each engine, and it must be situated as closed of the corresponding engine as possible in order to guarantee the engine response to the transitory conditions. The maximum length of the fuel gas pipe between the GVU and the engine inlet is as a general rule of 10 metres.

1.1.1.3. Engine

As mentioned before, the engines that are taken into account in this study have dual-fuel technology, capable of operate with natural gas and liquid fuels derived from the petroleum, MGO/MDO fundamentally. These engines have been selected according to the current power installed on each ship and according to the current possibilities offered by the market. The space where the engines are installed shall be defined as

In the mode of operating with LNG, the gas reaches the engine to be consumed as fuel, which has the conditions required by the manufacturer in term of pressure and temperature, which are provided by the GVU as explained in the previous point.

1.1.1.4. Bunkering station (BS)

The filling of the LNG tanks is carried out through the BS, for which the station has a tank filling line or pipe, in addition to having connections with the corresponding external supply line and with the inertization system and nitrogen purge. In addition to the local pressure indicators, the BS includes a pressure transmitter for the remote monitoring of the pressure in the filling line. On the other hand, there are provided relief systems whose mission is to protect the bunkering station from a possible overpressure.

To ensure the protection of the hull, protective covers and stainless steel drip trays must be installed, below the fuel line connections and where LNG leaks may occur. During bunkering operations, the drip tray directs the LNG to the outside of the vessel and a layer of water prevents any LNG dripping damages the hull.

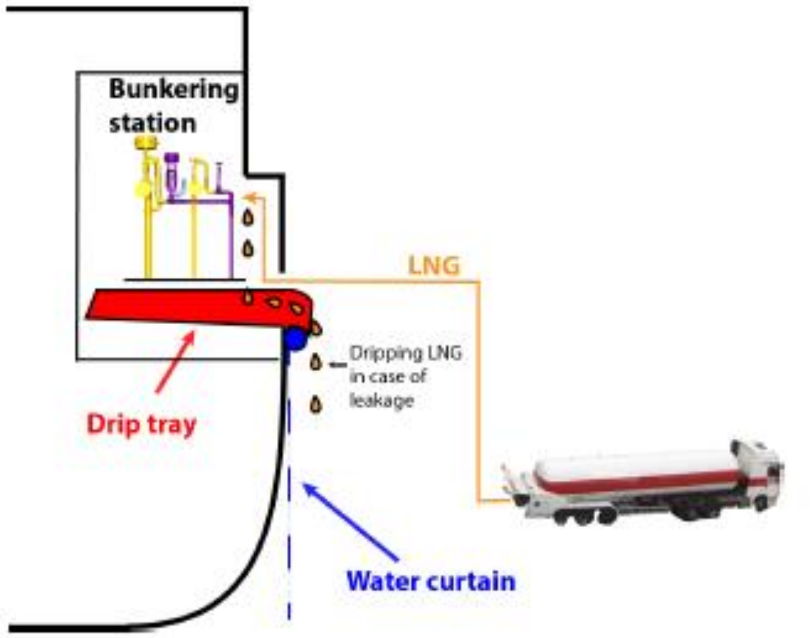


Figure 21. Scheme of the operation of the Bunkering Station (BS).

The LNG is transferred from the BS to the storage tank through the double wall pipes. The filling is done by adding LNG to the bottom of the storage tank or by spraying through nozzles in the top of the tanks, using the top filling line for the control of the pressure during the supply. The fundamental scheme is shown in the following image:

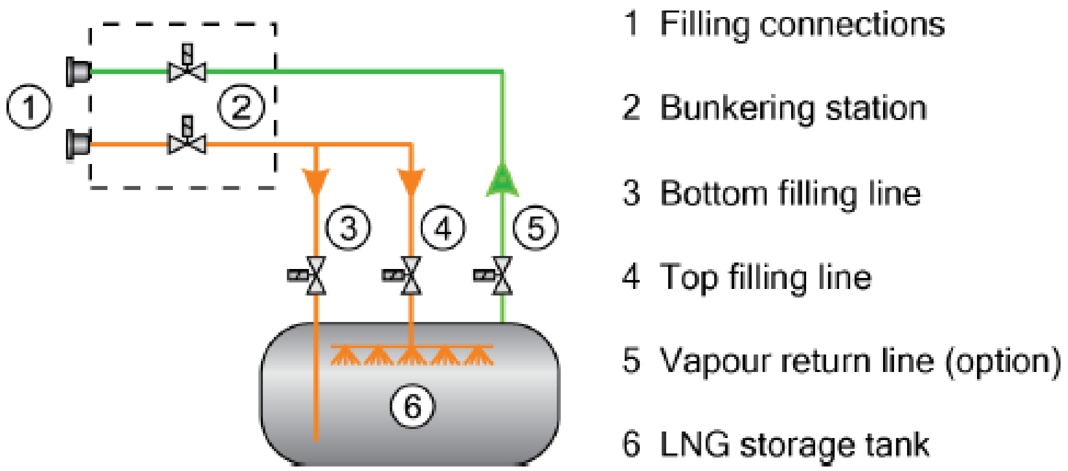


Figure 22. Scheme of the filling of LNG tanks.

Once the fuel intake operation is finished, the fuel supply line is inertized, for which the nitrogen system is connected to the bunkering station and to the filling lines.

1.1.1.5. Valves

The flow of natural gas in the gaseous state is controlled by several automatic valves located in each TCS:

- Master isolating valve: This isolation valve should be located as close as possible to the outside of the tank. In this case, it is disposed directly at the bottom outlet of the LNG tank and has a remote closing device.
- Manual isolating valves: These manual isolation valves are necessary to safely perform maintenance work when working inside the tank connection space.
- Remote controlled valves: All the valves located inside the tank connection space are remote controlled.
- Combined manual and pneumatic valve: One of them is located at the entrance of the LNG fuel pipe of the bunkering station, and another one in the tank connection space, after the MGE.
- Safety valves: Safety and pressure relief valves are installed to reduce excessive pressure in the storage tank or in the pipes. The safety valves are connected to the vent mast, by which the let the excess gas escape, thus relieving the pressure. These valves cannot be used under normal operating conditions; they can only be used in emergency situations. These valves cannot be used under normal operating conditions; they can only be used in emergency situations.

In the case of the LNG tank, two safety valves of the same size are disposed, capable of relief the excess gas that can be in the tank by a LNG heating due, for example, an outside fire.

The tank relief valves are designed with respect to the tank design pressure (MARVS) and the rest of the relief valves with respect to the design pressure of the system element for which they are arranged.

1.1.1.6. Vent mast

From the TCS, all the safety valves and pressure relief valves are connected to an aeration point called Vent Mast or venting tower that discharges the vapours relative to possible overpressures of the system to a safe place. These aeration points must be at a certain height from the main deck by normative criteria as the space around the point of release to the atmosphere is considered a potentially hazardous area due to the risk of explosion, as indicated in the part of the study dedicated to regulatory aspects.

2.6.2 Initial dimensioning of the equipment associated to the use of LNG

As indicated in the previous point, the main equipment or systems involved in the use of LNG as fuel are:

- Tanks
- Tank connection space
- GVU
- Engines / Auxiliary groups
- Bunkering station

A pre-dimensioning of the tanks for each type of vessel will then be carried out in order to assess the size requirements on board according to the LNG capacity calculated before. For the dimensioning of the rest of equipment are taken the data from the manufacturer WÄRTSILÄ.

1.1.1.7. Tanks and tank connection spaces

Based on the necessary volumes of LNG to provide the different categories of ship with an additional range of 10%, 25% and 50% using only natural gas as alternative fuel, and that are summarized in the following table:

Type of vessel	Net volume required to increase a certain percentage the current range of each type of vessel (m^3)		
	10 %	25 %	50 %
SALVAMARES	0.47 / 1.13	1.18 / 2.83	2.35 / 5.66
GUARDAMARES	3.47	8.67	17.33
HIGH SEAS TUG	58.70	146.76	293.52
MULTIPURPOSE CATEGORY 1	137.41	343.52	687.04
MULTIPURPOSE CATEGORY 2	337.200	843.00	1,686.00

Table 25. Summary of the LNG net volume required to increase a certain percentage the current range of each type of vessel.

At this point, the total volume of the LNG storage tanks and the Tank Connection Spaces are predefined, using as a reference the data from the LNGPac of WÄRTSILÄ, which integrates both equipment in order to make the on board installation as compact as possible. The information supplied by the manufacturer is indicated below:

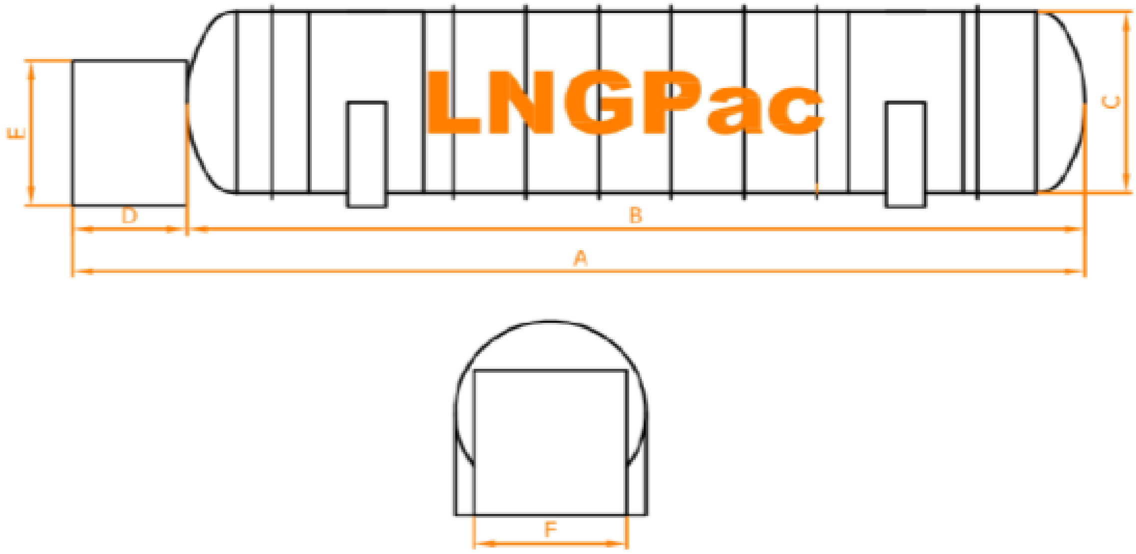


Figure 23. Scheme and dimensions of the LNGPac. Source: Wärtsilä

	A	B	C	D	E	F	Vol.	weight
Unit	m	m	m	m	m	m	cbm	ton
LNGPac 105	19,2	16,7	3,5	2,5	4,0	3,5	105	47
LNGPac 145	19,4	16,9	4,0	2,5	4,0	4,0	145	62
LNGPac 194	21,8	19,1	4,3	2,7	4,0	4,0	194	77
LNGPac 239	25,8	23,1	4,3	2,7	4,0	4,0	239	90
LNGPac 284	30,1	27,1	4,3	3,0	4,0	4,0	284	104
LNGPac 308	26,4	23,4	4,8	3,0	4,0	4,0	308	113
LNGPac 339	26,5	23,5	5,0	3,0	4,0	4,0	339	119
LNGPac 402	30,5	27,5	5,0	3,0	4,0	4,0	402	135
LNGPac 440	26,8	23,8	5,6	3,0	4,0	4,0	440	152
LNGPac 520	31,3	27,8	5,6	3,5	4,0	4,0	520	162

Table 26. LNGPac Dimensions. Source: Wärtsilä

From this data, it is made the calculation to establish the number of tanks and the total volume of each of them in order to verify if it is possible their installation in the different categories of vessels.

This calculation has been made making into account the standardized sizes offered by this manufacturer. For the cases in which there is no standard size, the sizes have been estimated according to rest of the data. Regarding the layout of the Tank Connection Spaces, this first analysis will assume one for each tank although this aspect could be optimized in later stages of development in the case of having more than one tank, in order to optimize the cost. In the following table the calculations are indicated, presenting several alternatives regarding the volume and size of the tanks for each ship category.

10% OF RANGE												
Type of vessel	**Volume of LNG (m^3)**	**LNGPac**	**A**	**B**	**C**	**D**	**E**	**F**	**Vol. (m^3)**	**Weight (ton)**	**nº**	**Total volume (m^3)**
SALVAMARES (type 1 motorization)	1.131	N/A	N/A	2.50	1.00	N/A	N/A	N/A	1.37	N/A	1	1.37
	0.492	N/A	N/A	1.50	1.00	N/A	N/A	N/A	0.82	N/A	1	0.82
SALVAMARES (type 2 motorization)	1.082	N/A	N/A	2.50	1.00	N/A	N/A	N/A	1.37	N/A	1	1.37
	0.470	N/A	N/A	1.50	1.00	N/A	N/A	N/A	0.82	N/A	1	0.82
GUARDAMARES	3.465	N/A	N/A	3.00	1.50	N/A	N/A	N/A	3.71	N/A	1	3.71
HIGH SEAS TUG	58.703	N/A	N/A	7.00	4.00	N/A	N/A	N/A	61.58	N/A	1	61.58
MULTIPURPOSE VESSEL CATEGORY 1	137.407	LNGPac 145	19.40	16.90	4.00	2.50	4.00	4.00	145	62	1	145.00
MULTIPURPOSE VESSEL CATEGORY 2	337.2	LNGPac 194	21.80	19.10	4.30	2.70	4.00	4.00	194	77	2	388.00
		LNGPac 339	26.50	23.50	5.00	3.00	4.00	4.00	339	119	1	339.00

Table 27. Calculation to obtain the required LNG capacity to increase the range at 10% in the different types of the vessels of the SASEMAR fleet.

25% OF RANGE													
Type of vessel	**Volume of LNG (m^3)**	**LNGPac**	**A**	**B**	**C**	**D**	**E**	**F**	**Vol. (m^3)**	**Weight (ton)**	**nº**	**Total volume (m^3)**
SALVAMARES (type 1 motorization)	2.828	N/A	N/A	3.00	1.50	N/A	N/A	N/A	3.71	N/A	1	3.71
	1.229	N/A	N/A	2.50	1.00	N/A	N/A	N/A	1.37	N/A	1	1.37
SALVAMARES (type 2 motorization)	2.704	N/A	N/A	3.00	1.50	N/A	N/A	N/A	3.71	N/A	1	3.71
	1.176	N/A	N/A	2.50	1.00	N/A	N/A	N/A	1.37	N/A	1	1.37
GUARDAMARES	8.663	N/A	N/A	4.00	2.00	N/A	N/A	N/A	8.80	N/A	1	8.80
HIGH SEAS TUG	146.756	LNGPac 145	19.4	16.9	4.00	2.5	4.00	4.00	145	62	1	145.00
MULTIPURPOSE VESSEL CATEGORY 1	343.518	LNGPac 339	26.50	23.50	5.00	3.00	4.00	4.00	339	119	1	339.00
		LNGPac 402	30.50	27.50	5.00	3.00	4.00	4.00	402	135	1	402.00
		LNGPac 194	21.80	19.10	4.30	2.70	4.00	4.00	194	77	2	388.00
MULTIPURPOSE VESSEL CATEGORY 2	842.999	LNGPac 440	26.80	23.80	5.60	3.00	4.00	4.00	440	152	2	880.00

Table 28. Calculation to obtain the required LNG capacity to increase the range at 25% in the different types of the vessels of the SASEMAR fleet.

50% OF RANGE												
Type of vessel	**Volume of LNG (m^3)**	**LNGPac**	**A**	**B**	**C**	**D**	**E**	**F**	**Vol. (m^3)**	**Weight (ton)**	**nº**	**Total volume (m^3)**
SALVAMARES (type 1 motorization)	5.655	N/A	N/A	5.00	1.50	N/A	N/A	N/A	6.19	N/A	1	6.19
	2.459	N/A	N/A	2.50	1.50	N/A	N/A	N/A	3.09	N/A	1	3.09
SALVAMARES (type 2 motorization)	5.408	N/A	N/A	5.00	1.50	N/A	N/A	N/A	6.19	N/A	1	6.19
	2.351	N/A	N/A	2.50	1.50	N/A	N/A	N/A	3.09	N/A	1	3.09
GUARDAMARES	17.326	N/A	N/A	5.50	2.50	N/A	N/A	N/A	18.90	N/A	1	18.90
HIGH SEAS TUG	293.513	LNGPac 284	30.10	27.10	4.30	3.00	4.00	4.00	284.00	104	1	284.00
		LNGPac 308	26.40	23.40	4.80	3.00	4.00	4.00	308.00	113	1	308.00
MULTIPURPOSE VESSEL CATEGORY 1	687.036	LNGPac 402	30.50	27.50	5.00	3.00	4.00	4.00	402	135	2	804.00
		LNGPac 194	21.80	19.10	4.30	2.70	4.00	4.00	194	77	4	776.00
MULTIPURPOSE VESSEL CATEGORY 2	1,685.998	LNGPac 440	26.80	23.80	5.60	3.00	4.00	4.00	440	152	4	1,760.00

Table 29. Calculation to obtain the required LNG capacity to increase the range at 50% in the different types of the vessels of the SASEMAR fleet.

In relation to the sizes of the Tank Connection Spaces for non-standards tanks, a proportional size is taken based on the standard size data provided by the manufacturer.

In view of the results, it is not contemplated to evaluate the configuration alternatives required to achieve the 50% of the current range of each vessel because it is considered an excessive capacity, as deduce in section 5.2. With respect to the cases of 10% and 25%, the alternatives with smaller length and with smaller number of tanks are selected, in this order of preference.

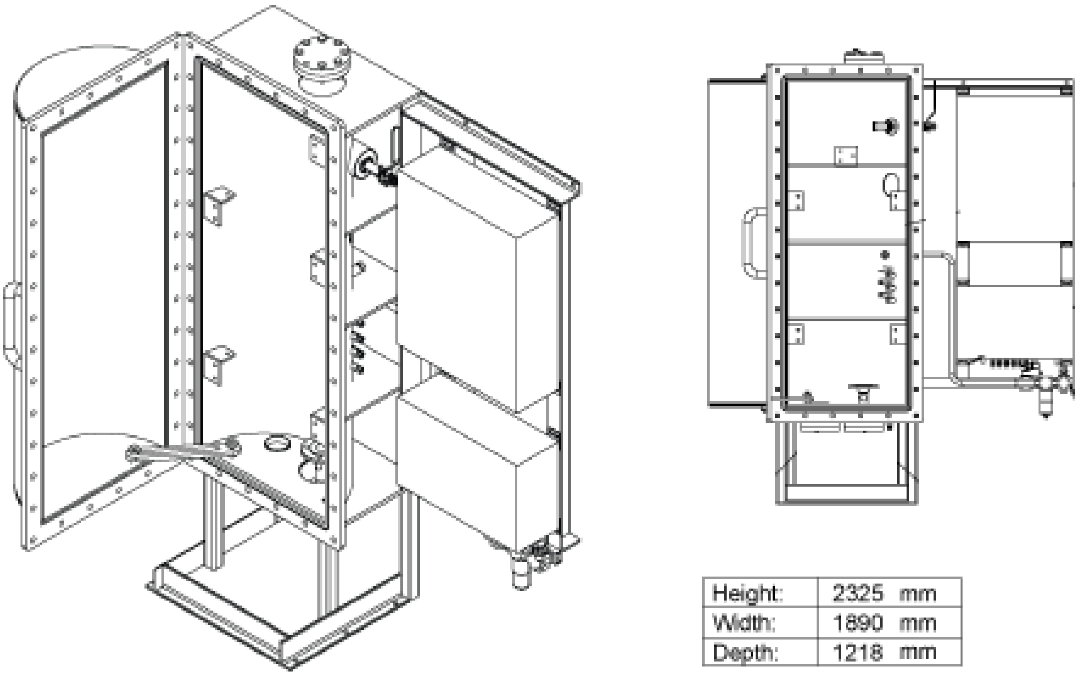
Configuration of LNG tanks needed to reach an equivalent percentage of the current range			
Vessel type	**10 %**	**25 %**	**50 %**
SALVAMARES	1 Tank of 1.4 m^3	1 Tank of 3.7 m^3	Not viable
GUARDAMARES	1 Tank of 3.7 m^3	1 Tank of 8.8 m^3	Not viable
HIGH SEAS TUG	1 Tank of 61.6 m^3	1 LNGPac 145 of 145 m^3	Not viable
MULTIPURPOSE CATEGORY 1	1 LNGPac 145 of 145.0 m^3	2 LNGPac 194 of 388.0 m^3	Not viable
MULTIPURPOSE CATEGORY 2	2 LNGPac 194 of 388.0 m^3	2 LNGPac 440 of 880.0 m^3	Not viable

Table 30. Summary of the selected alternatives for the configuration of the tanks.

For all these tank alternatives it is necessary to carry out a preliminary positioning of them, taking into account also the regulatory requirements, so that a first trial can be carried out and conclusions can be drawn about the feasibility of its installation on board the different units.

1.1.1.8. Gas valve unit (GVU)

Based on what was explained in previous point, each engine would need to have a GVU. For simplification in this phase of the study it is estimated that the size of GVU is the same regardless the type of the engine. To size this equipment it is taken as a reference the WÄRTSILÄ data, as shown in the following image:



Height:	2325 mm
Width:	1890 mm
Depth:	1218 mm

Figure 24. Dimensions of the Gas Valve Unit. Source: Wärtsilä

1.1.1.9. Engines / Auxiliary groups

Regarding the dual-fuel engines found in section 4.2, the manufacturer offers the following data with respect to their dimensions and weights. It is considered that the sizes are equivalent to the currently installed so at this point it is considered viable its installation on board in each case.

1.1.1.9.1. Wärtsilä 20DF 6L20DF

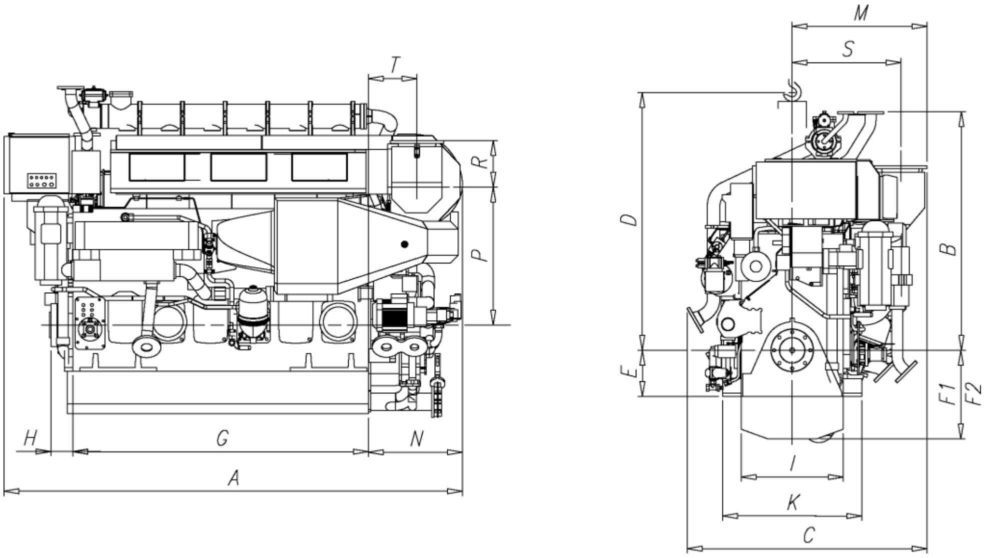


Figure 25. Scheme of the engine Wartsila 20DF 6L20DF. Source: Wärtsilä

Main dimensions (m) and weights (tons)	A	B	C	D	E	F1	F2	G	H
	3.108	1.706	1.69	1.8	0.325	0.624	0.824	2.08	0.155
	I	**K**	**M**	**N**	**P**	**R**	**S**	**T**	**Weight**
	0.718	0.98	0.95	0.663	0.971	0.328	0.762	0.339	9.4

Table 31. Characteristics of the engine Wärtsilä 20DF 6L20DF. Source: Wärtsilä

1.1.1.9.2. ABC 12DZD

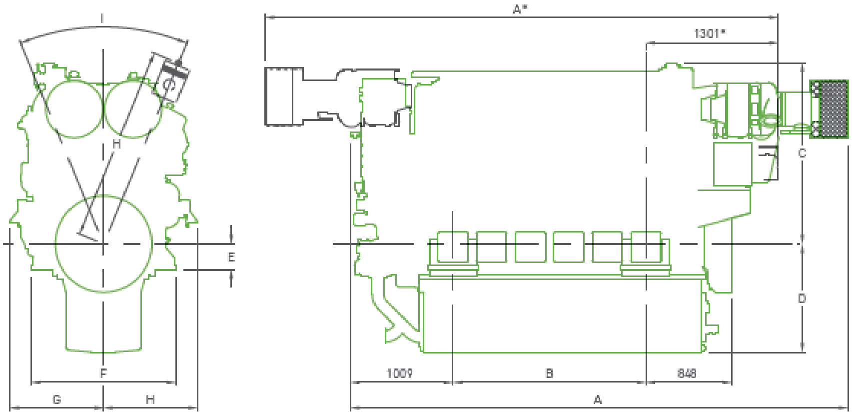


Figure 26. Scheme of the engine ABC 12 DZD.

Main dimensions (m) and weights (tons)	A	A *	B	C	D	E
	4.896	5.053	1.900	1.780	1.060	0.250
	F	G	H	I (º)	J	Weight
	1.425	0.925	0.925	45	1.95	18.2

Table 32. Characteristics of the engine ABC 12 DZD. Source: ABC

1.1.1.9.3. Wärtsilä 34DF 8L34DF

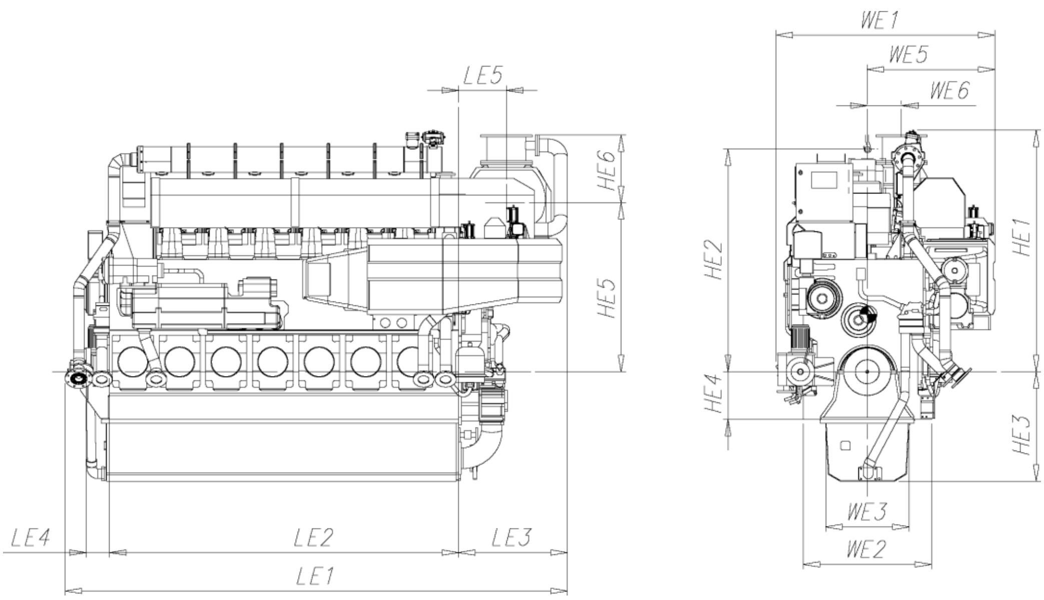


Figure 27. Scheme of the engine Wärtsilä 34DF 8L34DF. Source: Wärtsilä

Main dimensions (m) and weights (tons)	LE1	HE1	WE1	HE2	HE4	HE3	LE2	LE4	
	5.96	2.55	2.61	2.345	0.5	1.155	4.23	0.25	
	WE2	**WE5**	**LE3**	**HE5**	**HE6**	**WE6**	**LE5**	**WE3**	**Weight**
	1.35	1.65	1.285	1.718	0.607	1.34	0.705	0.88	44

Table 33. Characteristics of the engine Wärtsilä 34DF 8L34DF. Source: Wärtsilä

1.1.1.9.4. Wärtsilä 20DF 9L20DF Generating Set

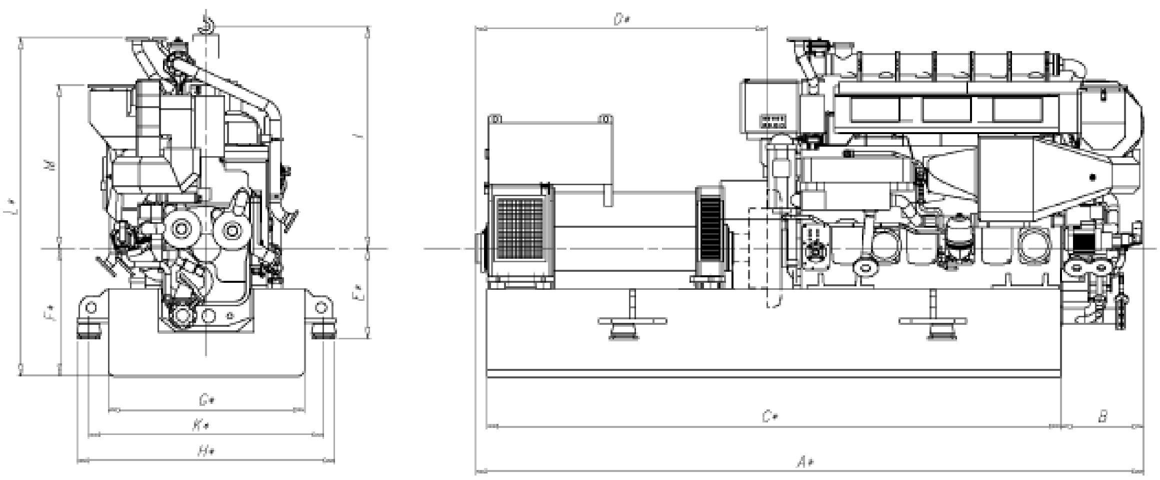


Figure 28. Scheme of the engine Wärtsilä 20DF 9L20DF. Source: Wärtsilä

Main dimensions (m) and weights (tons)	A*	B	C*	D*	E*	F*	G*
	6.535	0.731	5.4	2.58	0.75	1.075-1.125	1.57-1.8
	H*	**I**	**K***	**L***	**M***	**Weight**	
	2.07-2.3	1.8	1.88-2.11	2.781-2.831	1.390	23.9	

Table 34. Characteristics of the generating set Wärtsilä 20DF 9L20 DF Generating Set. Source: Wärtsilä

1.1.1.10. BUNKERING STATION

Finally, the last system to be dimensioned is the bunkering station. This station, from which the LNG tanks are filled, must be disposed on one side of the vessel and on the main deck. WÄRTSILÄ provides minimum approximate dimensions for the bunkering station, although these dimensions must be adapted to each vessel taking into account the available space. To simplify this phase of the study, the same dimensions of the bunkering station will be taken for the different vessels, although this aspect should be studied deeper in the following stages of the sub activity. The minimum dimension that are taken as reference are indicated in the following image:

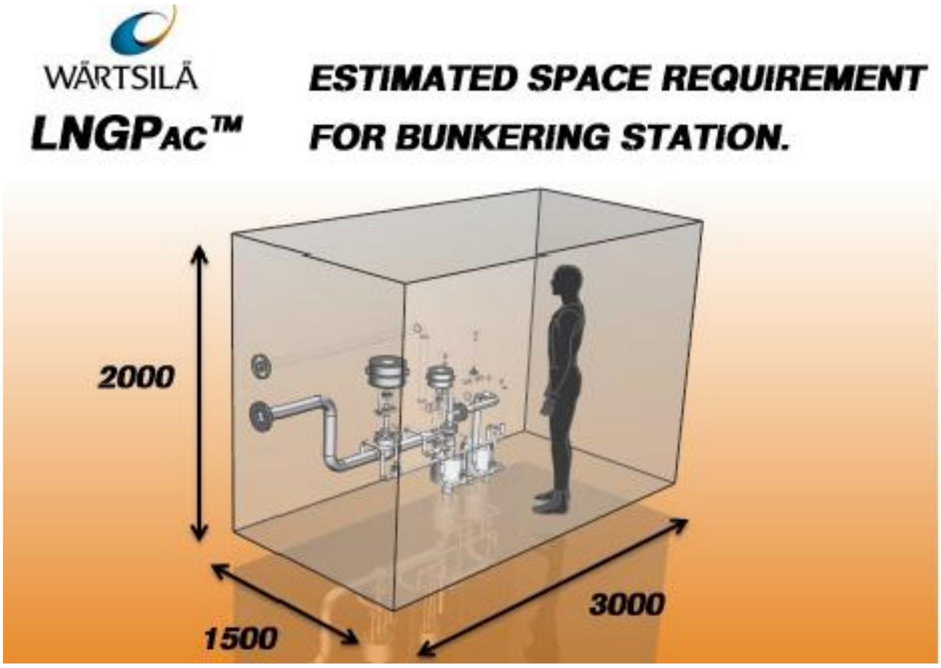


Figure 29. Dimensions required for the installation of the Bunkering Station (BS). Source: Wärtsilä

A comparative analysis of the dimensions of the equipment and the layouts of the various vessels has been made to assess the feasibility of integrating them on board of the existing ships. Since in this first analysis it is not contemplated the possibility of reducing the range of conventional fuels currently available to ships and therefore does not change the layout of the tanks for these fuels, the LNG tanks must be integrated above the principal deck.

The following images show, for each type of ship, a view of the side and the main and upper decks, including a series of sketches with the size of the equipment that it is needed to be installed according to the estimated dimensions for each one of them at this point. In addition, in these images have been marked the limits where it is not possible to dispose the tanks, as established in rule 5.3.3 of the IGF code, which will be analysed in section 1.1.1.13 of this document.

SALVAMARES

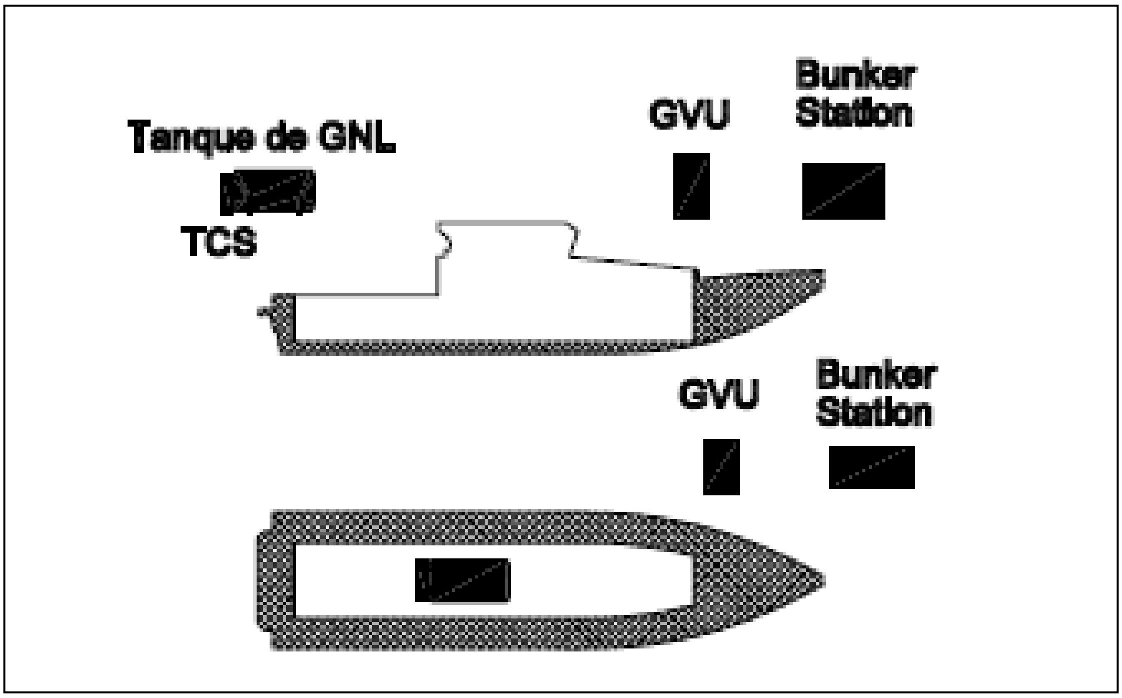


Figure 30. Salvamares. Comparison of the size of tanks and equipment for the alternative of one tank of 1.4 m3.

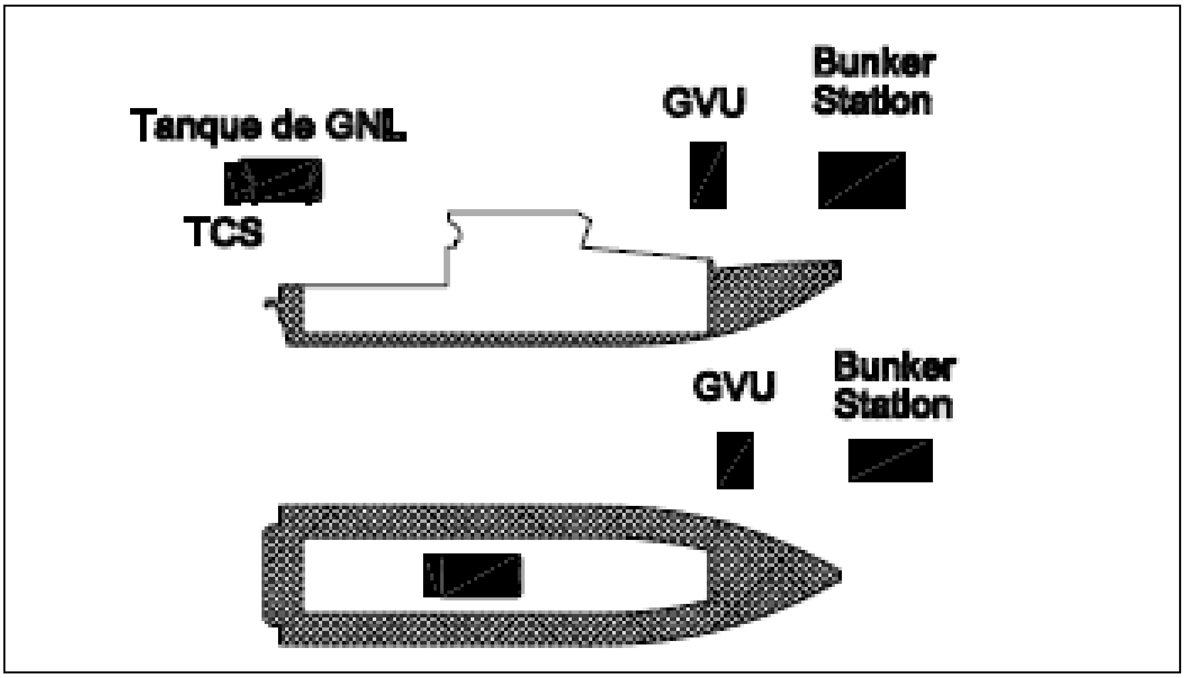


Figure 31. Salvamares. Comparison of the size of tanks and equipment for the alternative of one tank of 3.7 m3.

GUARDAMARES

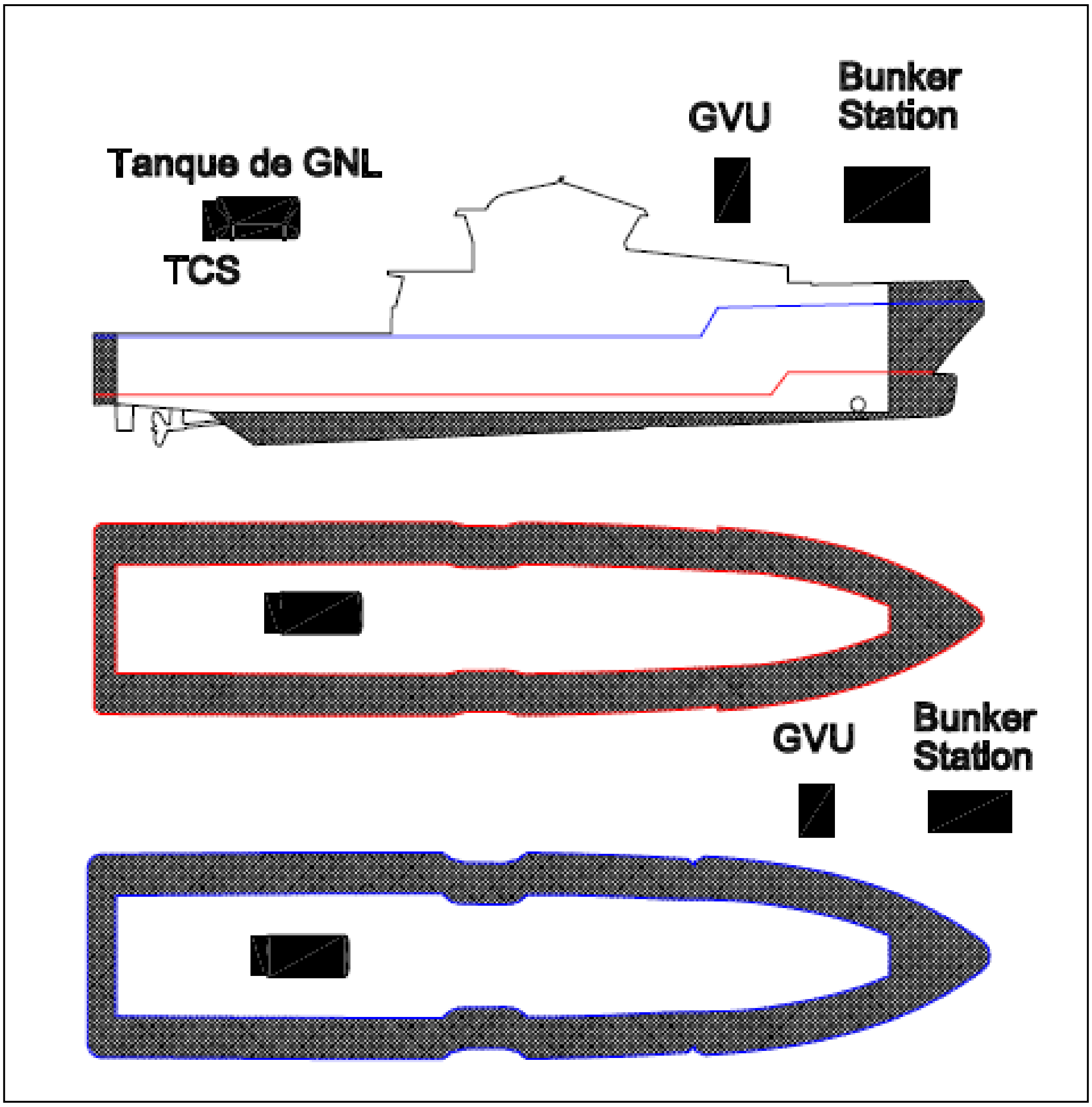


Figure 32. Coast guards. Comparison of the size of tanks and equipment for the alternative of one tank of 3.7 m3.

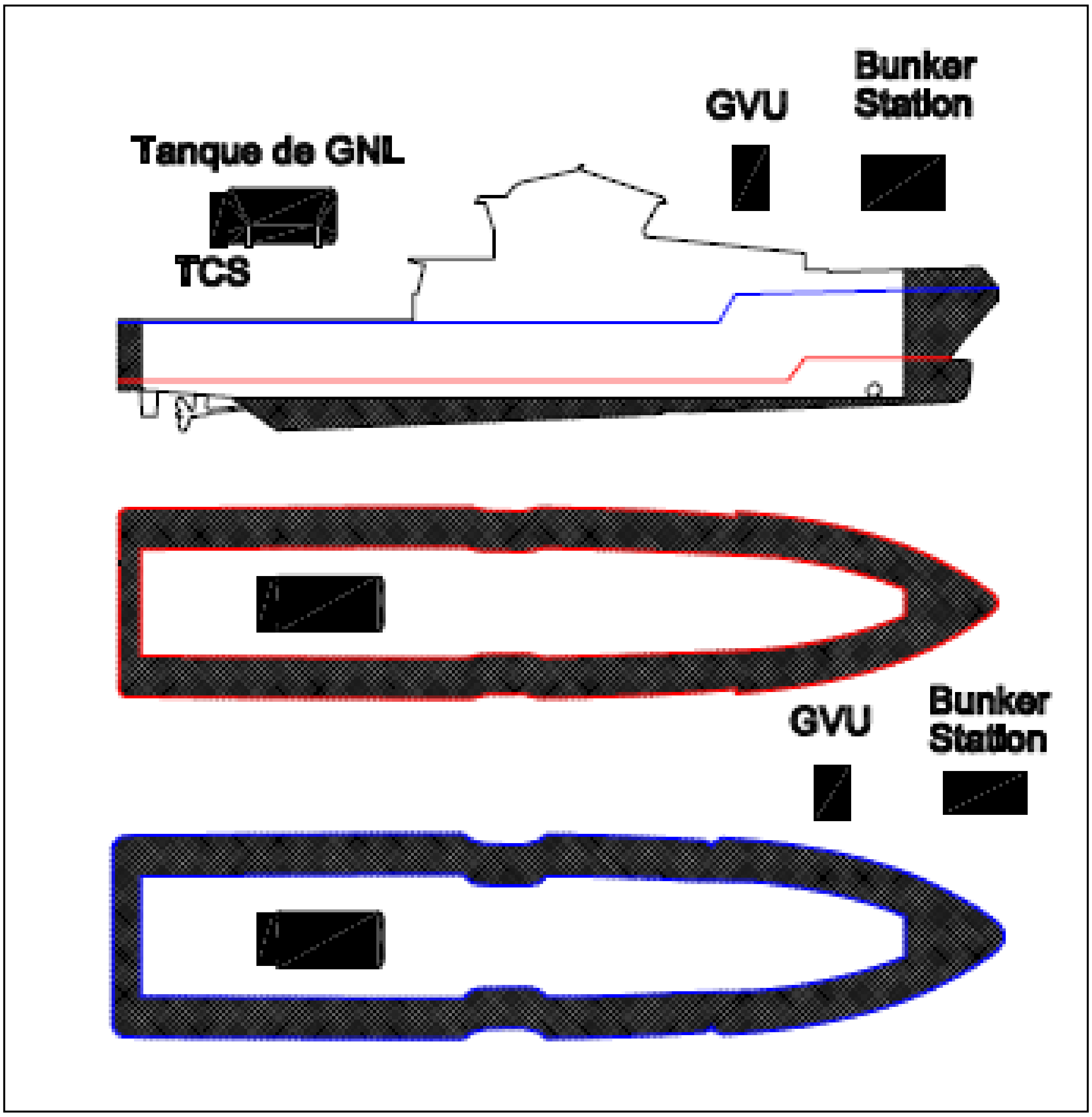


Figure 33. Guardamares. Comparison of the size of tanks and equipment for the alternative of one tank of 8.8 m3.

OCEAN GOING TUGS

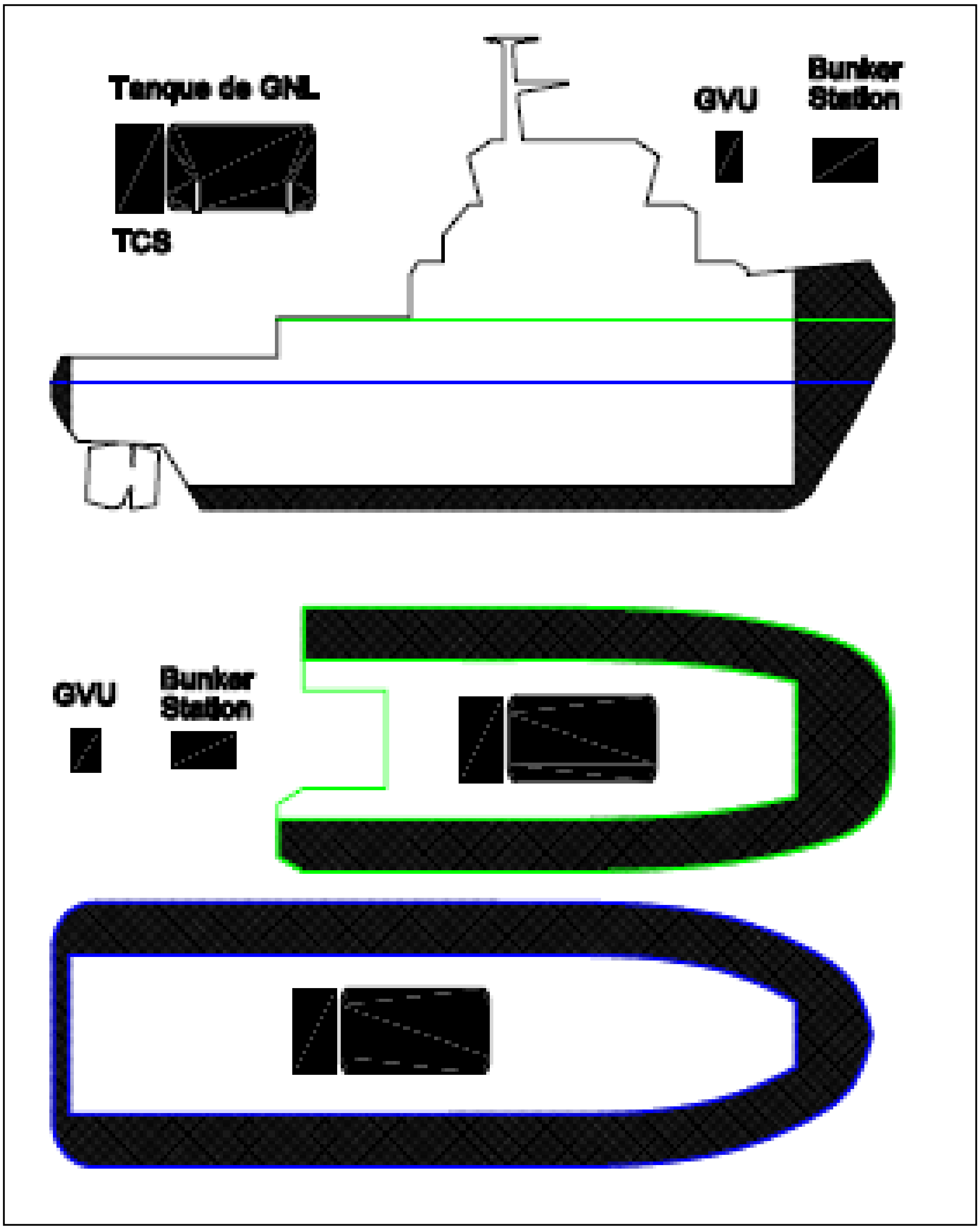


Figure 34. High seas tug. Comparison of the size of tanks and equipment for the alternative of one tank of 61.6 m3.

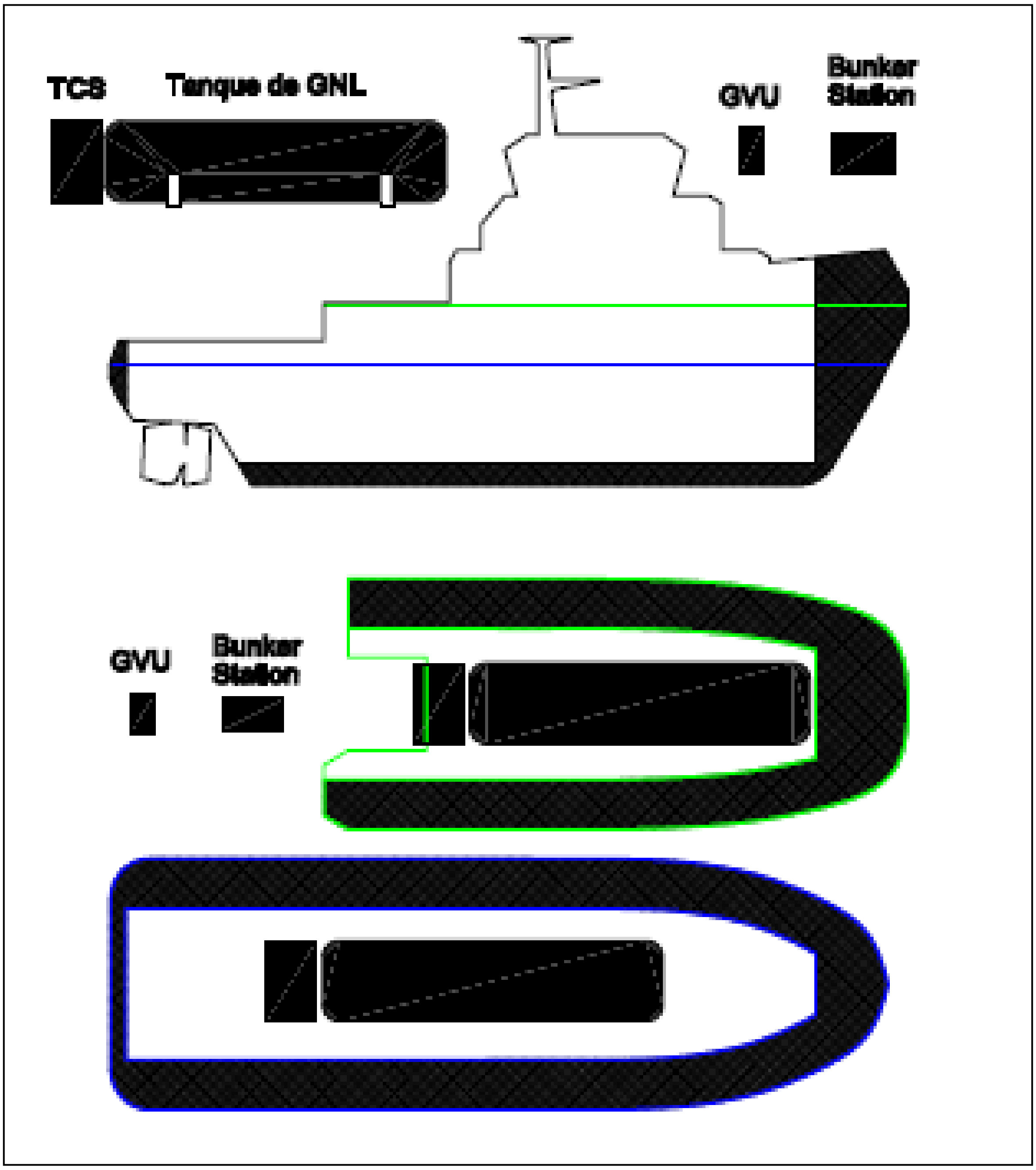


Figure 35. High seas tug. Comparison of the size of tanks and equipment for the alternative of one LNGPac 145 (145 m3).

MULTIPURPOSE VESSEL CATEGORY 1

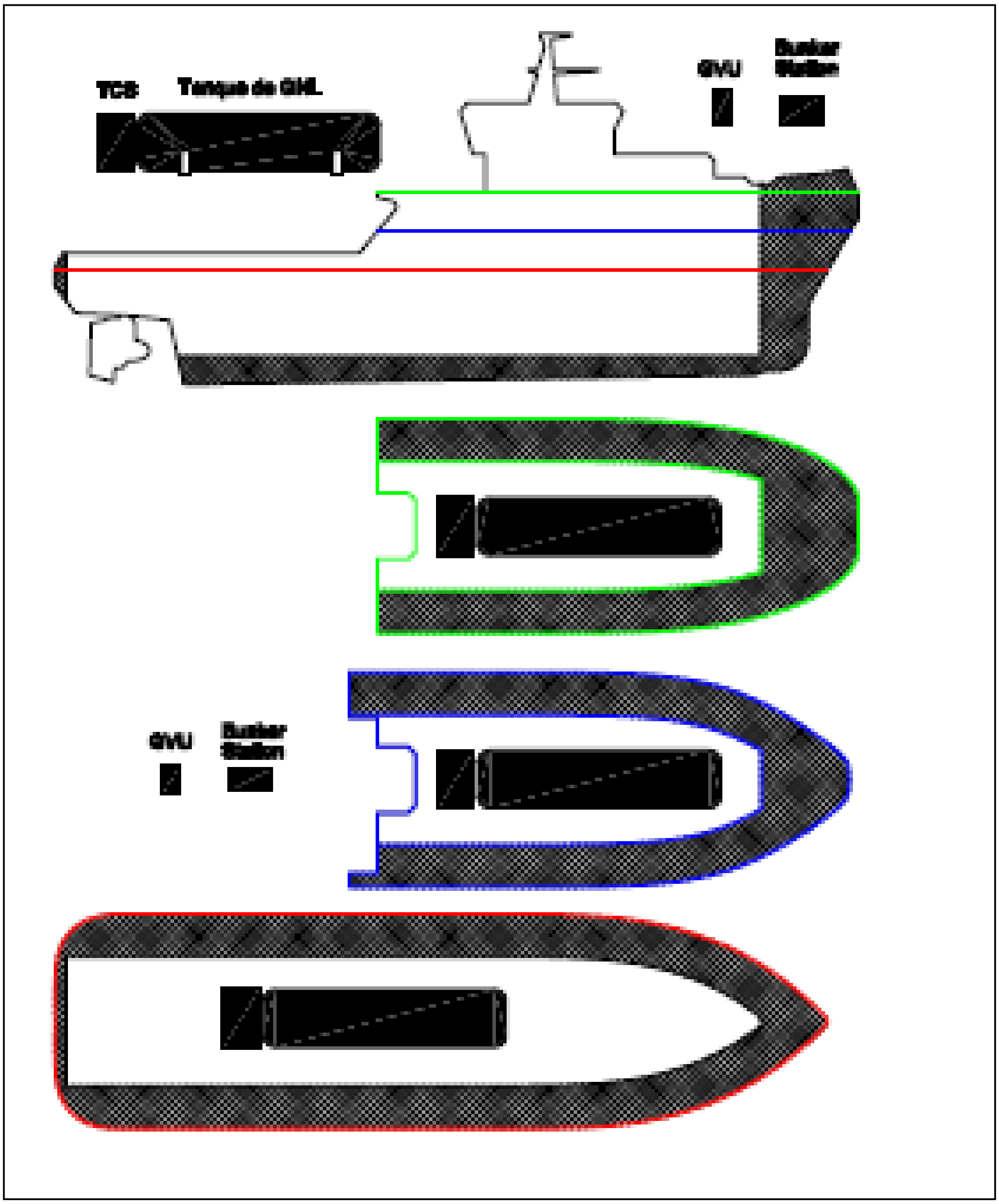


Figure 36. Multipurpose vessel category 1. Comparison of the size of tanks and equipment for the alternative of one LNGPac 145 (145 m3).

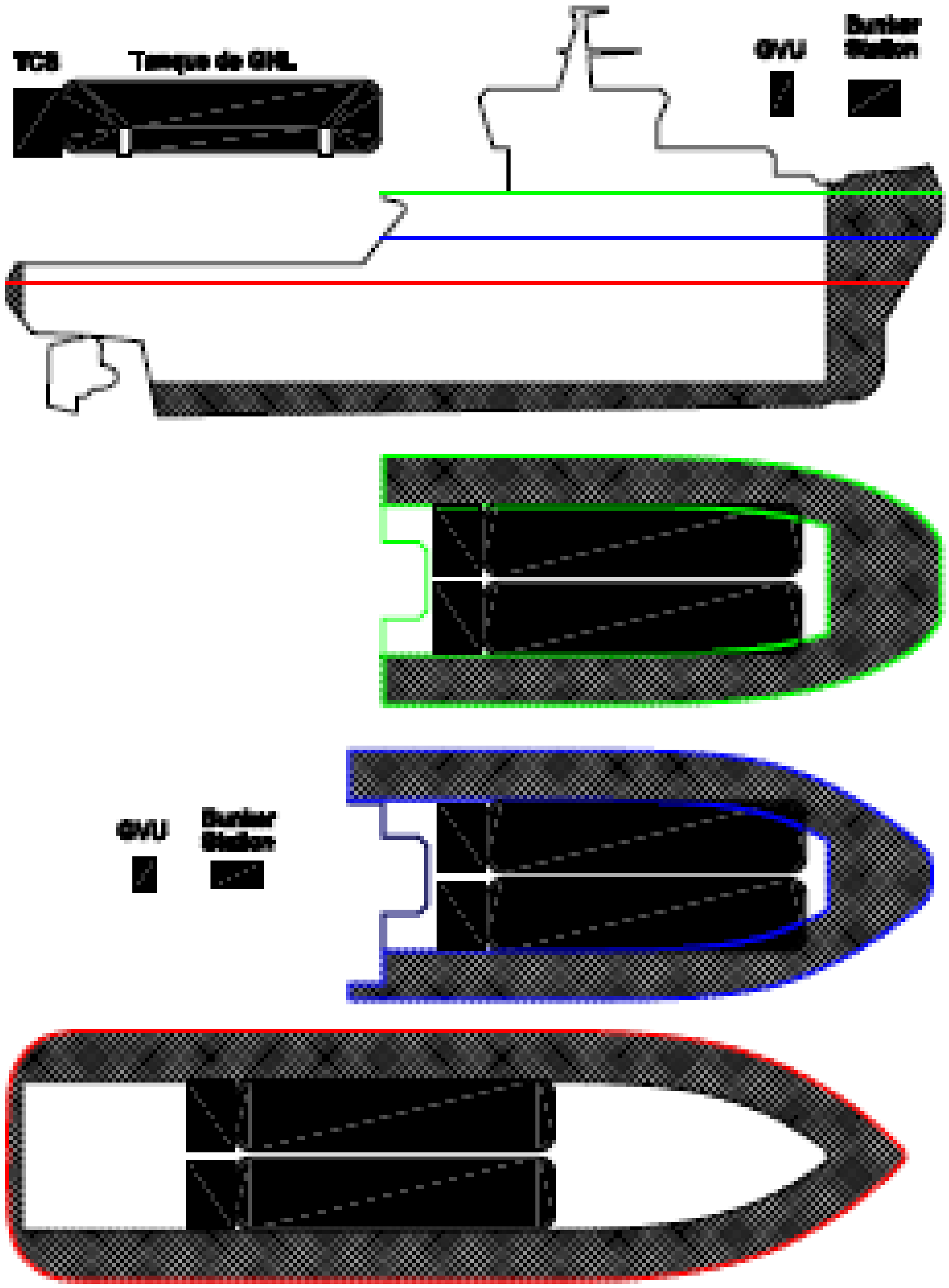


Figure 37. Multipurpose vessel category 1. Comparison of the size of tanks and equipment for the alternative of two LNGPac 194 (388 m3).

MULTIPURPOSE VESSEL CATEGORY 2

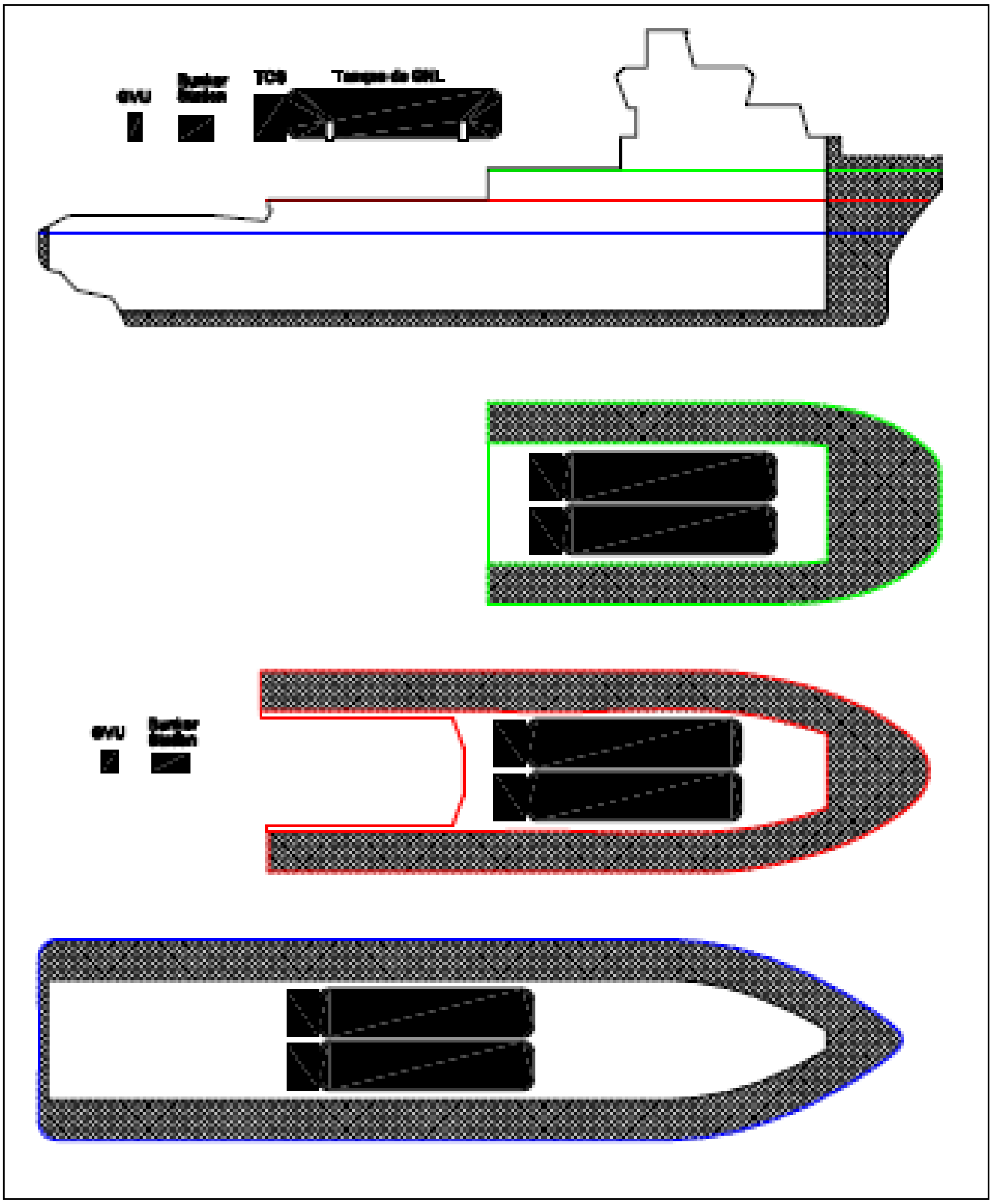


Figure 38. Multipurpose vessel category 2. Comparison of the size of tanks and equipment for the alternative of two LNGPac 194 (388 m3).

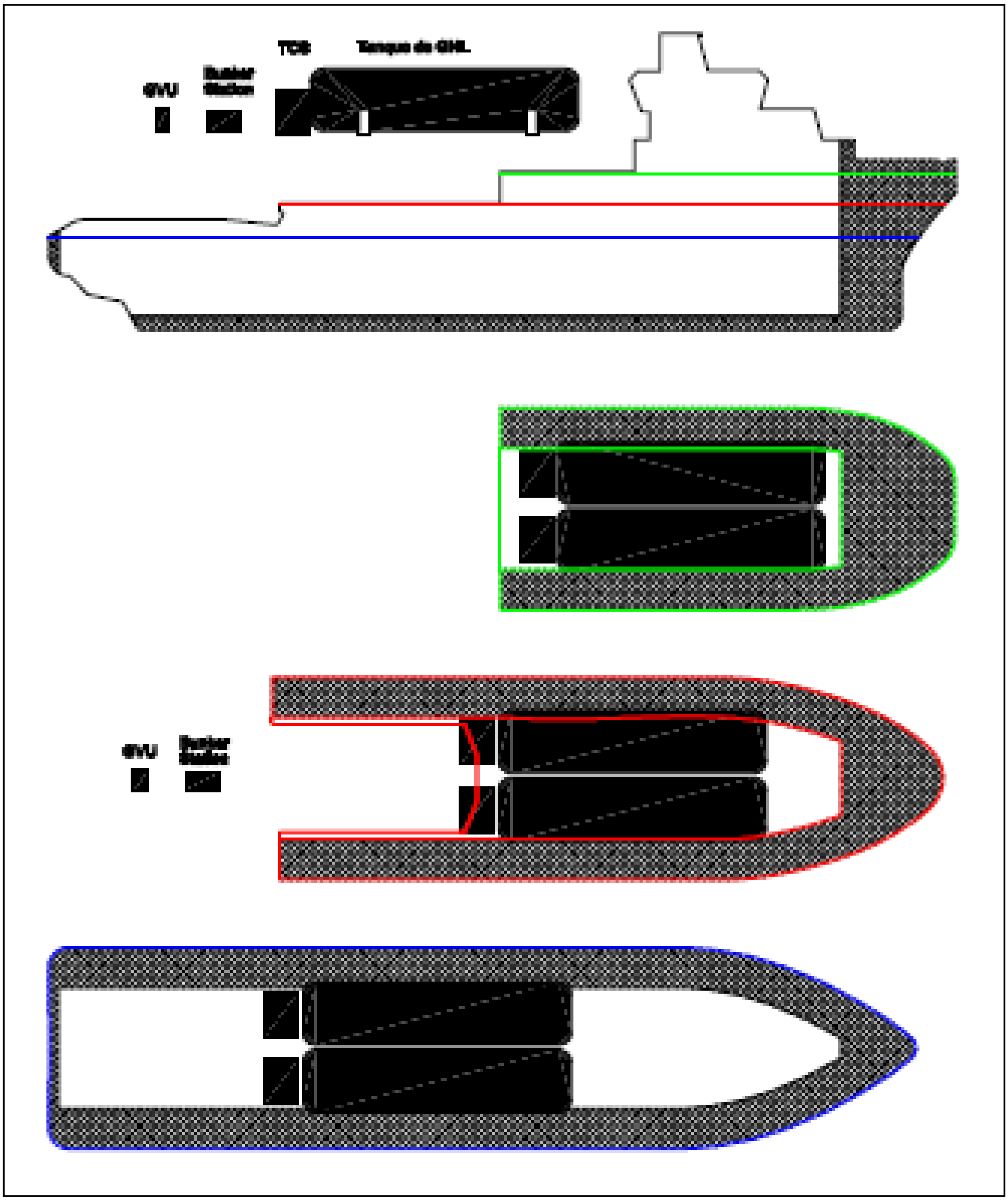


Figure 39. Multipurpose vessel category 2. Comparison of the size of tanks and equipment for the alternative of two LNGPac 440 (880 m3).

The volumes of LNG required to increase a certain percentage the range of each type of vessel are generally very high, particularly in relation to the larger vessels. This is also due to the fact that these ships currently have a high range which is required by the type of operations and service they make.

On the basis of dimensional analysis, the alternatives to the increase the range a 25% are discarded because the resulting gas capacity remains too high for the vessels under analysis.

Regarding the case of increasing the range of 10% in relation to the current one, it is not considered feasible to install the necessary equipment in the smaller ships (SALVAMARES, GUARDAMARES and OCEAN GOING TUGS) since even ir there could exist physical space for its installation, It would interfere with the rest of the functions (towing, rescue areas, cranes, etc), especially in relation to the tanks. This is why at this point, the study discards the possibility of introducing LNG as fuel in these ships maintaining their current conventional fuel capacities.

In relation to MULTIPURPOSE VESSELS it is considered that it may become viable to install these equipment since, although a priori all the space on the main deck is optimized for the proper functions of each ship, if it is considered feasible the installation of the equipment rethinking the distribution of certain spaces and the operation of certain equipment. With the results obtained, it is obtained as an important conclusion that the increase of range that can occur must be less than 10% with respect to the current one, since otherwise the volumes of the LNG tanks are too large even for vessels of the category 2.

Therefore, the net volume of LNG needed to increase the range by 10% that has been obtained for the MULTIPURPOSE VESSELS CATEGORY 1 and 2 correspond respectively to 66% and 59% of the current volume of conventional fuel available. The volume that is needed on board increases significantly with respect to this net value since the LNG tanks have a very low filling percentage compared to liquid fuel tanks and additional equipment for the consumption of LNG (Tank Connection Space, Bunkering Station or Gas Valve Unit) are needed also. This is clearly a major disadvantage that becomes much more important in compact vessels with a large number of functions, such as the ships under study.

As a summary of what is discussed in this point, the following table is included, where the feasibility of installing different equipment is assessed for each case based on its size for each type of vessel:

Sizing of the main equipment for the use on LNG as fuel for each vessel category						
Vessel type	LNG Tanks and Tank Connection Space for the different increases of range			GVU L x B x h (m3)	Engines / Auxiliary Groups	Bunkering Station L x B x h (m3)
	10 %	25%	50%			
SALVAMARES	1 Tank of 1.4 m^3	Not viable	Not viable	1.2 x 1.9 x 2.3	Wärtsilä 6L20DF	3 x 1.5 x 2
GUARDAMARES	1 Tank of 3.7 m^3	Not viable	Not viable	1.2 x 1.9 x 2.3	ABC 12DZD	3 x 1.5 x 2
HIGH SEAS TUG	1 Tank of 61.6 m^3	Not viable	Not viable	1.2 x 1.9 x 2.3	ABC 12DZD	3 x 1.5 x 2
MULTIPURPOSE CATEGORY 1	1 LNGPac 145 of 145.0 m^3	Not viable	Not viable	1.2 x 1.9 x 2.3	Wärtsilä 8L34DF Wärtsilä 9L20DF generating set	3 x 1.5 x 2
MULTIPURPOSE CATEGORY 2	2 LNGPac 194 of 388.0 m^3	Not viable	Not viable	1.2 x 1.9 x 2.3	Wärtsilä 8L34DF Wärtsilä 20DF 9L20DF generating set	3 x 1.5 x 2

Table 35. Feasibility analysis of the installation of the main equipment for the use of LNG on board.

2.6.3 Regulatory aspects

Until the appearance of the first guidelines and drafts of the International Safety Code for the vessels that use gas or other low-flash point fuels (IGF Code) developed by IMO, the installations fuelled by gas had to comply with the requirements of the international code for the construction and equipment of vessels carrying liquefied fuel in bulk (IGC Code or Gas Vessels Code). Regarding the Classification Societies, the first specific regulation for installations with gas powered engines was the regulation published by the DNV in 2001. Nowadays, each Classification Society has specific rules for vessels with gas propulsion.

As indicated in the introduction of this document, the reference regulation that will be used for the study of the regulatory aspects is the IGF Code, adopted by the IMO through the resolution MSC.391(95) of 11 June 2015, which shall take effect on 1 January 2017 for vessels of more than 500 tonnes of gross tonnage that use gas or other low-flash point fuels.

For new constructions, the code is applicable the indicated ships whose contract was awarded on or after 1 January 2017 or later, whose keel is laid on or after 1 July 2017 or delivered on 1 January 2021 or later. In relation to transformations, the code establishes that every vessel regardless of its date of construction, including those built before 1 January 2009, which becomes a ship using low-flash point fuels on 1 January 2017 or later, it shall be considered to be a ships that uses low-flash point fuels on the date on which the conversion began.

On the basis of the foregoing, the IGF Code establishes mandatory provisions for the indicated ships with respect to the layout, installation, control and surveillance of machinery, equipment and systems that consume low-flash point fuels in order to minimize the risks to the ship, the crew and the environment, taking into account the nature of the used fuels.

In the present study it has been analysed the aspects that have been considered relative to the first stages of a ship design, at conceptual development level for the case of LNG as an alternative fuel, and which are the following:

- Objective and functional prescriptions
- General prescriptions
- Specific prescriptions concerning vessels that consume LNG as fuel
  - Design and layout of the vessel
  - Fuel containment system
  - Explosion prevention
  - Ventilation

It will be analysed in the following pages the parameters indicated in the regulations to be complied with by the vessels in each one of these blocks for each one of the categories of vessels to analyse, so that a preliminary analysis of the feasibility of the use of LNG from the normative or regulatory point of view can be made. For this, it is taken as a reference the size of the tanks for increase the range a 10% depending on the results obtained in the previous point.

1.1.1.11. Objective and functional prescriptions

In this section it is established a series of generalities in order to promote the design, construction and operation in safe and ecological conditions of vessels, and in particular of their equipment that use LNG as fuel. Of all of them are considered relevant, in this phase of the study, the following:

3.2.12 The fuel containment system and the machinery spaces that contain sources capable of discharging gas into the space must be arranged and placed in such a way that a fire or a explosion in any of them does not cause an inadmissible loss of power or leave out of operation the equipment of other compartments.

Based on that, it is established as a first conclusion that the main engines in the various ships must be located in independent and isolated spaces, which implies splitting the machine spaces in as many sub-spaces as engines exist. In the following table are shown the different typologies of vessels under study, the total power, the number of main and auxiliary engines they have, the actual number of subdivisions in the machinery spaces and finally the number required on the basis of the interpretation of rule 3.2.12:

Vessel type	Propulsion power (Main Engines)	Power of the auxiliary engines	Current machinery sub-spaces	(Rule 3.2.12) Needed machinery sub-spaces
SALVAMARES	2,030 – 2,090 kW (2)	6-7 kW (1)	1	2
GUARDAMARES	3,480 kW (2)	178 kW (2)	2	2
HIGH SEAS TUG	3,744 kW (2)	478 kW (2)	2	2
MULTIPURPOSE CATEGORY 1	7,680 kW (2)	2,960 kW (2)	2	2
MULTIPURPOSE CATEGORY 2	16,000 kW (4)	3,000 kW (2)	1	4

Table 36. Feasibility analysis of the application of Rule 3.2.12 (IGF).

1.1.1.12. General prescriptions

In this section, as an importan rule in this phase of the study, it is considered the Rule 4.3 that refers to the limitation of the consequences of explosions, imposing a series of requirements on the layout on board of the sources of LNG discharge and ignition, which must not interfere in the event of an explosion in an equipment or systems located in other spaces different than the one where the event happened, interfere with another essential systems, damage the vessel so that there is a flood below the main deck o damage work areas or people accommodation.

Naturally, complying with this provisions is less feasible the smaller the size of the vessel, despite this it is not considered in this phase of the study that these requirements are limiting in any case, since it will always be possible to rethink the current layout of the spaces and equipment of all ships and/or adopt technical solutions for explosion isolation in the different equipment and systems indicated in this part of the regulation. The following table summarizes the feasibility assessment of compliance with both rules:

Vessel type	Rule 4.3
SALVAMARES	Yes
GUARDAMARES	Yes
HIGH SEAS TUG	Yes
MULTIPURPOSE VESSEL CATEGORY 1	Yes
MULTIPURPOSE VESSEL CATEGORY 2	Yes

Table 37. Feasibility analysis of the application of Rule 4.3 (IGF).

1.1.1.13. Specific prescriptions concerning vessels that consume LNG as fuel

<u>Design and layout of the vessel</u>

The purpose of this chapter of the regulation is to establish provisions for safe emplacement, adequate space distribution and mechanic protection of power generation equipment, the fuel storage system, the fuel supply equipment and the systems of refuelling.

The first important provision that is considered applicable to this phase of the study regarding the equipment placement appears in the Rule 5.3.3, which refers to the minimum distance that must be kept between the tank and the limits of the hull, as indicated as follows:

5.3.3 The tank or the tanks of fuel will be protected from outside failures caused by collision or stranding in the following manner:

.1 Fuel tanks shall be located at a minimum distance of B/5 or 11.5 m, if it is less, measured from the side of the vessel perpendicular to the longitudinal axis at the draft level of the summer load line;

.4 In no case the fuel tank limit will be placed at a distance from the liner plates or the lower end of the ship which is less than the following:

.2 In the case of bulkcarriers:

.1 For Vc lower or equal to 1,000 m^3, 0.8 m; being Vc the gross design volume of the fuel tank at 20 ºC, including archs and appendages.

.5 The lowest limit of the tank or tanks of fuel will be situated above a minimum distance of B/15 o 2,0 m, if lower, to be measured from the moulded line of the bottom shell plating at centerline.

.7 The fuel tank or tanks shall be aft of a transverse plane, at a distance of 0.08 L, measured from the forward perpendicular, in accordance with the rule II-1/8.1 of the SOLAS Convention for passenger ships, and astern of the collision bulkhead for the bulkcarriers.

There is a statistical method for the calculation of these values, although in this phase of the study will be used only the deterministic rules indicated above because of their greater ease of calculation, in order to obtain an estimative value for each one of the vessel types in function of the size of the tanks calculated in the section 7.2. In the following figure can be clearly seen the different distances referred to in the code according to the rules indicated above:

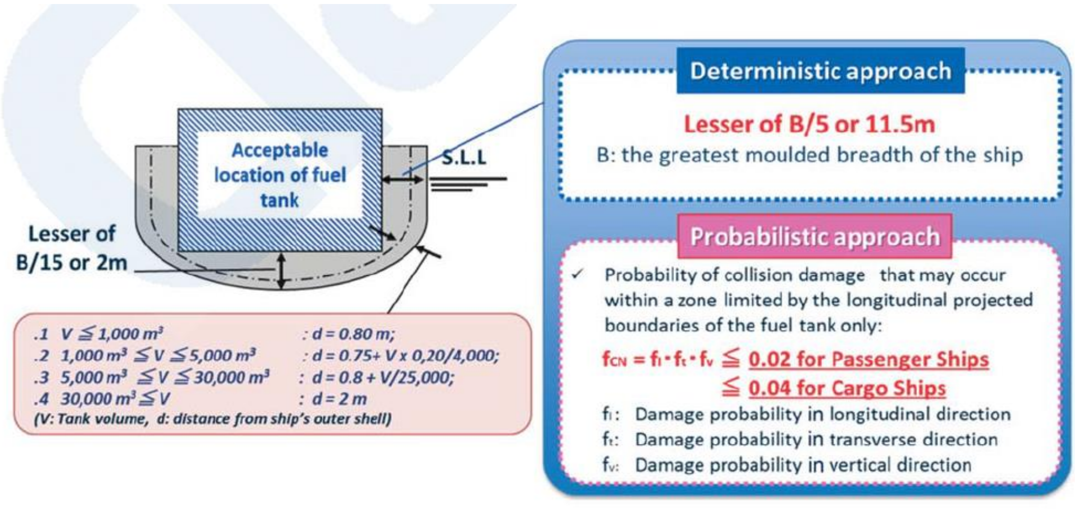


Figure 40. Regulated distances to the side and bottom of the fuel tank.

The following table presents a summary of the various calculations and parameters by type of ship and then it is evaluated the feasibility of on-board installation based on these requirements:

Vessel type	LNG capacity – Total in tanks	Tank dimensions LxBxD (m)	L_{pp} x B (m)	Distance to side – stern extreme - bottom – bow perpendicular (m)	(Rule 5.3.3) Feasibility of installation of LNG tanks
SALVAMARES	1 x 1.4 m^3	2.5 x 1.0 x 1.0	16.8/15 x 5.6/3.8	1.1/0.8 0.8 0.4/0.3 1.3/1.2	Yes
GUARDAMARES	1 x 3.7 m^3	3.0 x 1.5 x 1.5	29.8 x 7.5	1.5 0.8 0.5 2.4	Yes
HIGH SEAS TUG	2 x 61.6 m^3	7.0 x 4.0 x 4.0	34.5 x 12.5	2.5 0.8 0.8 2.8	Yes
MULTIPURPOSE CATEGORY 1	1 x 145 m^3	16.9 x 4.0 x 4.0	48 x 15	3.0 0.8 1.0 3.8	Yes
MULTIPURPOSE CATEGORY 2	2 x 194 m^3	19.10 x 4.3 x 4.3	70.1 x 18	3.6 0.8 1.2 5.6	Yes

Table 38. Feasibility analysis of the application of Rule 5.3.3 (IGF).

Fuel containment system

The objective of this chapter is to ensure that the gas storage is adequate to minimize the risks to the crew, the vessel and the environment at a level that is equivalent to that of traditional vessels consuming liquid fuels:

6.7.1.1 All fuel storage tanks shall be provided with a pressure relief system appropriate to the design characteristic of the fuel containment system and the fuel to be transported. The fuel storage spaces, the interbarriers, the tank connection spaces and the cofferdams that may be subjected to pressures higher than their design characteristics shall also have an adequate pressure relief system. The pressure control system specified in 6.9 shall be independent of pressure relief systems.

6.7.2.7 Any pressure relief valve installed in a liquefied gas fuel tank shall be connected to a venting system, which shall be:

.1 constructed so that the pressure is freely discharged and is directed vertically upwards;

.2 arranged in such a way as to minimize the possibility of water or snow entering the inside; and

.3 arranged in such a way that the height of the venting outlets is normally not less than B/3 or 6 m, if this is higher, above the weather deck and 6 m above the work areas and walkways. However, the venting masts may be limited to a lower value according to a special consideration given by the Administration.

6.7.2.8 Normally, the outlet of the pressure relief valves shall be located, at least, 10 m from:

.1 the air intake, the air outlet or the opening to accommodation, air intake, service and control spaces, or any other non-potentially hazardous area which is nearest; and

.2 the exhaust outlet of the nearest machine facility.

All this indicates the necessity of having a vent mast where they would discharge the different pressure relief systems, imposing in addition a series of requirements in reference to its position with regard to the arrangement of other elements of the vessel, such as the air outlets or openings of the areas of accommodation, service and control, hazardous areas or the exhaust outlets of machinery installations. In the following it is shown the needed calculations to evaluate the compliance of these rules by each of the analysed units:

Vessel type	Breadth (m)	(Rule 6.7.2.7) Vent height from the base line	(Rule 6.7.2.7) Vent height from the upper deck	(Rule 6.7.2.8) 10 m from certain areas
SALVAMARES	5.6/3.8	10.8 m.	9.3 m	No
GUARDAMARES	7.5	13.8 m.	10.5 m.	No
HIGH SEAS TUG	12.5	22.8 m.	17.0 m.	Yes
MULTIPURPOSE VESSEL CATEGORY 1	15.0	27.0 m.	20.0 m.	Yes
MULTIPURPOSE VESSEL CATEGORY 2	18.0	28.2 m.	21.3 m.	Yes

Table 39. Feasibility analysis of the application of Rule 6.7 (IGF).

The height in the case of SALVAMARES and GUARDAMARES is considered excessive and may affect the venting mast to some of the functions they develop, although this aspect should be studied in detail in later phases of the project.

Explosion prevention

The objective of this chapter is to guarantee the prevention of explosions and limit their effects, for which it is established in the regulation an analysis and classification method for the zones of the vessel in which explosive gas atmospheres can be generated. Based on that, the areas that are potentially dangerous are divided in emplacements 0, 1 and 2, according to the indications given by the following rules of the code:

12.5 Locations of potentially hazardous areas

12.5.1 Locations 0 of potentially hazardous areas:

This locations include, but are not limited to, the inside of the fuel tanks and all pressure relief pipes ot other venting systems of the fuel tanks and the pipes and equipment that contain fuel.

12.5.2 Locations 1 of potentially hazardous areas: These emplacements include, but are not limited to:

.1 the spaces of the tank connections, the spaces of fuel storage and the spaces interbarriers;

.2 the fuel preparation rooms with ventilation means stipulated 13.6;

.3 exposed deck areas, or half-enclosed spaces, situated at less than 3 m of any fuel tank outlet or any fuel or steam outlet, fuel collector valves, other fuel valves, fuel pipe flanges, outlet venting of the fuel preparation room and pressure relief openings of the fuel tank disposed in order to allow the flow of small volumes of gas or vapour mixtures caused by the thermal variation;

.4 the zones of exposed areas of half-enclosed spaces within less than 1.5 m of the fuel preparation room entries, ventilation inlets for fuel preparation rooms and other openings leading to location 1 spaces;

.5 the exposed deck areas within spillage coamings surrounding gas fuel intake collector valves and 3 m beyond them, up to a height of 2.4 m above the deck;

.6 closed or half-closed in which the pipes that contain fuel are located; for example, ducts located around fuel lines, half-enclosed fuel ports, etc.;

.7 machinery spaces protected by emergency deactivation are considered to be non-hazardous areas during normal operation, but in order to be certified as suitable for locations 1, they must be equipped with the equipment required to operate after detecting a gas leak;

.8 the spaces protected by pneumatic locks are considered to be non-hazardous areas during normal operation but, in order to be certified as suitable for locations 1, require the equipment prescribed for operate after a differential pressure loss between the protected space and the potentially hazardous area; and

.9 with the exception of type C tanks, any area situated at less than 2.4 m of the outside surface of a containment fuel system, if that surface is exposed to the elements.

12.5.3 Locations 2 of potentially hazardous areas:

12.5.3.1 These emplacements include, but are not limited to, areas situated at less than 1.5 m around open or half-open locations 1.

12.5.3.2 The spaces that have hatches with pins for the spaces of the connections of the tanks.

All this is evaluated in this phase of the preliminary feasibility study in order to propose the layout of the ventilation elements, the arrangement of which is directly related to the classification of the zones as will be seen in the following point.

Ventilation

The purpose of this chapter is to ensure that the ventilation is adequate for the safe operation of the gas machinery and equipment. The code establishes a series of requirements that must be complied by the ventilation equipment with respect to its design and operation. In relation to the study carried out in this document the provisions of the following rules are considered relevant:

13.3.5 The air intakes that serve to enclosed spaces that are potentially hazardous will allow air from areas that are not potentially hazardous before installing such intakes. The air intakes that serve to enclosed spaces that are non-potentially hazardous will allow air from zones non-potentially hazardous and shall be located at least 1.5 m from the limits of any potentially hazardous zone. In the cases where the intake conduit passes through a potentially more hazardous space, the conduit will be gas tight and will has an overpressure compare to the pressure in that space.

13.3.6 The air outlets of non-potentially hazardous spaces shall be located outside of potentially hazardous areas.

13.3.7 The air outlets of potentially hazardous closed spaces shall be located in an open area which, before installing the air outlet, would have a potential hazard level equal or lower than the ventilated space.

These rules are, of course, more difficult to comply the smaller the size of the vessel. A detailed analysis of the location of LNG equipment giving rise to hazardous areas of different categories must be carried out on the vessel to which the feasibility study design actions are applied. At this stage of the analysis it is estimated that it might be possible to comply with this part of the code depending on the location of the different equipment on board.

Vessel type	(Rule 13.3.5)	(Rule 13.3.6)	(Rule 13.3.7)
SALVAMARES	Yes	Yes	Yes
GUARDAMARES	Yes	Yes	Yes
HIGH SEAS TUG	Yes	Yes	Yes
MULTIPURPOSE VESSEL CATEGORY 1	Yes	Yes	Yes
MULTIPURPOSE VESSEL CATEGORY 2	Yes	Yes	Yes

Table 40. Feasibility analysis of the application of the Rule 13 (IGF).

2.7. Conclusions

Based on the analysis carried out throughout this section, a series of conclusions and data are summarized below, for each of the blocks in which the study has been divided:

POWER REQUIREMENTS / AVAILABLE LNG ENGINES	RANGE REQUIREMENTS / CALCULATED VOLUME
Dual main engine alternatives have been found for all the ship categories in the current power ranges. Regarding the auxiliary groups only dual alternatives have been found for the multipurpose vessels. The analysis of this point has yielded the following preliminary feasibility results: SALVAMARES ✓ GUARDAMARES ✓ HIGH SEAS TUG ✓ MULTIPURPOSE CATEGORY 1 ✓ MULTIPURPOSE CATEGORY 2 ✓	It is calculated the required volume of LNG to reach the 10%, 25% and 50% of the range. In a first analysis, it is not possible to evaluate the volumes corresponding to the 50% because they are considered excessive. The rest of the calculations are evaluated once the tanks are dimensioned in the section of technology integration. SALVAMARES ✓ GUARDAMARES ✓ HIGH SEAS TUG ✓ MULTIPURPOSE CATEGORY 1 ✓ MULTIPURPOSE CATEGORY 2 ✓
SUPPLY CHAIN / RESPONSE TIME	**LNG TECHNOLOGY INTEGRATION ON BOARD / AVAILABLE SPACE**
It is evaluated the state of the LNG supply infrastructures in Spain, although the results of the horizontal activities of the CORE LNGas HIVE project regarding the current and planned infrastructure os LNG supply points are awaited. The following conclusions based on the current requirements of the SASEMAR fleet are obtained: SALVAMARES × GUARDAMARES × HIGH SEAS TUG ✓ MULTIPURPOSE CATEGORY 1 ✓ MULTIPURPOSE CATEGORY 2 ✓	The preliminary dimensioning of the different equipment and a first analysis on the integration of these equipment into the current provisions of the ships are carried out at this point. Also a series of requirements imposed by the IMO in relation to the location of tanks and the classification of spaces are analysed. The following results are obtained: SALVAMARES × GUARDAMARES × HIGH SEAS TUG × MULTIPURPOSE CATEGORY 1 ✓ MULTIPURPOSE CATEGORY 2 ✓

Table 41. Summary of the preliminary feasibility analysis on the use of LNG on SASEMAR fleet units.

The implementation of power plants based on dual engines is technically complex since it involves the installation of additional systems and equipment, having in addition to comply with demanding requirements regarding their disposal on board, which are imposed by regulation. The versatility of the vessels under study greatly complicates this work since the normal operation of the new equipment cannot interfere in any way with the missions/operations that they develop. This will require a detailed analysis of the location of each element as well as the study of hazardous areas and escape routes, in accordance with the applicable regulations.

The on board volume requirements needed by the gas equipment are very high, since in addition to occupying more space than the equivalent technology of oil-based liquid fuels, require significant regulatory distances, which further complicates the feasibility of installation on board.

The preliminary feasibility study addressed in this section has resulted in the integration of LNG technology could become possible in the MULTIPURPOSE VESSELS, since they have a larger space and therefore offer greater possibilities in terms of generating alternatives for the integration of the necessary equipment for the consumption of LNG on board.

As the feasibility study concludes that the implementation of gas as fuel in SASEMAR fleet must be accomplished on the categories of MULTIPURPOSE VESSELS, the following actions are carried out in the following sections.

- Feasibility study of the transformation of MULTIPURPOSE VESSELS CATEGORY 1. The reasons for this are several: on one hand the LNG volume requirements are lower than in category 2 and therefore there is more versatility in the generation of alternatives, since both the tanks and other associated LNG equipment will be more easily adaptable to the disposal of a given vessel the lower the capacity and requirements imposed by the system.
  - On the other hand, in the case of carrying out the transformation once the study has been completed and with the conclusions obtained from it, it is considered that is less complex and more economical to make the pertinent modifications regarding the layout of spaces and equipment on board in this category than in category 2.
  - The operational profile of these units fits better with the possibility of having a small percentage of their range using LNG as a fuel, since in principle the missions of these ships will require less time and range than those of category 2, having therefore a higher resupply capacity than category 1 vessels.
- The feasibility study on a new building with equivalent characteristics to the MULTIPURPOSE VESSELS CATEGORY 2 will be carried out in the section 4 of the present document. The new building will allow the optimization of the design of a gas fuelled vessel from the beginning instead of being tied to an existing vessel.

It is necessary to point out that the implementation of LNG technology on board ships in addition to the additional volume (space) to be taken into account, it requires a very significant increase in weight that must be considered. This aspect is particularly important in the case of the feasibility study concerning the transformation of MULTIPURPOSE VESSELS CATEGORY 1 since the solution initially proposed is to arrange the gas equipment on board complementing those currently installed on this type of vessels.

Once the feasibility study on the implementation of LNG as an alternative fuel in life-saving and pollution control units shown in the present section is completed, the following studies will be included in the following sections:

- Feasibility study of the transformation of MULTIPURPOSE VESSELS CATEGORY 1
- New building definition with equivalent characteristics to the MULTIPURPOSE VESSELS CATEGORY 2

3. RETROFITTING OF A MULTIPURPOSE SALVAGE TUG

As per the conclusions on the previous section, the vessel more suitable for the retrofitting is the MULTIPURPOSE VESSELS CATEGORY 1, based on the twin ships Luz de Mar and Miguel de Cervantes. This kind of ship is capable of carrying out numerous operations, even in adverse weather conditions. As ships working under the instructions and authority of SASEMAR, they operate in Spanish coasts. Specifically, the vessel Miguel de Cervantes' influence zone is the Canary Islands, while Luz de Mar's is the South of the Iberian Peninsula and the Strait of Gibraltar.

Figure 41. Miguel de Cervantes and Luz de Mar operational areas.

Its main dimensions are 56.00 m of length, 15.00 m of beam and 7.00 m of depth to main deck, with a range of 5,230 nm and a crew composed of 18 people, expandable with 8 more for auxiliary services. Descriptions of the main characteristics of the vessels are shown in the following table:

Main Particulars	Name	Miguel de Cervantes / Luz de Mar	
	Vessel Type	Multipurpose Salvage and Rescue Tug, Oil Spill Response Vessel	
	Length Overall		56.00 m
	Length Between Perpendiculars		48.00 m
	Beam		15.00 m
	Depth	To Main Deck	7.00 m
	Draft	Design	5.50 m
	Net Tonnage		534
	Gross Tonnage		1,780
	Displacement (at summer draft)		2,940 t
	Deadweight		483/1,190 t
	Hull	Material	Steel
	Speed	Maximum	16.40 knots
		Cruise	13 knots
		Back	15.80 knots
	Range (80% MCR)		6,000 nm
	Bollard Pull	100% MCR	128.5 t
		80% MCR	107.0 t
	Crew	Standard	14
		Maximum	18
		Technicians And Auxiliary Services	8
Registration and P&I	Flag	Spain (CSR)	
	Port of Registry	Santa Cruz de Tenerife	
	Current P&I Club	Britannia Steam Ship Inc Assoc	

Classification	Classification Society	Bureau Veritas	
	Class	I HULL MACH, Fire Fighting Ship, Tug, Water Spraying-1, Unrestricted Navigation, AUT-UMS, Dynypos-R, IG	
Propellers	Bow Propellers	Manufacturer	SCHOTTEL Gmbh
		Model	SRP 3040 CP
		Diameter	4,300 mm
		Number of Blades	4
		Speed SRP	600 RPM
		SRP Gear Reduction	3.246:1
		Turn Rate	15 s / 180°
	Stern Thruster	Manufacturer	SCHOTTEL
		Model	STT 330 LK CP
		Power	400 kW
		Rotatory Speed	1.470 RPM
		Reduction Rate	3,54:1
		Propeller Diameter	1.490 mm
		Number of Blades	4
		Blades Type	Variable Pitch
		Nominal Push	68 kN

Engines	Main Engines	Manufacturer	MAK
		Model	8M32C
		Number of Engines	2
		Power	5,222.40 CV / 3,870.00 kW
		Rotatory Speed	600 RPM
		Gearbox	Kumera 4FGCCC500/525
		Fuel Consumption	214 g/kW at 2,400 RPM
		Number of Shafts	2
Generators	Auxiliary	Manufacturer	CATERPILLAR
		Model	3508B
		Rotatory Speed	1500 RPM
		Power	1.480 kW / 2.013 HP at 1.500 RPM
		Fuel Consumption	206 g/kW
		Fuel	Gas-Oil
		Generator	CATERPILLAR
		Power	1.000 kVA / 800 kW
		Voltage	400 V
		Frequency	50 Hz

	Harbour Generator (Emergency Generator)	Manufacturer	CATERPILLAR
		Model	CATERPILLAR 3406
		Power	307 kW / 494 HP
		Consumption	204 g/kWh
		Power	440 kVA / 352 kW
		Voltage	400 V
		Units	1
	Tail Shaft Generator	Generator	Satmfor
		Power	1.000 kVA / 800 kW
		Voltage	400 V
		Frequency	50 Hz

Table 42 - Luz de Mar Main particulars

3.1. Operative Capacities

As a multipurpose vessel, it can operate in many different scenarios, with can be resumed in the following scheme:

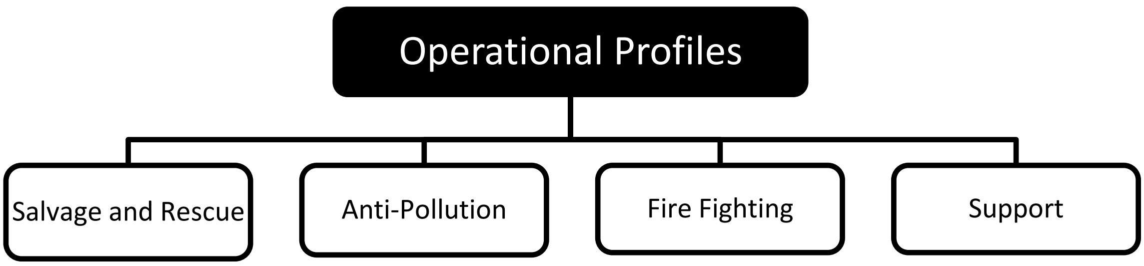


Figure 42. Operational profiles scheme of MULTIPURPOSE VESSELS CATEGORY 1.

Each of these situations requires different specialized equipment in order to complete the missions with the maximum efficiency possible, what makes this kind of ships highly technological instruments.

3.1.1 Salvage and rescue

Includes operations to assist ships in danger of sinking or to people who are drifting. With a bollard pull of 107 t at 80% of MCR (128.50 t at 100%) it can tow vessels much bigger tan it. For these salvage actions it uses 3 main tow machines and 2 auxiliary.

Figure 43. Towing operation.

It has also a rescue zone, which serves as point of shipment for those people in danger.

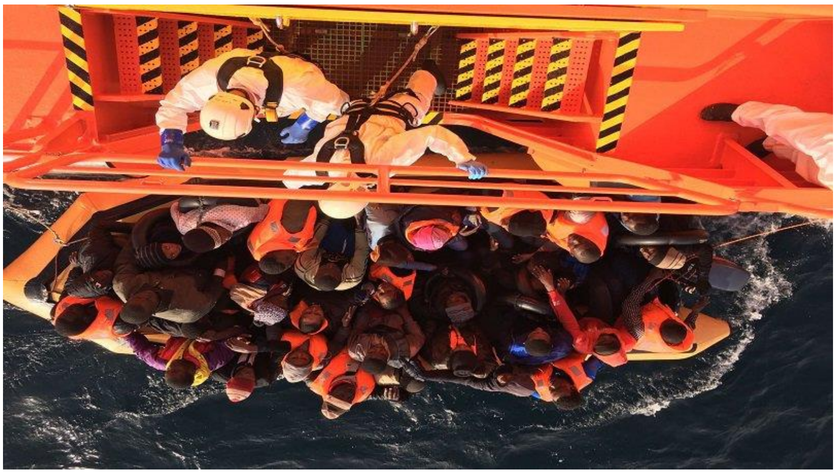


Figure 44. Rescue operation.

3.1.2 Anti-Pollution

One of the main problems associated with salvage operations, that sometimes imply the existence of a damaged vessel, is the contamination of the water. For fight the oil spills, the ship is equipped with two flotable arms, positioned obliquely to the forward direction in the aft half. A suction pump at the end near the hull discharges the waste to the tanks. These residues are poured into the aft recoil tanks that can be used individually or together and, by decantation, separate the water from the oil. Another pump discharges the tanks to land or to other systems or ships. The aft deck can stow and transport additional portable tanks which, together with structural ones, increase the waste storage capacity. It also has dispersant equipment, an oil boom and an inert gas system.

Figure 45. Oil spill collection.

The arms are operated by two cranes, each one for each arm. When they are not being used they are left on the stern extreme of the deck.

Figure 46. Flotable arms on the deck.

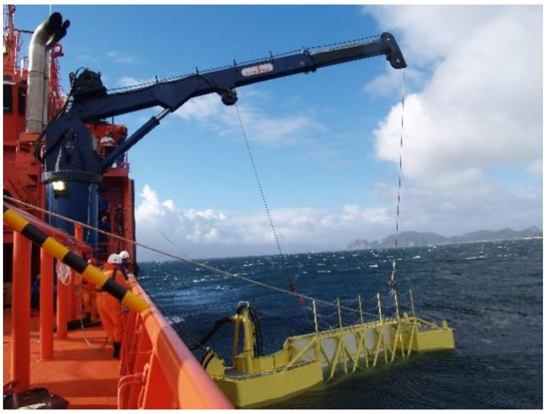


Figure 47. Crane moving one of the arms.

3.1.3 Fire fighting

The third main mission to be complete by the vessel is the fire fighting operations, many times related with maritime accidents. In order to respond to this type of situations it has an exterior fire fighting system, composed of 2 pumps each one with a capacity of 1,500 m3/h, and enough power to impulse the water (or foam) 120 m away and 50 m high from two monitors.

Figure 48. Fire-fighting system working demonstration.

It also has an auto protection system which covers the hull by means of water diffusers, protecting the vessel and the crew from the flames and high temperatures.

3.1.4 Support

It can also be used as a support platform for external equipment, such as divers, or as a support for machinery and personnel. A set of two hydraulically driven towing pins and jaws allows it for anchor and buoy handling on the high seas.

3.2. Propulsion plant and manoeuvrability

The power for propulsion is obtained from two main diesel engines model MAK 8M32C manufactured by Caterpillar.

These produced of 3,840 kW at 600 RPM, and each one is connected to two shaft lines in order to increase security and do not compromise the navigation in case of breakdown.

In relation with propellers, MULTIPURPOSE VESSELS CATEGORY 1 have azimuth aft propulsion with two variable pitch thrusters that rotate 360 degrees and, together with the bow thruster, give it full manoeuvrability at any regimen.

More technical details about the current ship propulsion plant will be presented in section 3.6 of this document.

3.3. Electric Power Production

Operational conditions in which the ship has to work, create a big necessity of electrical power supply. This is achieved through three different types of generators:

- Main auxiliary groups: two units providing 910 kW
- Shaft generators / PTO
- Emergency generator: One unit, it provides 214 kW.

More technical details about the current ship propulsion plant will be presented in section 3.6 of this document.

3.4. General Layout

The vessel has 4 decks, including the bridge, as it can be appreciated in the side view below:

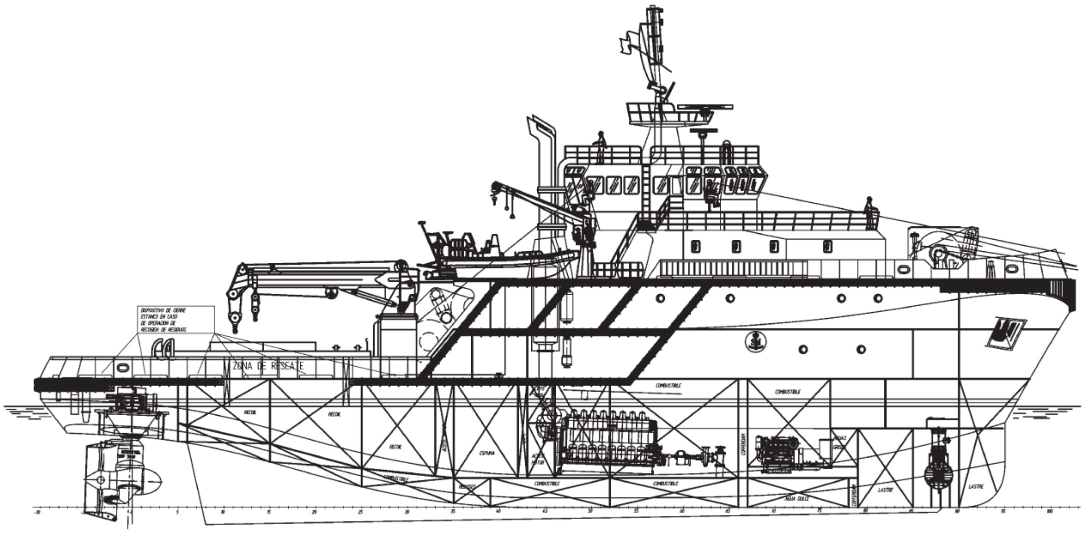


Figure 49. General layout side view.

One of the most important decks is the main deck. In it are found the cranes, winches, windlasses and oil spill recovery floatable arms, and also a part of the accommodation and several laboratories..

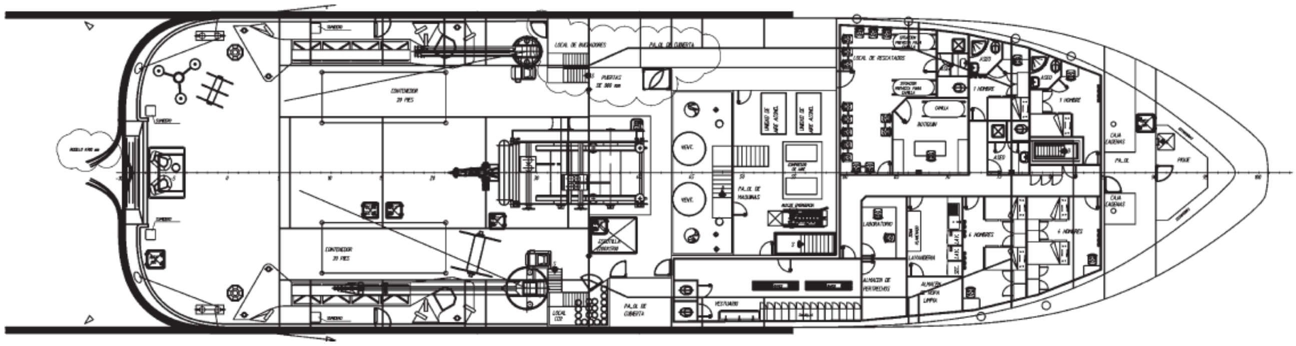


Figure 50. Main deck general layout.

Below the main deck is the double bottom, where is situated the engine room, the steering room, and several tanks (water, ballast, fuel, etc).

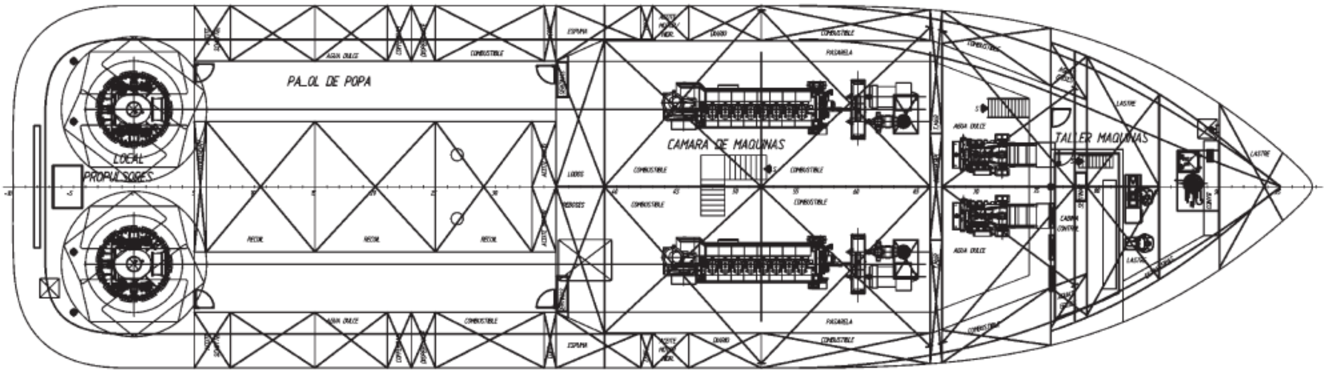


Figure 51. Double bottom general layout.

3.5. Requirements to be fulfilled for the use of Natural gas as fuel

In this section SASEMAR requirements are defined. The retrofitted vessel shall fulfil such requirements as the vessel cannot reduce its present operational capabilities.

- The current range should be maintained operating with diesel at 85% of the MCR.
- The current arrangement of fuel tanks should not be modified.
- The range will be approximately two days operating with LNG as fuel in a MCR range of 70% -85% (10-12 knots).
- Range in port will be ten days only using LNG as fuel.
- Current Bureau Veritas class notations will be maintained: I + HULL + MACH TUG, FIRE FIGHTING SHIP 1 WATER SPRAY, SPECIAL SERVICE, OIL RECOVERY SHIP, UNRESTRICTED NAVIGATION, + AUT-UMS, + DYNAPOS-AM-R Adding necessary requirements to the introduction of LNG as on-board as a fuel.
- It will be necessary to calculate the towing capacity reduction (From bow and stern) after retrofitting, in both cases using diesel and LNG as fuels. Do not miss more than 10% capacity in both cases.
- It will be necessary to calculate the ship speed reduction after retrofitting at different engine speeds and propeller pitches, do not miss more than more than 10% of the ship speed at any operational situation.
- It will be necessary to calculate the response time increments related to power demand and propulsion response at any operational situation.
- It will be necessary to calculate downtime due to LNG bunkering operations.
- If necessary, it would admit a loss of oil recovery capacity up to two thirds for LNG tanks installation.
- Rescue area, towing deck and towing operation area must be kept without obstacles.

3.6. Propulsion: initial characteristics and actions to be carried out for adaptation to LNG on the current installation.

The engine room is located at the middle of the length, and it is equipped with two main engines and two generating sets, all of them designed to work with gasoil.

3.6.1 Propulsive Power

The propulsive power is produced by two main diesel engines (model MAK 8M32C). From these engines two power-take-off are driven: The main shaft of each one is connected to an azimuthal thruster, SRP 3040 type, situated on the stern, providing the means of propulsion. On the other hand, each engine has another power-take-off to the bow which connects with a gearbox (Kumera 4FGCCC500/525). Each gearbox delivers power to a FI-FI pump and a shaft generator. A scheme of this configuration can be seen below:

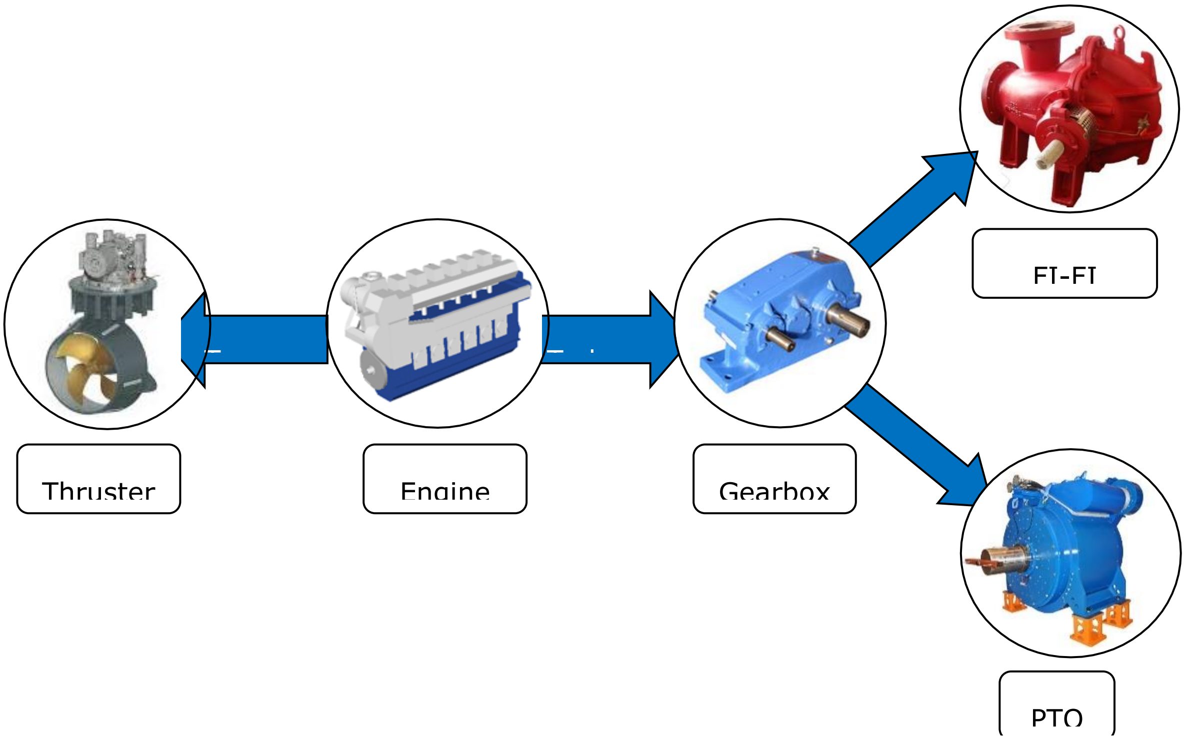


Figure 52. Propulsion power plant scheme.

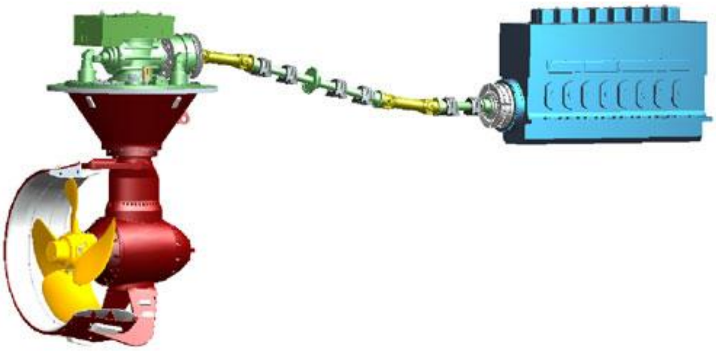


Figure 53. Z-drive configuration. Source: Nanjing High Accurate Marine Equipment Co.,Ltd.

3.6.2 Main Engines

The power for propulsion is obtained from two main diesel engines model MAK 8M32C manufactured by Caterpillar, working with gasoil. These produce 3,840 kW at 600 RPM. From each main engine it is derived a power-take-off to the bow, a FI-FI system and a shaft alternator.

Figure 54. Main engines. Source: Caterpillar.

The characteristics of these engines are shown in the following table:

Model	Ouput (kW/mhp)	Speed (rpm)	Mean eff. Pressure (bar)	Mean piston speed (m/s)	Bore (mm)	Stroke (mm)	Specific fuel consumption (g/kW*h)	
							100% MCR	85% MCR
8M32C	3,840/5,220	600	24.9	9.6	320	480	177	176

Table 43. Main engines characteristics. Source: Caterpillar

The dimensions of the engines as per manufacturer information are as follows:

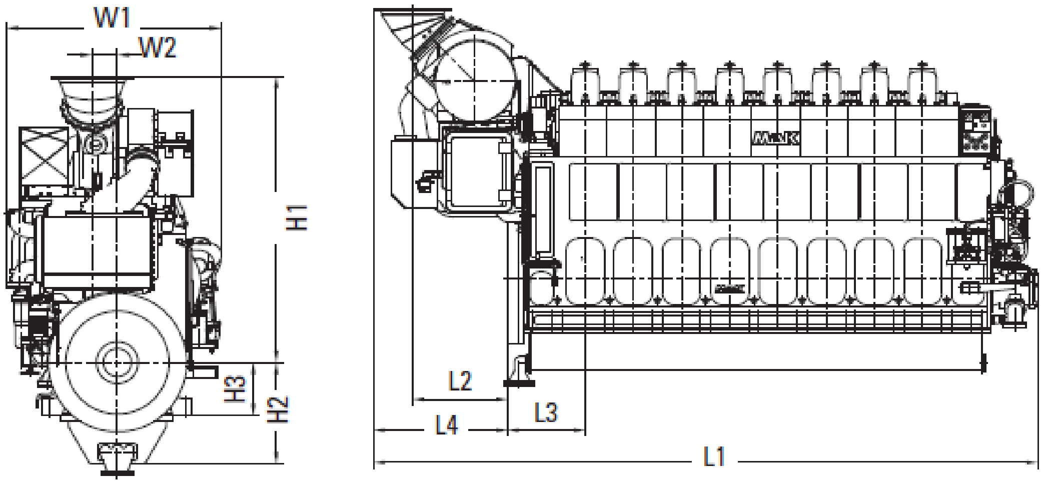


Figure 55. Main engines dimensions. Source: Caterpillar.

L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)	H1 (mm)	H2 (mm)	H3 (mm)	W1 (mm)	W2 (mm)	Weight (t)
7,298	1,044	852	1,472	2,969	1,052	550	2,229	262	49.0

Table 44. Main engines dimensions and weight. Source: Caterpillar.

3.6.3 Propellers

The propulsion system does not depend of the vessel electrical energy. It consist of two azimuth aft propulsion (or rudder propellers) with two variable pitch thrusters that rotate 360 degrees, type SRP 3040 CP, manufactured by SCHOTTEL. Due to the duplicity of the equipment, the failure of a thruster will maintain operative the navigation of the vessel without restrictions for its return to the port. Also, these systems have three main operating modes: tug, free operation and FI-FI.

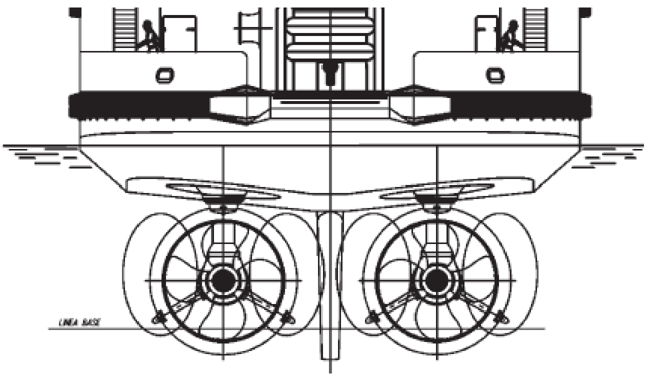


Figure 56. Azimuth propellers installed on the stern. Source: SASEMAR (left) and SCHOTTEL (right).

The blades of the propellers and their hubs are made of high quality CuAl10Ni, and surrounding each propeller there is coupled a nozzle. A more detailed picture of the thruster and its main characteristics can be seen in the figure and the table below.

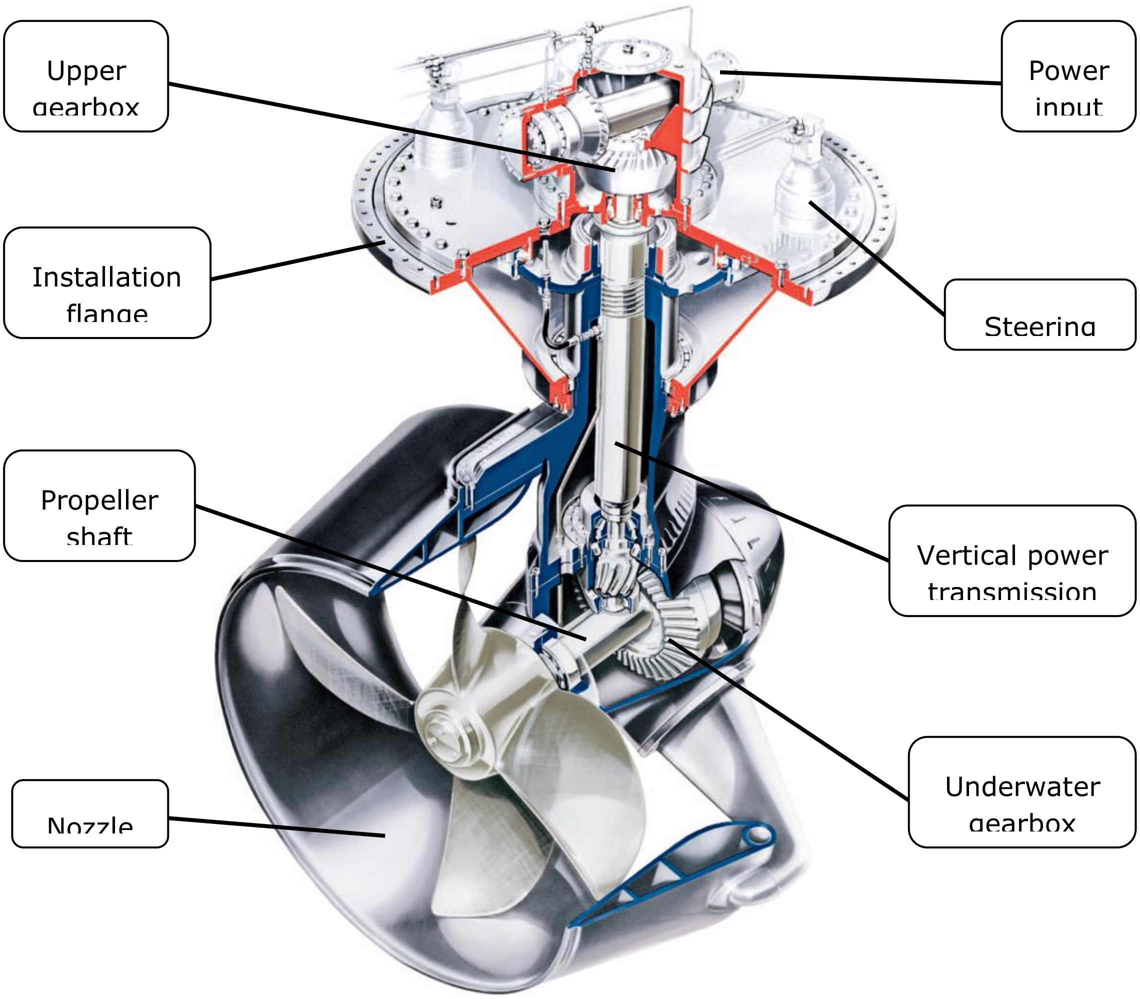


Figure 57. SRP Rudder propeller. Source: SCHOTTEL.

Model	Propeller			Rotatory direction		Rotatory speed (RPM)	Gear reduction	Turn rate
	Diameter (mm)	Nº of blades	Type	Br	Er			
SRP 3040 CP	4,300	4	Controllable pitch	CCW	CW	600	3.246:1	15s/180°

Table 45. SRP Rudder propeller main characteristics. Source: SCHOTTEL

There is also installed a transverse thruster situated in the bow (type STT 330 LK CP) which main characteristics and parts are shown below:

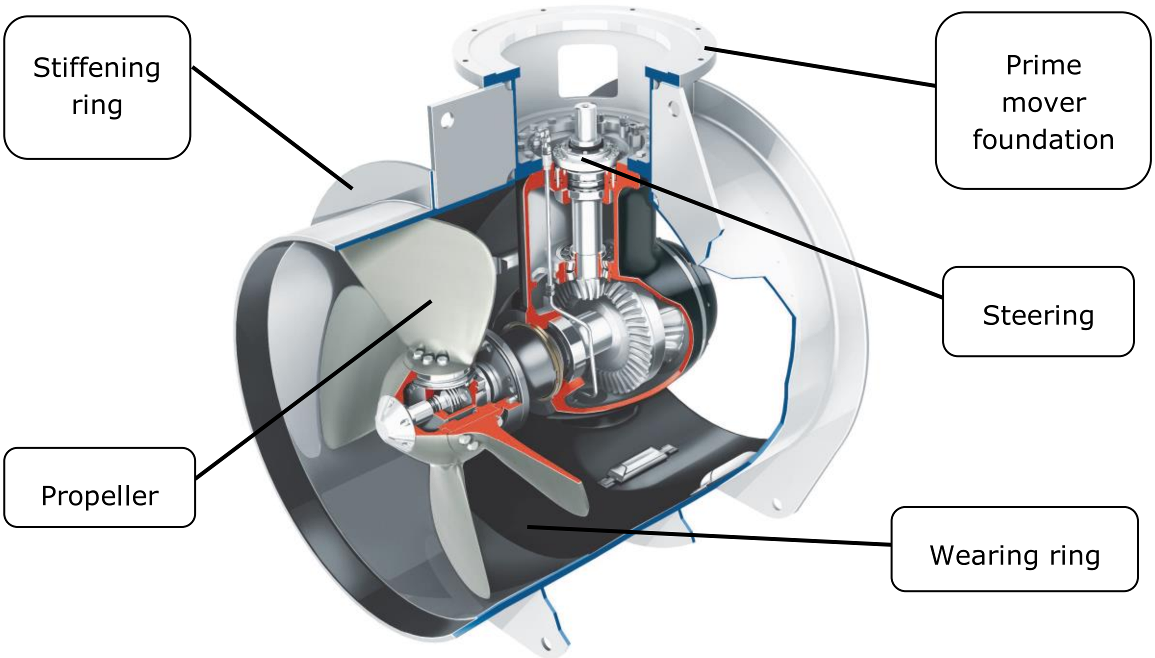


Figure 58. STT Transverse thruster. Source: SCHOTTEL.

Model	Power (kW)	Propeller			Nominal Thrust (kN)	Rotatory speed (RPM)	Reduction rate
		Diameter (mm)	Nº of blades	Type			
STT 330 LK CP	400	1,490	4	Controllable pitch	68	1,470	3.54:1

Table 46. STT Transverse thruster main characteristics. Source: SCHOTTEL.

Together with the azimuth thrusters, this equipment gives full manoeuvrability at any regimen. This gives to It the capacity to realise a whole turn in 30 seconds, or 39 seconds in the case of using only one propeller.

Figure 59. 360 degree turn demonstration. Source: SASEMAR.

It addition, It has a dynamic positioning system DYNAPOS AM of type DP2 to maintain the position.

3.6.4 Adaptation actions for LNG use

For the installation of the LNG system, there are some things to take into account. The most important fact is to find a place with enough capacity to contain the LNG tank. As commented before, the storage tank is an independent (type C) tank. This type of tank has much possibilities of installation on board, due to its portability, being only necessary an empty space which fulfil the safety restrictions imposed by the IGF code.

A key factor for the success of a gas conversion is finding sufficient space for storing the gas on board the vessel. The LNG storage location can be freely selected on board the vessel, and either vertical or horizontal tanks, on open deck or below deck, can be selected. When storage is above deck, the requirements set by the classification societies are slightly lower. In addition, for this case it is necessary to install the storage tank below deck, due to it is necessary to keep the deck clean from obstacles during operations. The LNG storage tanks and any additional steel structures may have an impact on the vessel’s stability.

Apart from the storage tank, there are some necessary equipment shall be installed on board, always regarding the fulfilment of the IFG code in order to keep the safety operation of the vessel. This equipment is:

- GVUs
- TCS
- Vent mast
- Inert gas system
- Drip tray
- Glycol-water heating system
- Bunkering station
- Single and double walled pipes
- Gas detection/ Fire suppression system

All this equipment is related with the LNG system. However, the auxiliary systems may suffer any modification in order to adapt to the new dual fuel engines. The modifications needed, can be obtained from comparing the Project Guides of both engines. The comparison is detailed further in the document.

Another important fact, is the installation of the bunkering stations. These modules are the link between the land gas installation and the vessel when bunkering. These operations use to be a critical situation due to the potential risks this operation involves. Apart from the installation of the station, including all necessary pipes, it is important to take into account that a drip tray must be installed. Drip trays shall be fitted where leakage may occur which can cause damage to the ship structure or where limitation of the area which is affected from a spill is necessary. The drip tray shall also be thermally insulated from the ship's structure so that the surrounding hull or deck structures are not exposed to unacceptable cooling, in case of leakage of liquid fuel. Finally, drip trays must be fitted with a drain valve for rain water. All these facts are important to take into account when installing on deck.

The installation of GVUs is also an important fact, due to there is one GVU per engine and because the necessity of operating in safety conditions. These units must be located in gas safe spaces and as close as possible of the engines, being the maximum pipe length allowed 10 meters. For this reason, it is necessary to have space enough in the engine room for the disposition of these units.

In general terms, the installation shall satisfy the IGF code, so it is necessary to modify any system or equipment in order to keep satisfying the IGF restrictions. There is also needed an upgrade in automation and control systems, and a specific training for the vessel crew in order to a correct operation of the vessel in safety terms.

3.6.5 Dual fuel main engines

For using the LNG as fuel, it is necessary to replace / upgrade the current main engines by dual fuel engines. These engines are capable of operating on both LNG and conventional fuels, without sacrificing their marine engines features. In order not to modify the configuration of the current power plants, the selected engines must be similar to the current installed in power range and dimensions terms.

Additionally, the ship owner wanted a main engine manufactured by Mak, so it becomes easier the selection of the dual fuel engines. Finally, the engines selected are a Mak 8 M 34DF, which develops 4000 kW at 720/750 rpm, depending if it is using diesel or gas as fuel.

Taking into account that the current engines speed is 600 rpm, there is a speed difference which means that propellers and power-take-off units will not be working in the same conditions, inducing to some problems which will be mentioned in further sections.

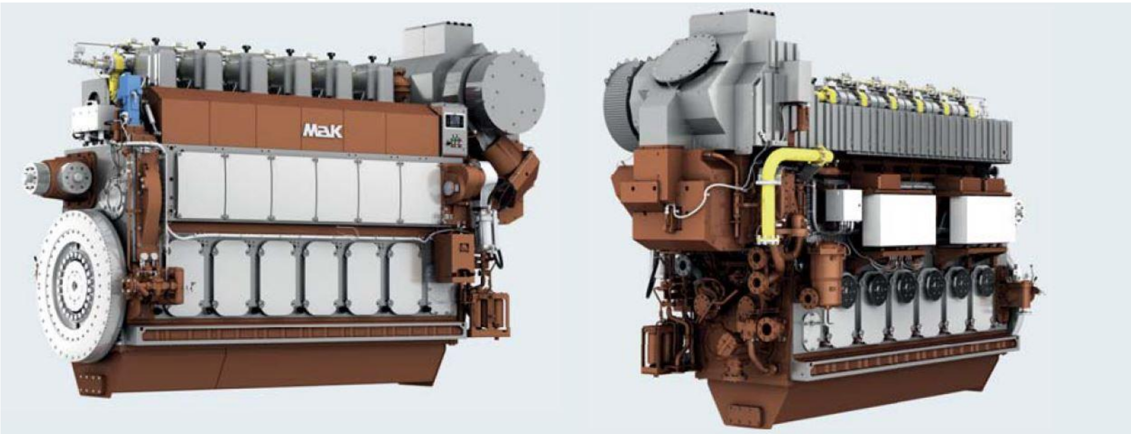


Figure 60. Dual fuel main engines. Source: Mak

The main features of this engine are shown below:

Type	Output (kW)	Revolutions Diesel/Gas (rpm)	Bore (mm)	Stroke (mm)	BMEP Diesel/Gas (bar)	Mean piston speed Diesel/Gas (m/s)
8M34DF	4000	720/750	340	460	19,9/19,1	11,0/11,5

Table 47. Dual fuel engines main features. Source: Mak

The specific consumptions are specified in a different table, in which values are given separately depending on the diesel or gas working mode and for the different working engine loads.

% Load	Diesel (g/kWh)	Gas (KJ/kWh)
100	188	7665
85	187	7777
75	189	7925
50	195	8290

Table 48. Dual fuel engines specific fuel consumptions. Source: Mak

To obtain the gas consumption in tonnes or cubic meter per hour it is necessary to know the LHV (Lower Heating Value) and the density of the fuel gas. Depending on the composition of the gas, these properties may have different values. However, the variation range is so small than it can be taken medium values from these ranges in order to have a certain estimation of the specific fuel consumption. These values are specified in the next table:

Lower Calorific value (KJ/g)	Density (t/m3)
49,5	0,45

Table 49. Fuel gas LHV and density data. Source: Mak

Using these values, it is simple to express the fuel gas consumption in terms of tonnes or cubic meters per hour, which are easier to manage than kilo joules per kilo watt and hour, and it is simpler to make an idea of the fuel consumption rates. These rates appear in the table below:

% Load	Gas (t/h)	Gas (m3/h)
100	0,619	1,376
85	0,534	1,187
75	0,480	1,067
50	0,335	0,744

Table 50. Main dual fuel engines gas fuel consumptions.

The data provided by this table is presented in a more suitable way to make an idea of the fuel gas consumption and the tank capacities needed for the LNG storing.

The engine dimensions are defined below,

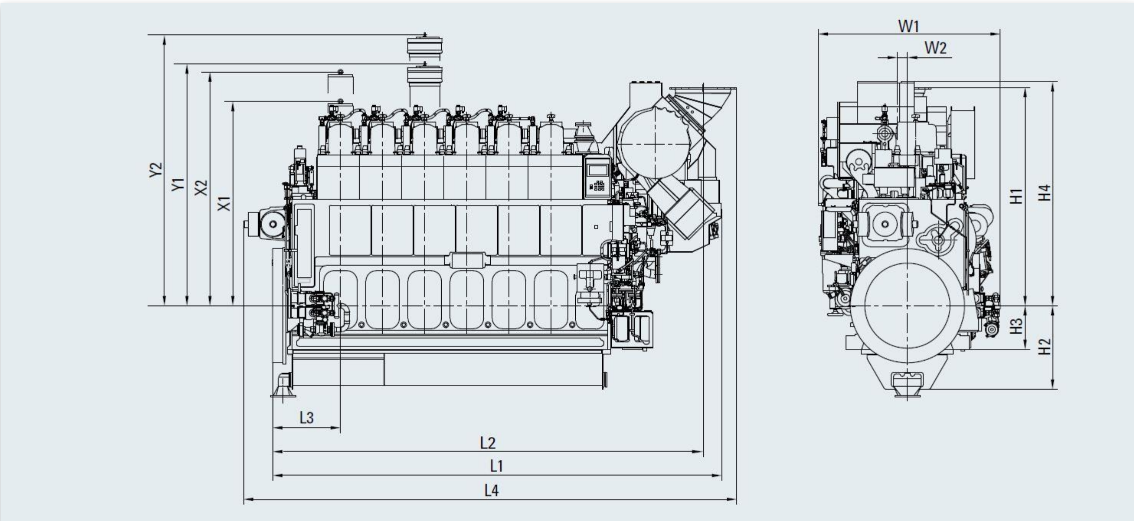


Table 51. Main dual fuel engine dimensions. Source: Mak

Dimensions (mm)										Weight
L1	L2	L3	L4	H1	H2	H3	H4	W1	W2	(t)
6980	6550	852	7410	2925	1052	550	2995	2460	190	49

Table 52. Main dual fuel engine. Source: Mak

The main conclusion can be obtained from this part is the disadvantage that suppose the difference between the engines speed. As commented on previous sections, there are some elements in the power plant which are fed from the engine speed as the azimuth propellers, the PTOs, the gearbox and the FI-FI pumps. These elements have been designed for a 600 rpm speed, so with the dual fuel engine speed of 720/750 rpm, some modifications could be required to fit the new rpm.

3.6.6 Comparison current against dual fuel engines

For the feasibility study it is important to analyse the previously shown features of both main engines in order to make an idea of the changes that could happen in the general lay out, operation ranges, auxiliary machinery, etc. when the retrofitting is done.

To compare both engine models, the features have been divided in three parts. On the first part, the main features of each engine are set, to make sure the output power delivered by each engine are the same, or at least, in a similar power range. The second part just shows the specific fuel consumptions for each engine (and for both types of fuel in case of dual fuel engine) for each load engine power range. Finally, the third part relates the dimensions of each engine. Mentioned parts are shown in the tables below:

Type	Working mode	Output (kW)	Revolutions (rpm)	Bore (mm)	Stroke (mm)	BMEP (bar)	Mean piston speed (m/s)
8M32C	-	4000	600	320	480	25,9	9,6
8M34DF	Diesel	4000	720	340	460	19,9	11
	Gas		750			19,1	11,5

Table 53. Main engines features comparisons. Source Mak.

As expected, both output powers are the same, so all of these values are more or less the same for the both engine models, excepting their revolutions. This speed variation between both engines has an important impact on the vessel power plant. On the one hand, the propellers are designed for a 600 rpm speed, so changes in this feature means changes in the propeller operative conditions. These variations must be studied with care to determine the negative effect of the speed variation in the propeller and its impact on the ship operative capacities.

The second part of the comparison consists of the specific fuel consumptions of each engine and for different load power ranges. The consumptions are given in the next table:

	8M32C		8M34DF		
% Load	Diesel (g/kWh)	Diesel (t/h)	Diesel (g/kWh)	Diesel (t/h)	Gas (t/h)
100	177	0,708	188	0,752	0,619
85	176	0,5984	187	0,6358	0,534
75	177	0,531	189	0,567	0,480
50	185	0,37	195	0,39	0,335

Table 54. Main engines specific fuel and gas consumptions comparison. Source Mak.

As all consumptions are given with the same units, it is simple to make a comparison between both engines. It is important to take account that, the dual fuel engine has a higher diesel consumption than the current installed engine. It is a negative point for the dual fuel, which, when working with diesel, would consume more than the current engine so the range (working with diesel) would decrease. This diesel-working decreasing range, even when the LNG provides a global range increment, also means a rising costs when bunkering operations in comparison with the actual costs.

In the end, the third part of the comparison shows the weight and main dimensions of each engine, which is an important fact due to the weight and space restrictions on board.

Type	Dimensions (mm)			Weight (t)
	Length	Width	Height	
8M32C	7293	2460	4119	49
8M34DF	7410	2460	4047	

Table 55. Main engines dimensions comparison.

As can be seen, both engines are basically the same in terms of dimensions and weight, but it is important to note that in this comparison has been only taken into account the dimensions of each engine, but not all the auxiliary machinery and devices needed for each option. Regarding, the dual fuel engine needs additional equipment and services whose weights and space necessities has not been taken into account for this comparison. This point would be studied and mentioned on further sections.

The main fact in this part is the engine speed differences, both output-speed engine curves are shown in the figure below:

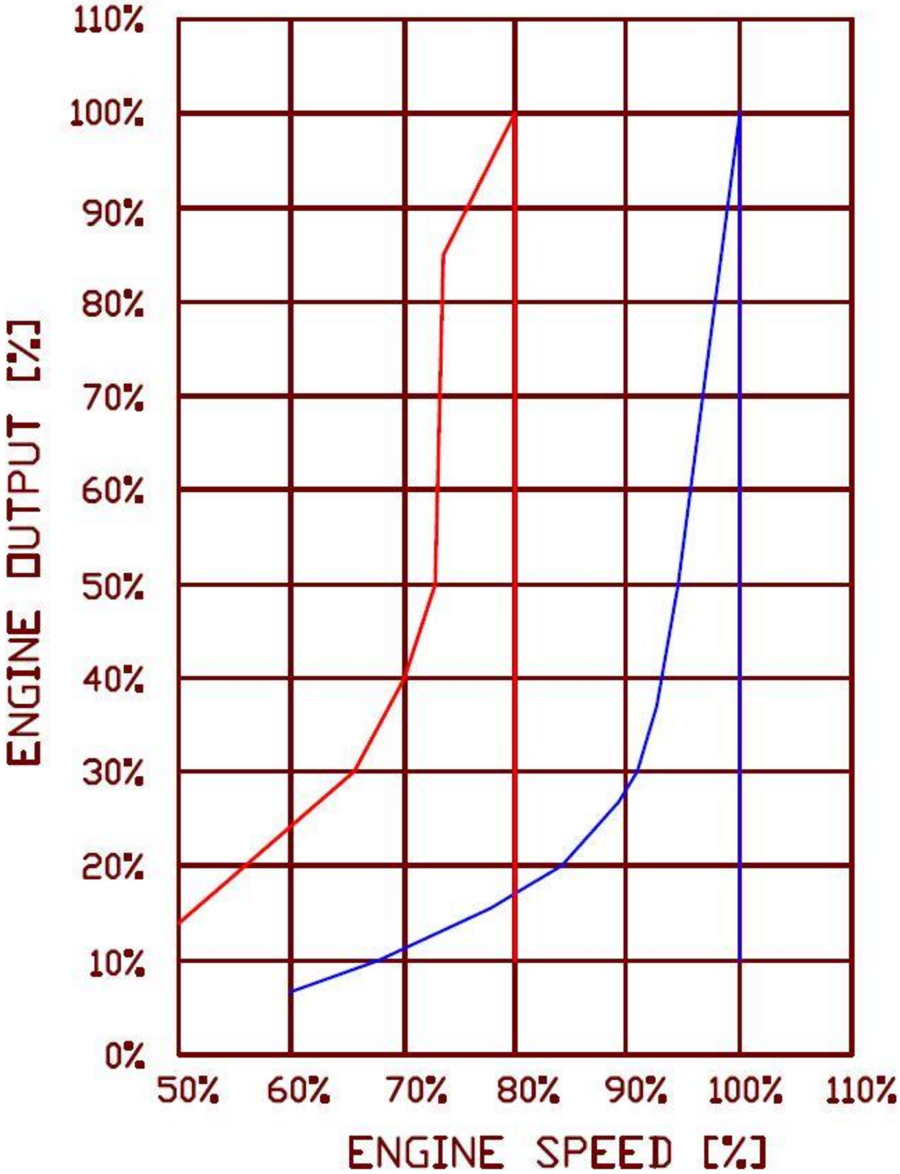


Figure 61. Output-Speed engines curve comparison.

Being, red curve for the current engine and blue curve for the dual fuel engine. As can be seen, for the same MCR, the dual fuel engine will work in a 20% higher speed, approximately. This speed increase directly affects to some equipment like PTOs, FI-FI pumps, gearbox and thrusters. Obviously, all this equipment may not work with the same efficiency as before, due to they were selected for working at 600 rpm. This is an important disadvantage in the feasibility of the retrofitting.

The optimum point of the dual motors is at 720/750 rpm, however, the propeller is designed to work at 600 rpm. This performance will suppose an incorrect performance of the propeller. To solve this problem, there are three alternatives:

- Make the motor to work at 600 rpm (although it is designed for 720/750 rpm), this situation will suppose that the motor won't work on its optimum point, jeopardizing its efficiency, resulting in more consumption, more cost and more contamination.
- Other option could be to replace the gearbox to an appropriated one. But here appears another problem; there will be a worst towing performance, which is very negative, especially when we are talking about a tugboat.
- To adjust the propeller pitch in order to obtain the same thrust with the new engine speed. It would be an expensive option, and would variate the operational features of the thrusters.

Estimations provided by the shipyard indicate that there would be a speed loss of 0,5 knots and between 9 and 10 tons of pulling power.

Related with these points, appears another problem apart from the propeller: in the case of the PTOs, the engine speed is intimately linked with the PTO working mode, so it would be also necessary and adjustment to keep the output features invariant even though the speed variation produced by the retrofitting.

3.6.7 List of actions for LNG use

Before the engine replacement, there are some actions that must be taken to carry out the engines retrofitting. At first, an auxiliary services review has to be done in order to check if this equipment could be used for the new engines or if it is necessary to replace any component.

By comparing the engines Project Guide a list of non-supported equipment could be done. As the output engine power is equal for both types, most of the auxiliary services does not have to be replaced, being only different the engine driven pumps and the modifications needed for the retrofitting does not have significant importance in the feasibility study. This is an important advantage for taking into account, due to the cost of the all auxiliary equipment installation would be so high that the feasibility will probably turn down.

For dual operation of the engine, it is required a gas feed system. The fuel gas system on the engine comprises the following built-on equipment:

- Low-pressure fuel gas common rail pipe
- Gas admission valve for each cylinder
- Safety filters at each gas admission valve
- Common rail pipe venting valve
- Double wall gas piping

The gas common rail pipe delivers fuel gas to each admission valve. The common rail pipe is a fully welded double wall pipe, with a large diameter, also acting as a pressure accumulator. Feed pipes distribute the fuel gas from the common rail pipe to the gas admission valves located at each cylinder.

The gas admission valves (one per cylinder) are electronically controlled and actuated to feed each individual cylinder with the correct amount of gas. The gas admission valves are controlled by the engine control system to regulate engine speed and power. The valves are located on the intake duct of the cylinder head. The gas admission valve is a direct actuated solenoid valve. The valve is closed by a spring (positive sealing) when there is no electrical signal. With the engine control system it is possible to adjust the amount of gas fed to each individual cylinder for load balancing of the engine, while the engine is running. The gas admission valves also include safety filters (80 µm).

The venting valve of the gas common rail pipe is used to release the gas from the common rail pipe when the engine is transferred from gas operating mode to diesel operating mode. The valve is pneumatically actuated and controlled by the engine control system.

In addition, for using gas fuel it is necessary a pilot fuel injection system. This pilot fuel injection system is used to ignite the air-gas mixture in the cylinder when operating the engine in gas mode. The pilot fuel system comprises the following built-on equipment:

- Pilot fuel oil filter
- Common rail high pressure pump
- Common rail piping
- Pilot fuel oil injection valve for each cylinder

The pilot fuel filter is a full flow duplex unit preventing impurities entering the pilot fuel system.

The high pressure pilot fuel pump is an engine-driven pump located at the driving end of the engine. The fuel oil pressure is elevated by the pilot pump to required level. The engine control system monitors and controls the pressure level during engine run.

Pressurized pilot fuel is delivered from the pump unit into a small diameter common rail pipe. The common rail pipe delivers pilot fuel to each injection valve and acts as a pressure accumulator against pressure pulses. The high pressure piping is of double wall shielded type and well protected inside the hot box. The feed pipes distribute the pilot fuel from the common rail to the injection valves.

The pilot fuel oil injection valve needle is actuated by a solenoid, which is controlled by the engine control system. The pilot diesel fuel is admitted through a high pressure connection screwed in the nozzle holder. When the engine runs in diesel mode the pilot fuel injection is also in operation to keep the needle clean.

The next figure shows the pilot fuel pipe marked in red:

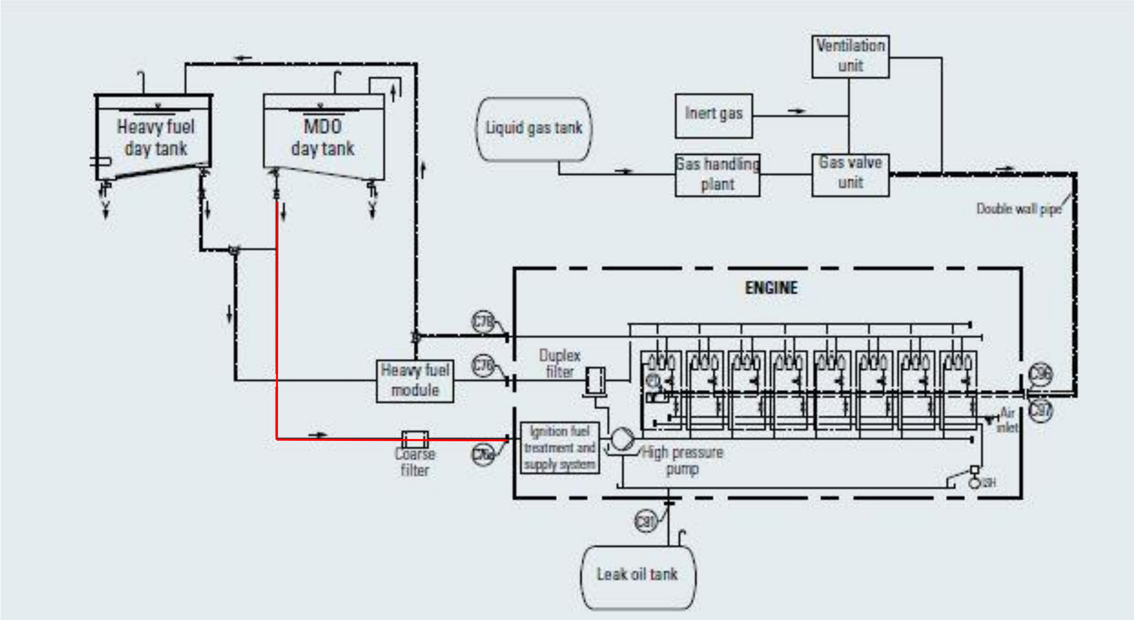


Figure 62. Dual fuel main engine gas system. Source Mak

The external fuel gas system, observed in the previous figure, is explained below:

Liquid gas tank

Type C tanks are considered leak proof, and no secondary barrier is required. The outer shell of the tank is a low temperature resistant material, typically stainless steel. It consists in cylindrical pressure vessels with dish ends.

The installation is easier than other systems and requires little maintenance. One of the advantages is that they allow pressure increase.

Gas handling plant

It is also known as tank connection space. It involves all the equipment and systems needed for normal operation of LNG as fuel. The main equipment contained in this unit are the Main Gas Evaporator (MGE), Pressure Build-up Evaporator (PBE) and the heating system.

The MGE function is a heat exchanger where the gas fuel and a water-glycol mixture flow in opposite senses in order to increase the gas temperature until it vaporizes.

The PBU is used for increasing the pressure in the LNG storage tank, to compensate the decreasing pressure suffered when supplying fuel gas to the engines. This unit allows to keep the pressure in the storage tank at a fixed value-

The heating system is used, as commented before, to increase the LNG temperature using a water-glycol mixture to heat it. This mixture flows by the action of the circulating pumps in a close circuit.

This gas handling plant shall be fitted with effective mechanical ventilation system, providing a ventilation capacity of at least 30 air changes per hour.

Ventilation unit

Gas piping system should be arranged with double wall piping. The space between the gas fuel piping and the wall of the outer pipe or duct should be equipped with mechanical under pressure ventilation.

Ventilation air inlet is located at the engine and the outside of the tank connection space at the end of the double wall piping. Ventilation air is recommended to be taken from the outside of the engine room and safe area and equipped with a valve to regulate the air flow. The requirement of air exchange in double piping system is minimum 30 air changes per hour, this number is based on classification societies.

Air flowing will be supplied to Gas Valve Unit room or to the enclosure of the gas valve unit. From the enclosure of the gas valve unit, the air will be ventilated by using ventilation fans and the air will be supplied to the safe area. Also, the ventilated air outlet should be placed in a position where no flammable gas and air mixture may be ignited and should be installed the gas detector to control any losses of the required ventilating capacity.

Gas Valve Unit

Before the gas is supplied to the engine it passes through a Gas Valve Unit (GVU). The GVU include a gas pressure control valve and a series of block and bleed valves to ensure reliable and safe operation on gas.

The unit includes a manual shut-off valve, inerting connection, filter, fuel gas pressure control valve, shut-off valves, ventilating valves, pressure transmitters/gauges, a gas temperature transmitter and control cabinets.

The filter is a full flow unit preventing impurities from entering the engine fuel gas system. The pressure drop over the filter is monitored and an alarm is activated when pressure drop is above permitted value due to dirty filter.

The fuel gas pressure control valve adjusts the gas feed pressure to the engine according to engine load. The pressure control valve is controlled by the engine control system. The system is designed to get the correct fuel gas pressure to the engine common rail pipe at all times.

Readings from sensors on the GVU as well as opening and closing of valves on the gas valve unit are electronically or electro-pneumatically controlled by the GVU control system.

The two shut-off valves together with gas ventilating valve (between the shut-off valves) form a double-block-and-bleed function. The block valves in the double-block-and-bleed function effectively close off gas supply to the engine on request. The solenoid operated venting valve in the double-block-and-bleed function will relief the pressure trapped between the block valves after closing of the block valves. The block valves and inert gas valve are operated as fail-to-close, i.e. they will close on current failure. Venting valves are fail-to-open, they will open on current failure. There is a connection for inerting the fuel gas pipe with nitrogen. The inerting of the fuel gas pipe before double block and bleed valves in the GVU is done from gas storage system. Gas is blown downstream the fuel gas pipe and out via vent valve on the GVU when inerting from gas storage system.

During a stop sequence of DF-engine gas operation (i.e. upon gas trip, pilot trip, stop, emergency stop or shutdown in gas operating mode, or transfer to diesel operating mode) the GVU performs a gas shut-off and ventilation sequence. Both block valves on the gas valve unit are closed and ventilation valve between block valves is opened. Additionally on emergency stop ventilation valve will open and on certain alarm situations the will inert the gas pipe between GVU and the engine.

The gas valve unit will perform a leak test procedure before engine starts operating on gas. This is a safety precaution to ensure the tightness of valves and the proper function of components.

One GVU is required for each engine. The GVU has to be located close to the engine to ensure engine response to transient conditions. The maximum length of fuel gas pipe between the GVU and the engine gas inlet is 10 m.

<u>Inert gas</u>

In gas valve unit system, there is a gas inert connection where before maintenance work is commenced on the engine and/or the GVU, it is required that any remaining natural gas is removed by substituting the natural gas with an inert gas, for example nitrogen.

The GVU inerting process ensures that natural gas cannot leak to the surrounding areas, thus eliminating potential risks. If there is a failure of fuel gas supply system, block valve will be automatically closed and vent valve will be automatically opened. During this situation, the piping will be automatically purged with inert gas system, therefore on the dual fuel engine, an inert gas valve should be installed. In case the nitrogen purging system fails, the gas pipe is once purged with charge air and a gas blocking is set. Thus an explosive atmosphere can only occur seldom and for short periods. Operation in gas mode is only possible if nitrogen pressure is available and gas blocking alarm has been reset by operator.

3.7. Electric power plant: initial characteristics and actions to be carried out for adaptation to LNG on the current installation.

All the equipment this type of vessel has, and the different operational conditions in which it has to work, creates a large requirement of electrical power supply. The equipment has four alternator of equal power that allows, in navigation, to use one alternator that can give full service to the vessel and by the use of two, three or the four alternators connected in parallel, give service in special conditions as can be the electrical supply to other ships.

3.7.1 Main generating sets

Each main generating set must be able to attend the necessary services on navigation or moving. There are two units of this type installed, which are diesel-electric generators. This means that they are composed by a diesel engine (internal combustion engine) and an alternator that is power by that engine, providing 910 ekW. The model of these generators is the CAT 3508B manufactured by Caterpillar, and their characteristics can be seen below:

Figure 63. Auxiliary group. Source: Caterpillar.

Model	Output ekW/kVA)	Diesel engine power (kW)	Engine speed (rpm)	Mean piston speed (m/s)	Bore (mm)	Stroke (mm)	Specific fuel consumption (l/h)		
							100% Load	75% Load	50% Load
3508 B	910/1,138	968	1,800	11.4	170	190	234	179	125

Figure 64. Main generating sets characteristics. Source: Caterpillar.

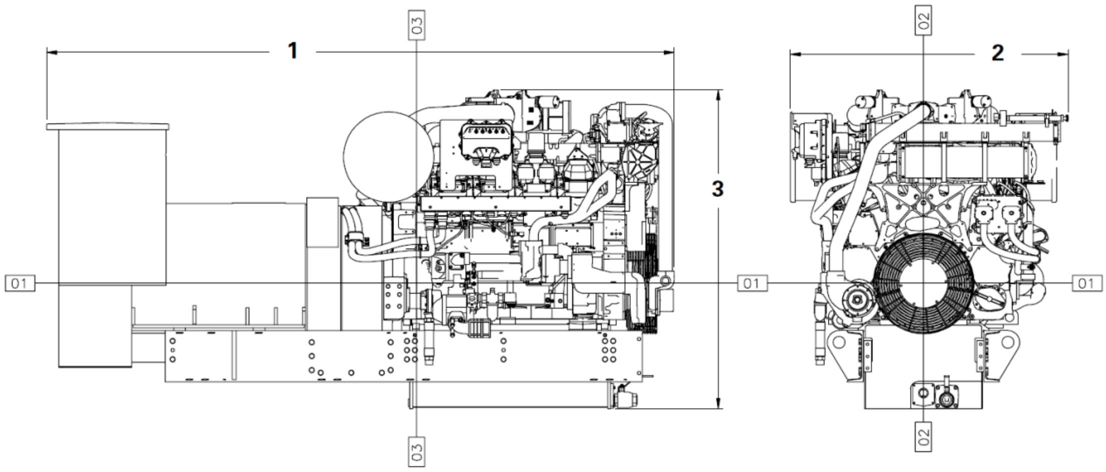


Figure 65. Main generating sets dimensions. Source: Caterpillar.

1 - Length (mm)	2 – Width (mm)	3 - Height (mm)	Weight (t)
4,031	1,784	2,048	12.475

Table 56. Main generating sets dimensions and weight. Source: Caterpillar.

3.7.2 Shaft generators/PTO

Two units model HCM-7E, manufactured by STAMFORD, that provide 800 kW of power, using the power from the main engines to generate electricity. With the use of both alternators the vessel service is covered for navegation and special operations.

Because of the equipment of this type of generators it is able, with the propulsion operative, to work all the systems of the vessel, even give service to other ships having the main generating sets disconnected or damaged.

3.7.3 Emergency/Harbour generating set

There is only one unit of this type, fitted on the main deck. The model is 3406, and is composed by a diesel engine manufactured by Caterpillar and an alternator manufactured by Leroy Somer, and providing 352 kW of electric power. The characteristics of these components are:

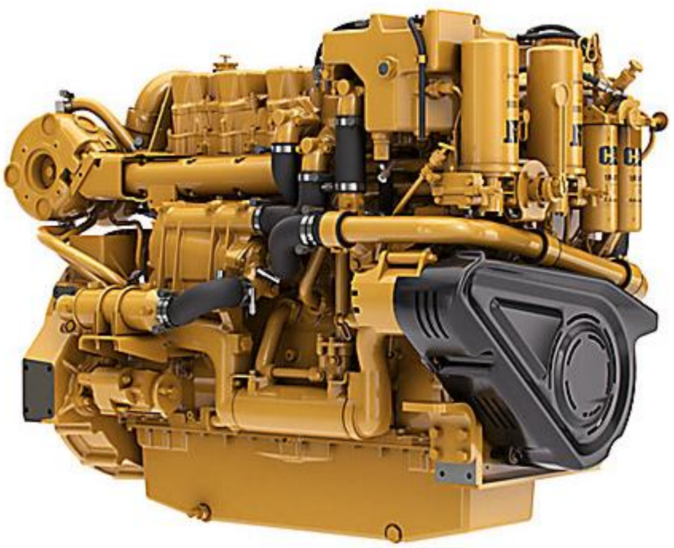


Figure 66. Harbour generating set diesel engine. Source: Caterpillar.

Model	Maximum output (kW/bhp)	Maximum rotatory speed (rpm)	Bore (mm)	Stroke (mm)	Specific fuel consumption at 100% MCR (g/kW*h)
3406C	533/715	2,100	145	183	223.9

Table 57. Harbour generating set diesel engine characteristics. Source: Caterpillar.

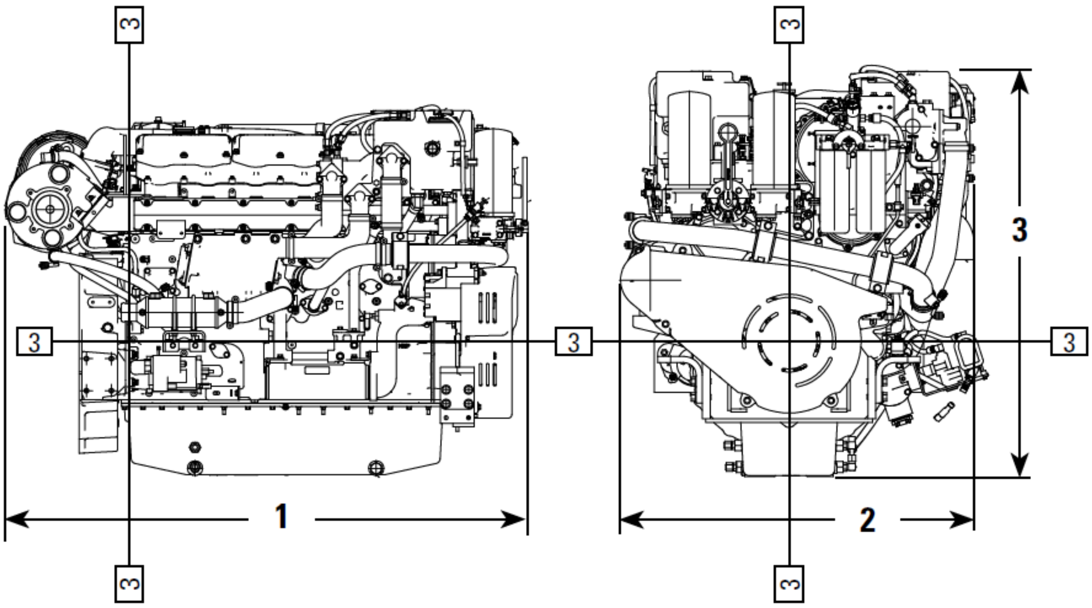


Figure 67. Harbour generating set diesel engine dimensions. Source: Caterpillar.

1 - Length (mm)	2 – Width (mm)	3 - Height (mm)	Weight (t)
1,854	1,134	1,300	1.95

Table 58. Harbour generating set diesel engine dimensions and weight. Source: Caterpillar.

Model	Output (kVA/kW)	Voltage (V)
47.1 L 10	440/352	400

Table 59. Harbour generating set alternator characteristics.

If the port where the vessel berths has available electrical connection, it is used instead of this generator. This prevents air pollution during the large periods of ready for emergency harbour operation.

3.7.4 Adaptation actions for LNG use

3.7.4.1 Dual fuel generating sets:

The current power plant consists of two diesel-electric sets, which supply the electrical power needed to attend all the vessel operation modes. To fulfill the new requirements of using LNG as fuel for electrical power generation the selection criteria must be in terms of power equality. Attending to these criteria, the selected engines correspond with the 6L20DF genset manufactured by Wärtsilä, which provides an output power of 960 kW. As the output power of both engine types are similar, the number of auxiliary engines does not differ, so the power plant keeps the same distribution in terms of engine disposition.

The main features of these genset are shown in the table below:

Model	Engine output (kW)	Generator output (ekW/kVA)	Revolutions (rpm)	BMEP (bar)
6L20DF	960	920/1150	1000	21,8

Table 60. Dual fuel generating set main features. Source: Wärtsilä.

In the following table are presented the different specific fuel consumptions depending on the working engine load in both diesel and gas working modes:

% Load	Diesel (g/kWh)	Gas (KJ/kWh)
100	195	8048
75	169	8326
50	207	8862

Table 61. Dual fuel generating set specific consumptions. Source: Wärtsilä.

As the same as before, using the LHV and density values the specific consumptions could be presented in terms of tonnes and cubic meters per hour, as the next table shows:

% Load	Gas consumption	
	(t/h)	(m3/h)
100	0,156	0,347
75	0,121	0,269
50	0,086	0,191

Table 62. Dual fuel generating set gas fuel consumptions. Source: Wärtsilä.

The engine dimensions are detailed in the following sketch and table:

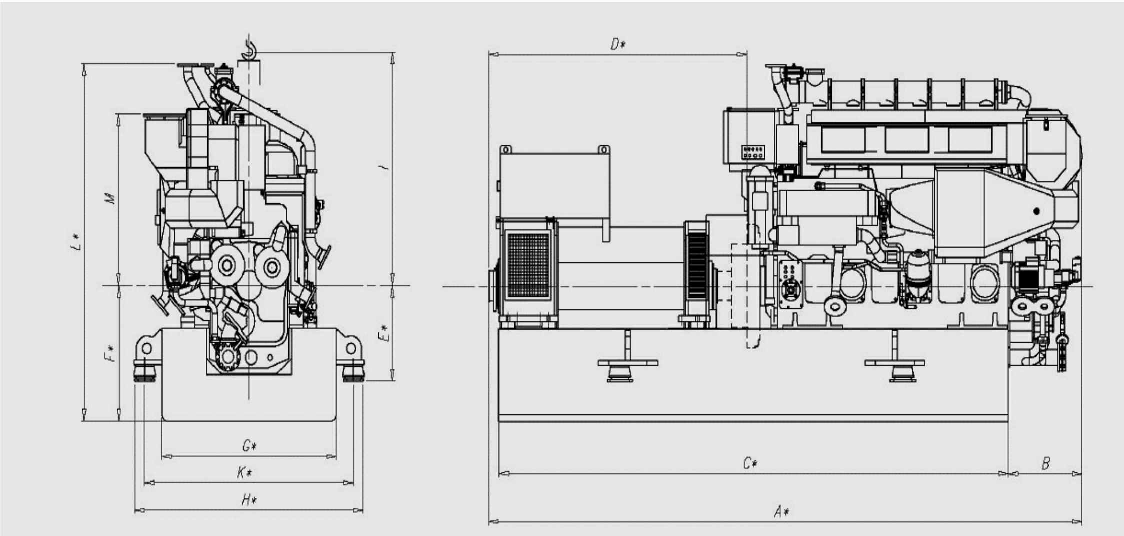


Figure 68. Dual fuel generating set main dimensions. Source: Wärtsilä.

	Dimensions (mm)												Weight (tonnes)
Engine type	A*	B	C*	D*	E*	F*	G*	H*	I	K*	L*	M*	
W 6L20DF	5325	663	4575	2300	725	895	1270	1770	1800	1580	2605	1299	16,9

Table 63. Dual fuel generating set main dimensions. Source: Wärtsilä

All the dimensions marked with an (*) may differ from the values given depending on the generator and flexible coupling.

3.7.4.2 Current and LNG generation sets comparison:

As it has been made with the main engines, in this part are going to be compared the auxiliary groups main features. The comparison between auxiliary engines follows the same scheme as the main engines done. It is divided in three parts, being the first for the main features, the second for fuel consumptions and the third for dimensions and weight.

Type	Engine output (kW)	Generator output (kVA)	Revolutions (rpm)	BMEP (bar)
C350 8B	958	1138	1800	18,51
6L20DF	960	1150	1000	21,8

Table 64. Current and dual fuel generating sets main features comparison.

As power was the main criteria for selecting an appropriate auxiliary engine, both engine outputs are practically the same, so the engine selected may be a suitable option for replacing the current auxiliary engines. In this case, the speed difference between engines is not an important fact, due to there is not any restriction about the engines speed as in the main engines case.

The next table shows the specific fuel consumption at some engine power loads:

	C350 8B	6L20DF	
% Load	Diesel (t/h)	Diesel (t/h)	Gas (t/h)
100	0,196	0,187	0,156
75	0,150	0,122	0,121
50	0,105	0,099	0,086

Table 65. Current and dual fuel generating sets consumptions comparison.

As can be seen, the diesel fuel consumptions are in the same range for both engines, specifically the dual fuel engine has lower fuel consumption than the other, and the gas consumption is also in a similar range. So in consumptions terms, the dual fuel auxiliary engine seems a suitable choice.

Finally, the table below shows the engine dimensions and weight:

Type	Dimensions (mm)			Weight (t)
	Length	Width	Height	
C350 8B	4031	1784	2048	12,75
6L20DF	5325	1770	2695	16,9

Table 66. Current and dual fuel generating sets main dimensions comparison.

As it was predictable, the engine dimensions are practically the same for both cases, so, at first, there will not be any problem on the engines replacing in space capacity terms.

It is important to note that in this comparison has not been taken into account all the LNG necessary services for the dual fuel engine installation, which involves some limitations that will be explained in other sections.

3.7.5 List of actions for LNG use

In contrast to the main engines case, the dual fuel gensets are not from the same manufacturer as the current ones. It means a not compatibility as in the main engines case achieved. However, for the generation sets, compatibility is not as important as for the main engines, due to the most important fact is to achieve a similar power generation and frequency, independently of the speed or other features, and because in generation sets most of the auxiliary services are integrated within them.

The most important fact is the installation of the gas system, which allows using LNG as fuel. The gas fuel is stored in the same tank as the gas fuel for the main engines, but it is necessary to install a Gas Valve Unit for each engine and the pipe and vent lines.

The fuel gas feed system is the same as for the main engines, explained on previous points. So, the actions to carry out the retrofitting are practically the same, excepting the installation of the GVU for each engine.

3.8. Sizing of LNG storage and processing equipment. Design alternatives

In this chapter there will be studied the gas needs to feed the different motor alternatives chosen from different companies, therefore, there will be a calculation of how much gas does need these motors to provide an acceptable performance given by SASEMAR. Once these calculations are done, it is necessary to find a tank, and check if it fits within the volume provided.

3.8.1 General characteristics

3.8.1.1 Location and requirements

It is necessary to find an optimal location for the tanks, two alternatives will be discussed: to install it on the main deck of the ship or inside the recoil tanks, choosing the most suitable locations and capacity.

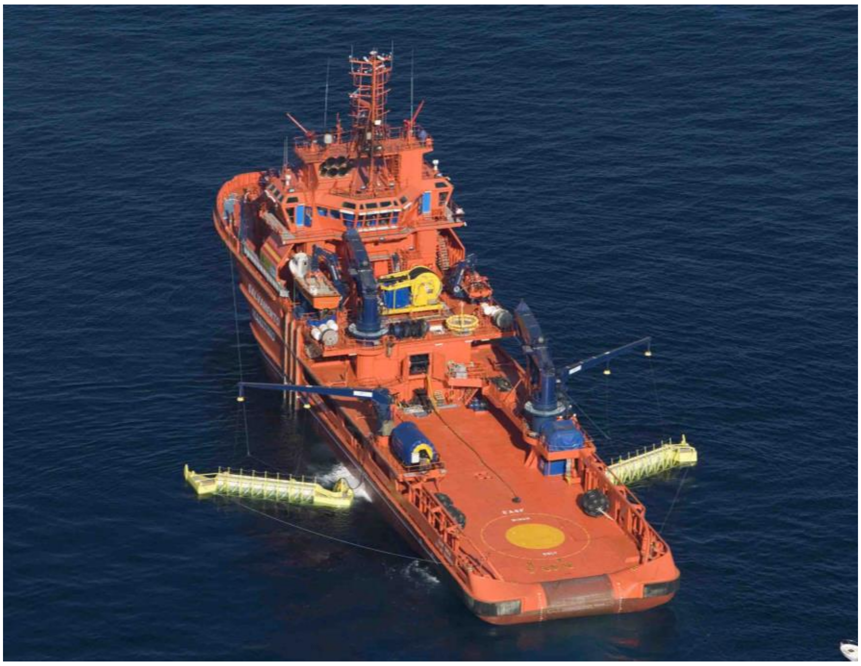


Figure 69. View of the ship *Cervantes*.

Location on main deck

According to SASEMAR, it is possible to use two of the three recoil tanks, because only this space can be used to house the LNG tanks.

At this type of ships, one alternative is to install the tanks on the main deck, this solution has a lot of advantages, because it allows a lot of space for the tank, even being large.

So, it could be a possibility, but there are some reasons why it is not possible:

The main reason is that this ship needs a free deck to assure its effectiveness during the different labours she can develop. To put a big tank in the deck would provoke big problems for the crew to carry out the different works for that this ship was built. Specially it would be very negative for the rescue, towing and recoil labours, as it will be shown in the following points, this location would not let the ship to work, so, this alternative will not be further studied.

Location inside the recoil tanks:

Another possibility would be to install the LNG tank inside the two of the three recoil tanks located at the stern of the ship because it is the only space feasible to be used without jeopardizing the operations on board. They are the tanks marked in red in the following image:

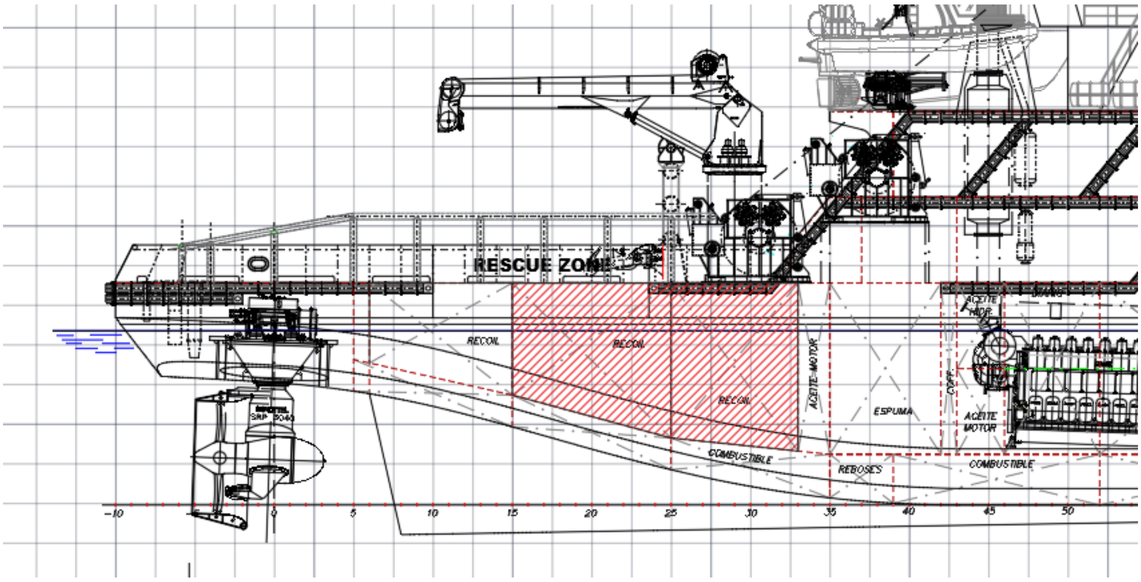


Figure 70. Lateral view of the recoil tanks position.

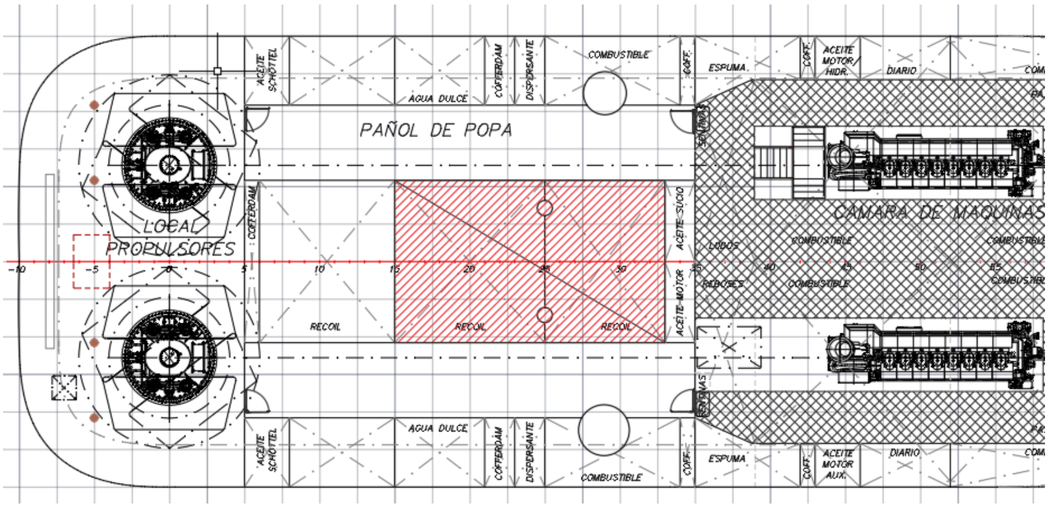


Figure 71. Top view of the recoil tanks position.

3.8.1.2 Suppliers

Tanks from many suppliers have been reviewed, but the information about gas handling, sizes, dimensions, and systems integrated into the tanks from Wärtsilä and MAN suppliers is available, for this reason in this report these two companies have been chosen to continue looking into the possibility of installing LNG tanks inside the recoil tanks.

Wärtsilä supplier

The first alternative for gas storage is the LNGPac, designed according to Type C requirements of the IMO's IGF code. The different sizes provided by the company are as follows:

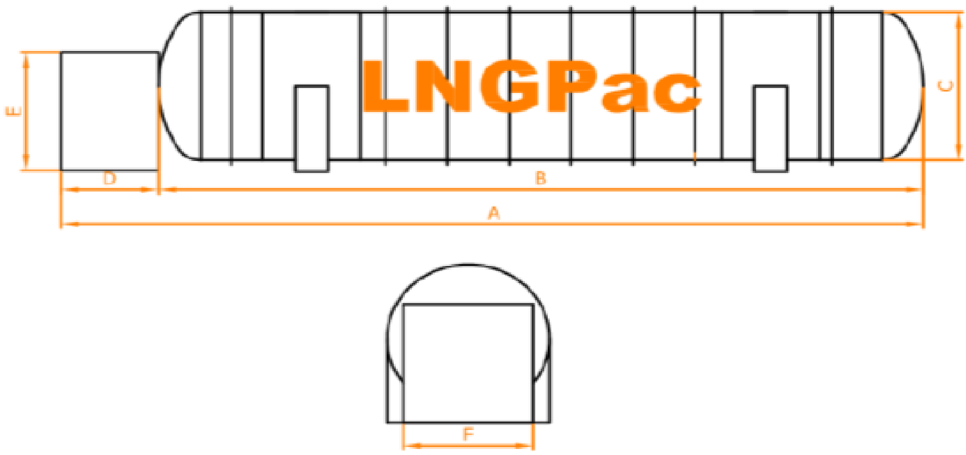


Figure 72. Main dimensions of the LNGPac. (Image extracted from Wärtsilä's brochure).

This system provides a safe way to handle the gas in a simpler way, according with IGC code (and according to IMO guidelines, would be a Type C tank) and IMO resolution MSC.285(86). It is specially design to fit with Wärtsilä's products, although it can be used with other motor brands.

These tanks are pressurized and composed by two vessels: a stainless-steel vessel, which is main designed to resist the pressure of the gas. Adding to this vessel, there is another external one composed of stainless steel or carbon steel. The ability to withstand pressure of the Type C tanks allows flexibility in the operation.

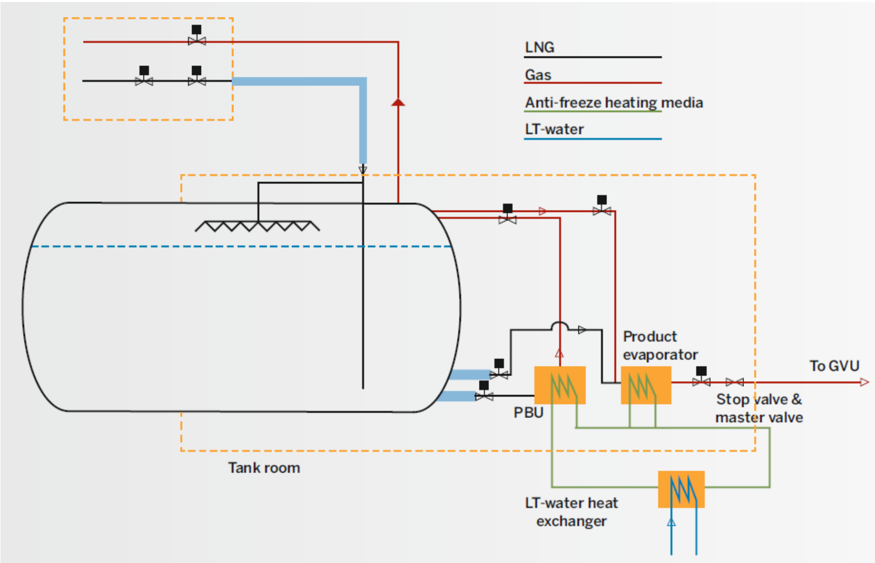


Figure 73. View of the gas handling (extracted from Wärtsilä's brochure).

Inside the coldbox are the PBU and product evaporator. The circulation to the PBU evaporator is achieved by the hydrostatic pressure difference between the top and the bottom of the tank (the evaporated gas will return to the top of the tank). This is a very important aspect because inside the system there is no cryogenic pumps or compressor.

There is a *product evaporator*, it consists of:

- Insulated pipe
- Evaporator
- Single wall pipe
- Valves
- Sensors

The evaporator converts LNG into gas. Then this gas will be delivered to the Gas Valve Units (GVU) and then it will be used in the engine.

MAN supplier

Figure 74. View of the LNG tanks MAN Cryo.

The second alternative will be the tanks MANcryo, provided by MAN company. These tanks follow the safety measures and the IMO codes according to the vacuum insulated C-Type tanks. It has a cold box attached, with a system fully automated, this coldbox contains the Vaporiser Unit, and the Pressure Build-up Unit. The work pressure inside these tanks is between 6 and 9 bar.

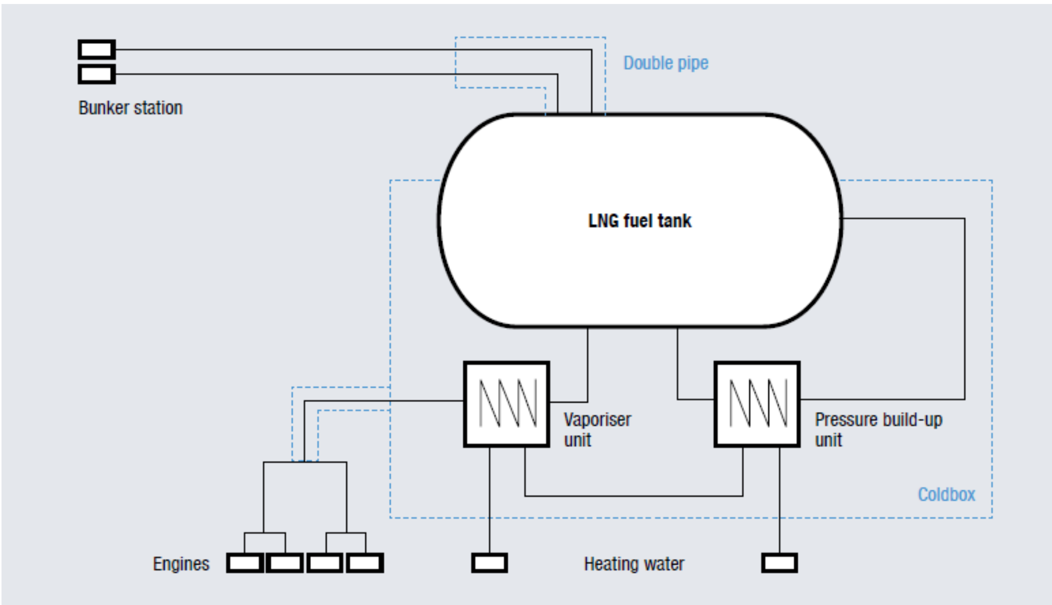


Figure 75. Gas handling of MAN Cryo (extracted from MAN's brochure).

The table below shows the different sizes offered by this company. As it is shown, there are many of them, the aim will be to find the one that fits the best with the gas needed, and check if it is possible to fit it inside the old recoil tanks, taking care of the rules about handling gas as a fuel, and the space considered by SASEMAR.

Type	Volume	Diameter	Length, incl. coldbox	Weight
Horizontal	30 m^3	3.6 m	8.8 m	26 tons
Horizontal	75 m^3	3.6 m	14.8 m	40 tons
Horizontal	115 m^3	4.2 m	14.5 m	50 tons
Horizontal	125 m^3	3.6 m	19.9 m	55 tons
Horizontal	201 m^3	5.3 m	15.5 m	80 tons

Figure 76. Sizes of the LNG tanks MAN Cryo. (Extracted from MAN's brochure)

So, these sizes will be taken into account to work with MAN supplier tanks, choosing the smallest as possible to fit it in the different operational modes that will be described in the following items.

The tank sizes shown are the standard ones. In case that specific size is required, it could be required to the suppliers.

3.8.2 Calculations for 1st Operational mode

First of all, it is necessary to perform calculations to know the gas needs of the different motors, so, the alternatives are as follows, and main requirements, in which these calculations are based.

Autonomy data	
Required nav. Days	2
Required days port	10
Speed [Knots]	13,4
Miles	643,2
Main Motors	2xMAK 8M34DF
Auxiliary Motors	2xWärtsilä 6L20DF

Table 67. Main requirements

3.8.2.1 Gas calculations

There are two situations:

- In **port** is necessary to use an auxiliary motor during 10 days. As the auxiliary genset will be used with the power requirements of the port generator.
- In **navigation** situation, it will be necessary to provide gas to the two main motors to work 2 days at the 85% of the power load.

The data of the main and auxiliary engines, were extracted from the project guides of the manufacturers:

Type of motors	ENGINE	LOAD (%)	MCR (kW)	FUEL COMPSUMPTION (KJ/kWh)
Main	MAK 8M34DF	85	4000	7777
Auxiliary	Wärtsilä 6L20DF	74	453	8048

Table 68. Main and auxiliary motors characterestics.

And the values of the LNG that will be taken into account:

Density [t/m^3]	LOWER HEATING VALUE (MJ/kg)
0,45	49,5

Table 69. Properties of the LNG.

Some calculations have been performed to figure out the quantity of LNG that these motors will need to work in this operational mode:

NAVIGATION (two main motors working at 85% of power load):

Calculations for main motors:

$$\left(\frac{Load[\%] \cdot MCR[kW] \cdot Comp.[KJ/kWh]}{LHV[Kj/kg]}\right) = \left(\frac{3400 \cdot 7777}{49{,}5\text{x}10^3}\right) = 534{,}2\ [kg/h]$$

And the volume of gas needed:

$$N_{motors} \cdot \frac{Nav.time[h] \cdot Consumption\left[\frac{t}{h}\right]}{Density\ LNG\left[\frac{t}{m^3}\right]} = 2 \cdot \frac{48 \cdot 0{,}5342}{0{,}45} = \boxed{\mathbf{113{,}96[m^3]}}$$

PORT (auxiliary motor working at 100% of power load):

Auxiliary motor (consume per unit), the calculations will follow the same path:

$$\left(\frac{MCR[kW] \cdot Comp.[KJ/kWh]}{LHV[KJ/kg]}\right) = \left(\frac{453 \cdot 8048}{49{,}5\text{x}10^3}\right) = 73{,}6\ [kg/h]$$

And the volume of gas needed:

$$\frac{Port.time[h] \cdot Consumption\left[\frac{t}{h}\right]}{Density\ LNG\left[\frac{t}{m^3}\right]} = \frac{240 \cdot 0{,}0736}{0{,}45} = \boxed{\mathbf{39{,}28[m^3]}}$$

As a result, the volume of LNG needed, with a margin of 5%, will be:

Condition	Capacity of LNG required (m^3)
Navigation	119,7
Port	39,28

Table 70. Capacity of LNG required for each condition.

3.8.2.2 *Wärtsilä supplier*

The capacity of both volumes would be 159 m^3, for the purpose of the present study, and considering the size of the vessel, it is going to be taken the maximum volume which is 119,66 m^3. So, a tank with enough volume for this situation will be considered, the different choices are shown in the following points:

Type	Units	LNGPac 105	LNGPac 145	LNGPac 194
Geometric Volume	[m^3]	105	145	194
Net Volume (90%)	[m^3]	95	131	175
Diameter (C)	[m]	3,5	4	4,3
Tank length (B)	[m]	16,7	16,9	19,1
Tank room (D)	[m]	2,5	2,5	2,7
Total length (A)	[m]	19,2	19,4	21,8

Table 71. Dimensions for the Wärtsilä's LNGPac.

The *LNGpac 145* is the one which fits the best with the requirements of 119,66 m^3 of net volume with its 131 m^3. The tanks have been modelated in Rhinoceros 3D program:

The tank must fit inside the old recoil tanks located at the stern of the ship. The shipowner allows to eliminate two of three of these tanks. However, as can be seen in the following image, the size of the LNGPac, is extremely large comparing to the container tank at the stern.

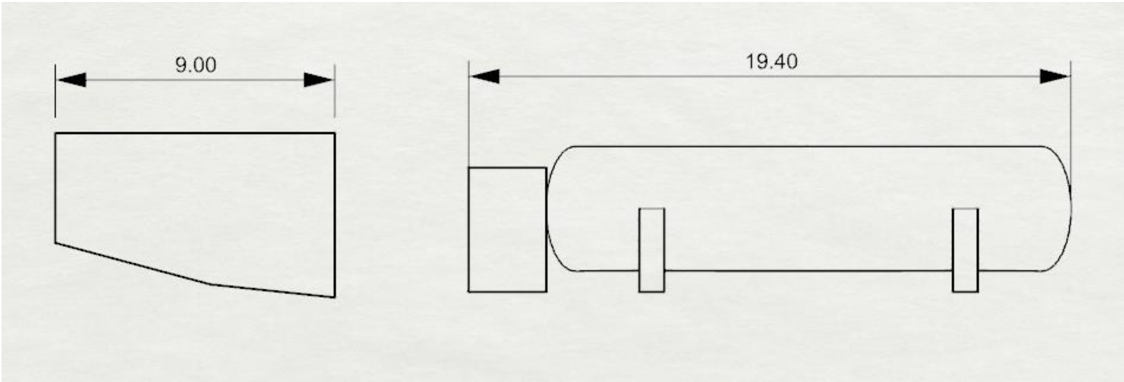


Figure 77. Lateral view of recoil tanks and LNGPac. (Dimensions in [m]).

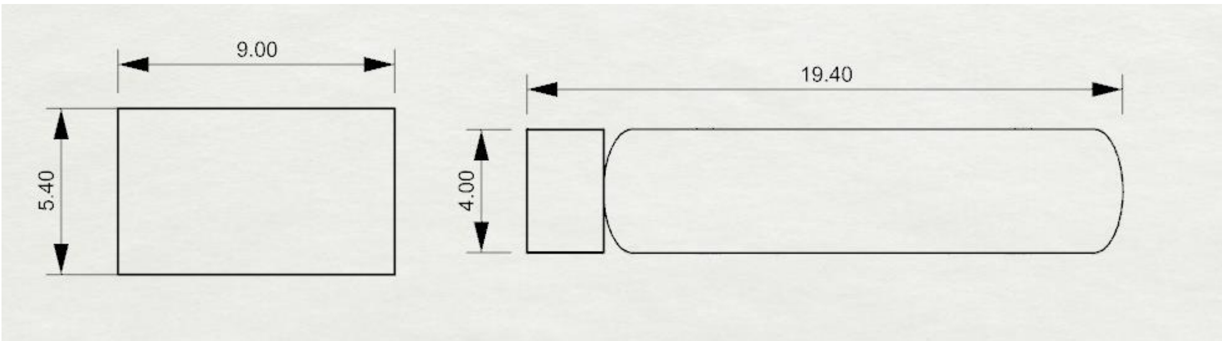


Figure 78. Top view of recoil tanks and LNGPac. (Dimensions in [m]).

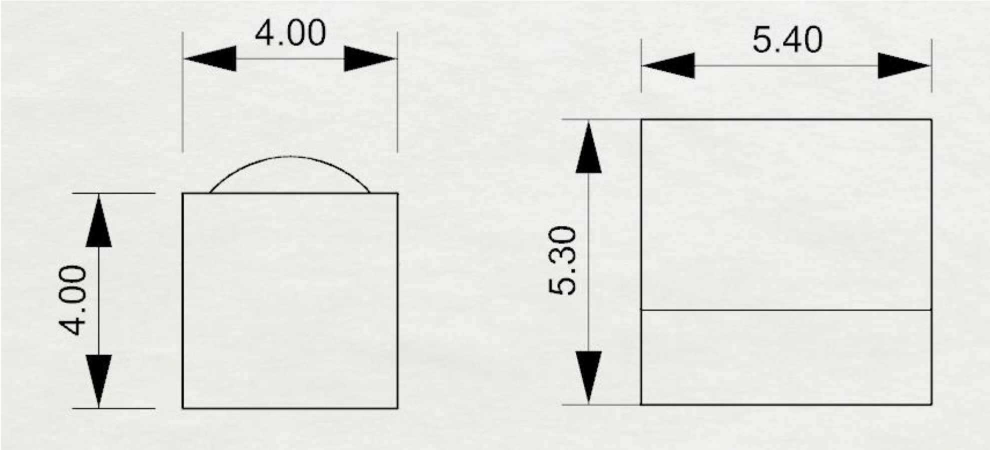


Figure 79. Front view of recoil tanks and LNGPac. (Dimensions in [m]).

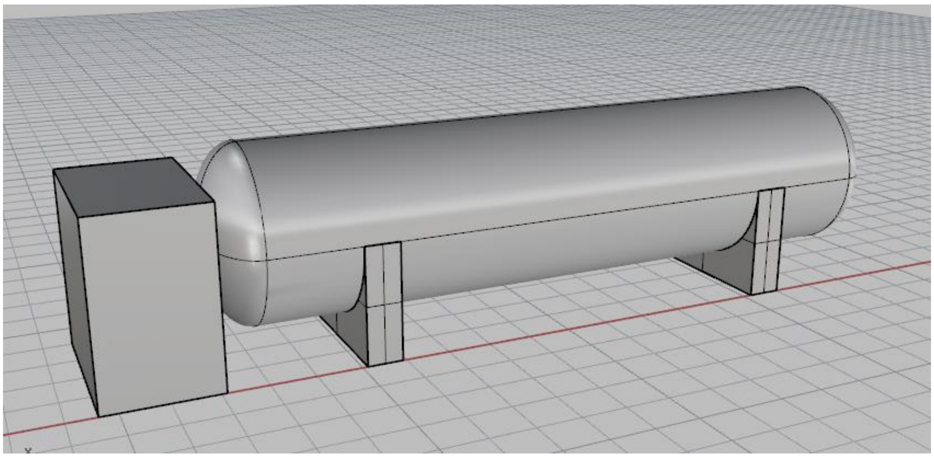


Figure 80. View of the tank in 3D

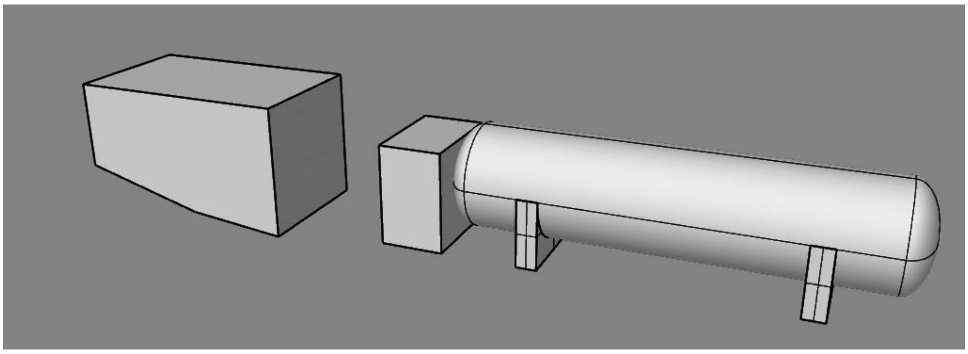


Figure 81. Comparison between tanks in 3D.

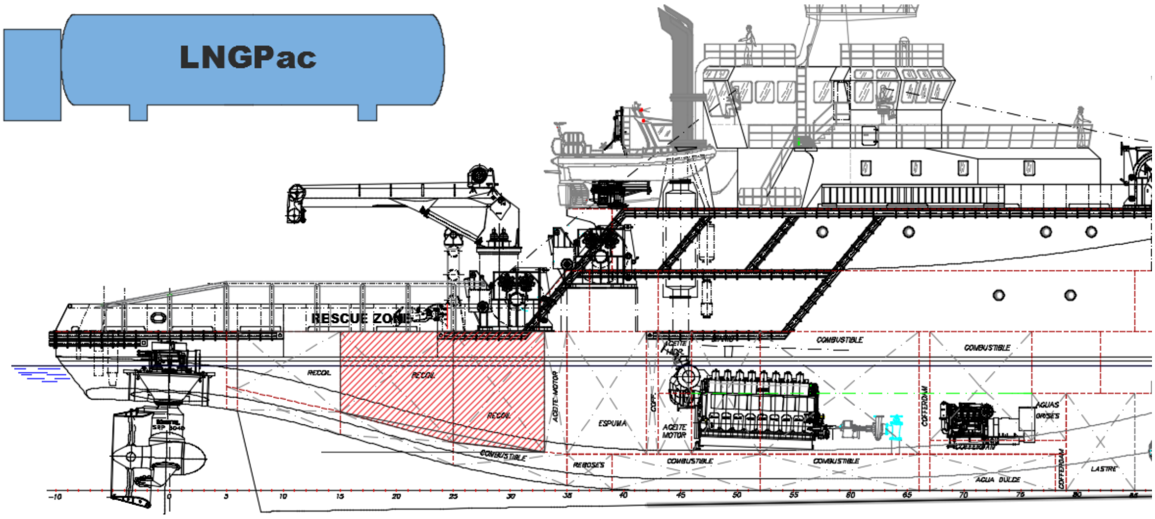


Figure 82. Side view of comparison between LNGPac and ship.

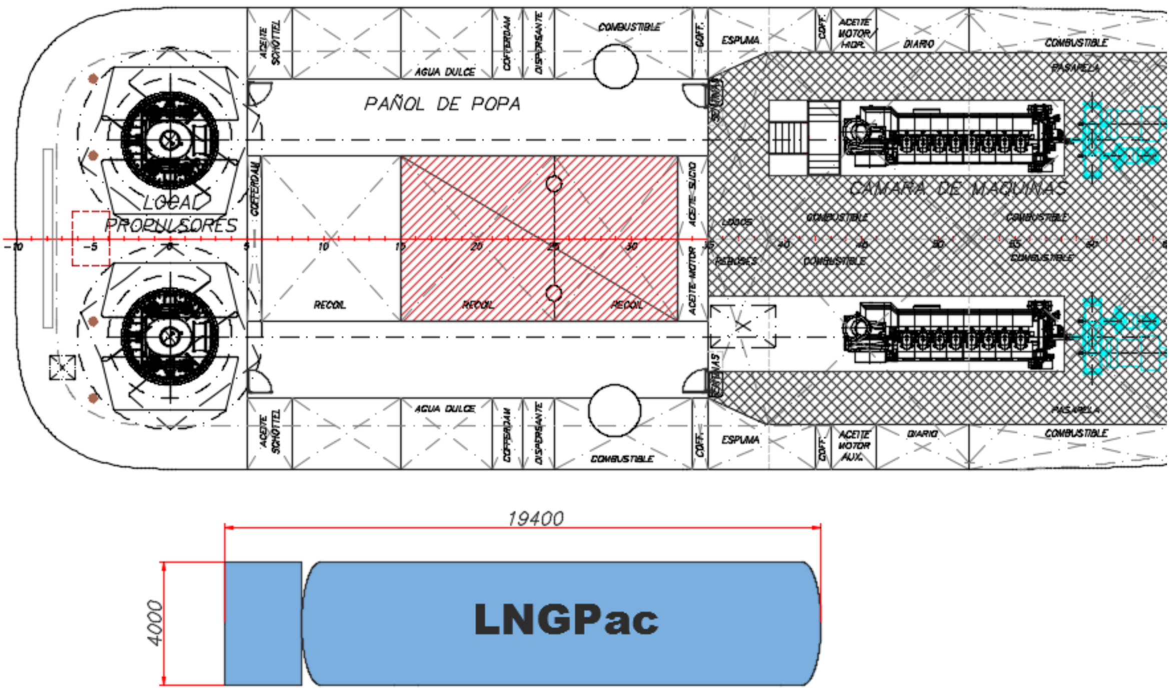


Figure 83 . Top view of comparison between LNGPac and ship.

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The problem can be identified at a glance. The LNGPac has a huge size comparing to the recoil tanks, and it is impossible to house the LNG tank inside it. For this reason, in this operational mode, there is not a satisfactory solution.

Comparison			
Recoil tanks		**LNGPac**	
Length [m]	9,5	Length [m]	19,4
Breadth [m]	5,4	Breadth [m]	4

Table 72. Comparison between LNG tank and recoil tanks.

In conclusion, according to the volume calculation and the standard tank dimensions available, it is not feasible to do the retrofitting labours, because the tanks are too large in comparison with the available space, which makes it impossible to storage enough LNG to satisfy the requirements for this operational mode.

3.8.2.3 MAN supplier

In this case the products of supplier MAN will be used to check if it is possible to fit their gas tanks MANcryo inside the recoil tanks, according to the gas needs calculated at the beginning of the point.

The horizontal C-Type tanks available are the following ones:

Volume [m^3]	Diameter [m]	Length including coldbox [m]	Weight [tons]
30	3.6	8.8	26
75	3.6	14.8	40
115	4.2	14.5	50
125	3.6	19.9	55
201	5.3	15.5	80

Table 73. Different MAN Cryo sizes provided by the company.

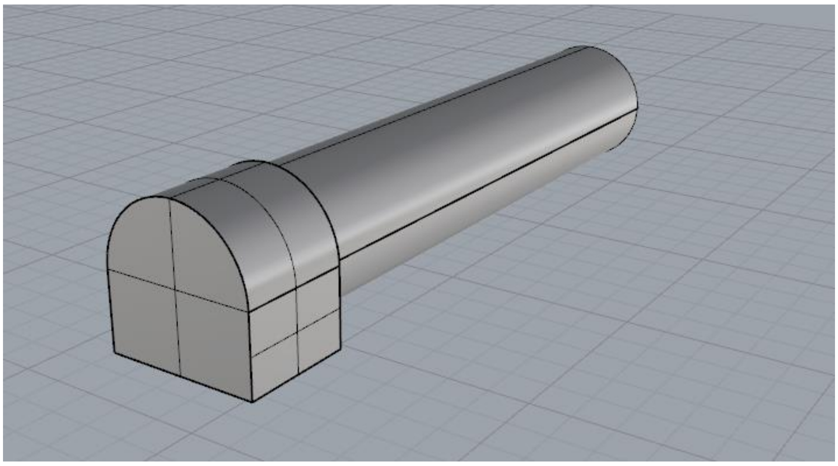


Figure 84. View of the MAN cryo tank in 3D.

The smallest tank that is capable of contain the 120m^3 of gas needed, is the one highlighted in bold. So, this tank will be modelated in 3D to compare its dimensions with the tank.

The views of the tank are as follows:

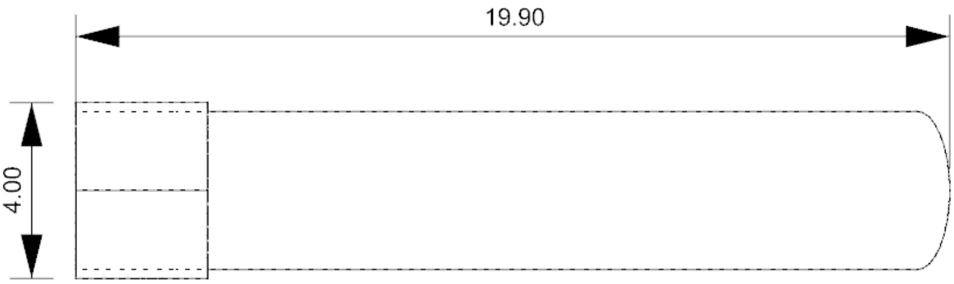


Figure 85. Side view of MAN Cryo tank.

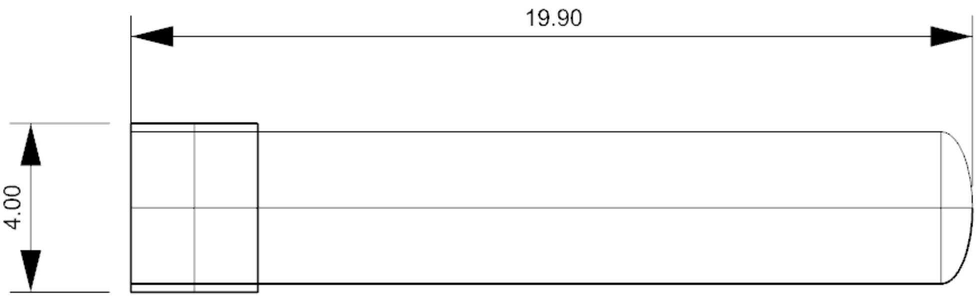


Figure 86. Top view of MAN Cryo tank.

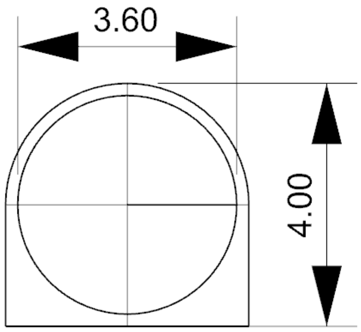


Figure 87. Front view of MAN Cryo tank.

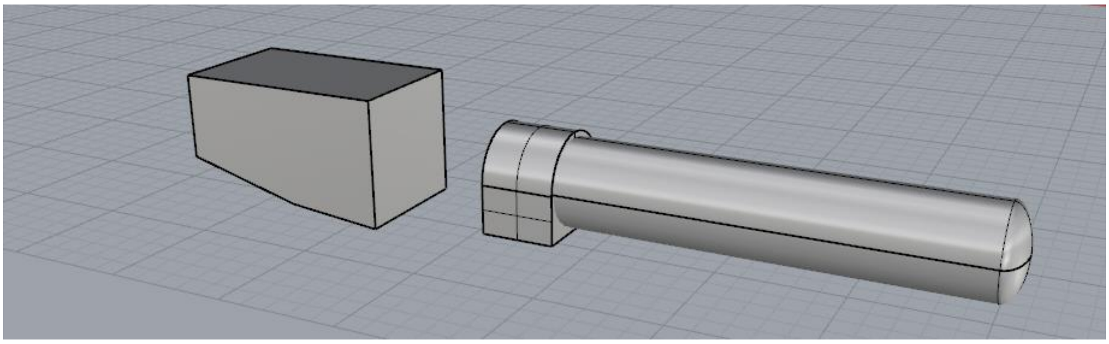


Figure 88. Comparison between tanks

And the comparison between the recoil tanks, the main deck and the MANCryo tank, is as showed in the following images:

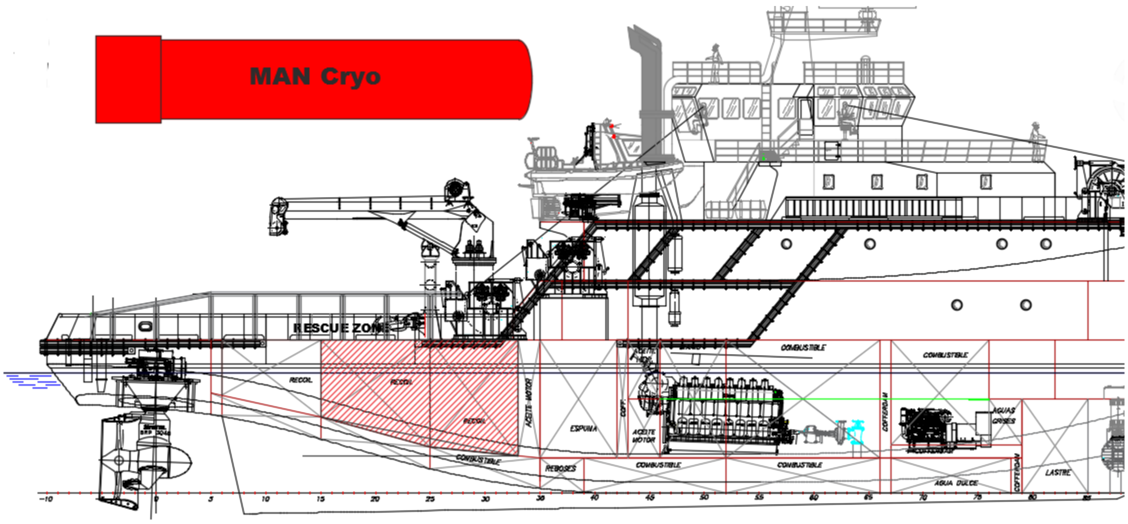


Figure 89. Side view of comparison between MAN Cryo and the ship.

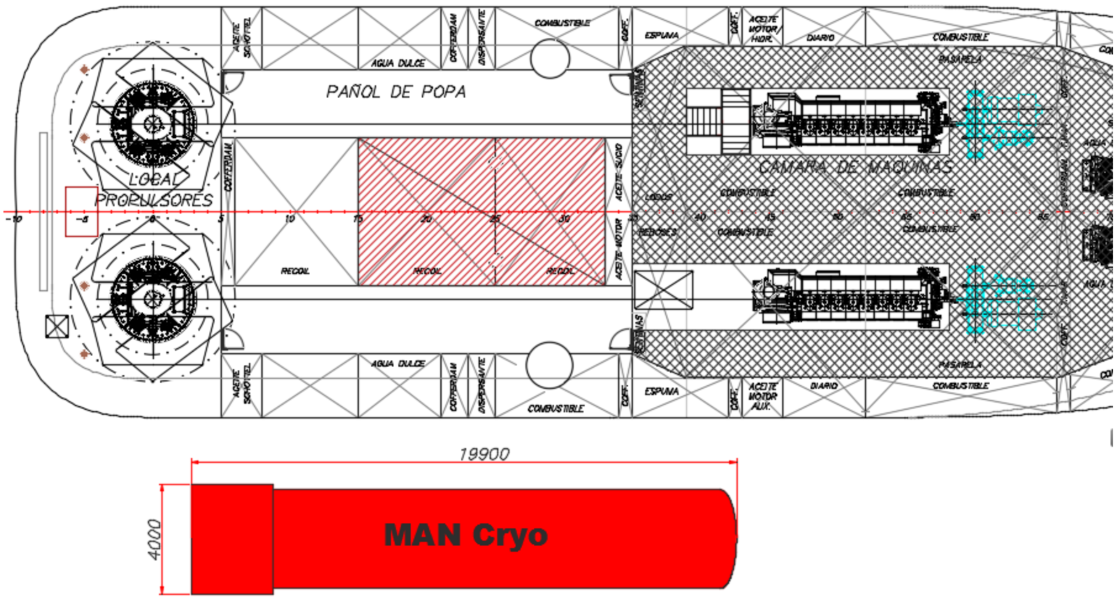


Figure 90. Top view of comparison between MAN Cryo and the ship.

As shown, the MAN Cryo tank do not fit in the recoil tanks.

3.8.3 Calculations for 2nd Operational mode

It is clear that the tanks aforementioned doesn't fit in the recoil tanks. So, it is necessary to study another alternative to find one that could be carried out.

For this reason, it is convenient to study the 2nd operational mode in accordance with SASEMAR, which consists in providing gas for the engines for the 50% of the requirements that can be checked in 1st operational mode. This will require less quantity of gas, and therefore the space needed will reduce.

First of all, the following table shows:

Autonomy data	
Required nav. Days	1
Required days port	5
Speed [Knot]	13,4
Miles	643,2
Main Motors	MAK 8M34DF
Auxiliary Motors	Wärtsilä 6L20DF

Table 74. Autonomy data for 2nd operational mode

Type of motors	ENGINE	LOAD (%)	MCR (kW)	FUEL COMPSUMPTION (KJ/kWh)
Main	MAK 8M34DF	85	4000	7777
Auxiliary	Wärtsilä 6L20DF	100	960	8048

Table 75. Motors used in the ship.

And the the values of the LNG that will be taken in account, (the same than operational mode):

Density [t/m^3]	LOWER HEATING VALUE (MJ/kg)
0,45	49,5

Table 76. Characteristics of the LNG.

3.8.3.1 Gas calculations

The new needs of gas can be calculated easily dividing in two the volumes of the point 6.2.1:

Condition	Capacity of LNG required (m^3)
Navigation	57
Port	41,6

Table 77. Volumes of gas required.

3.8.3.2 Wärtsilä supplier

To be chosen the largest result of both, which is 60 m^3 of gas needed. This volume requires the use of the smallest size of the LNGPac found, which is LNGPac 105, with data as follows, (see, to check dimensions):

Type	Units	LNGPac 105
Geometric Volume	[m^3]	105
Net Volume (90%)	[m^3]	95
Diameter (C)	[m]	3,5
Tank length (B)	[m]	16,7
Tank room (D)	[m]	2,5
Total length (A)	[m]	19,2

Table 78. LNGPac tank characteristics.

So, it is necessary to modelate this tank and check if it fits inside the recoil tanks:

Figure 91. Top view of the tank

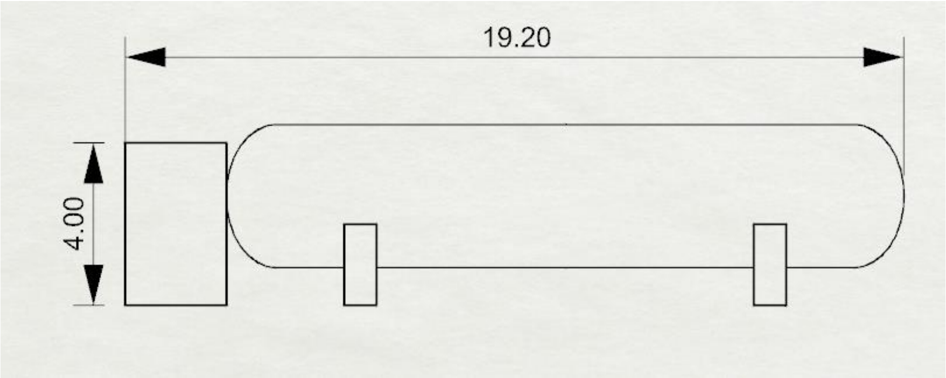


Figure 92. Side view of the tank

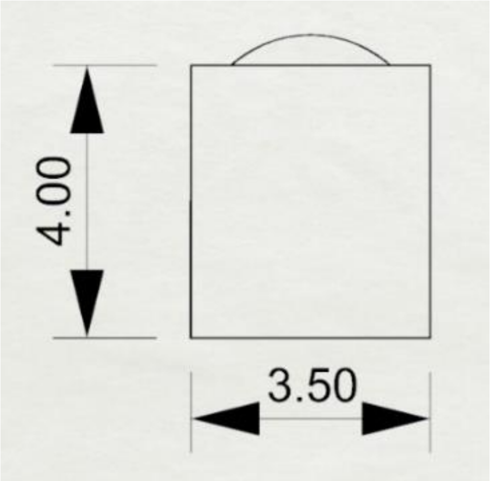


Figure 93. Front view of the tank

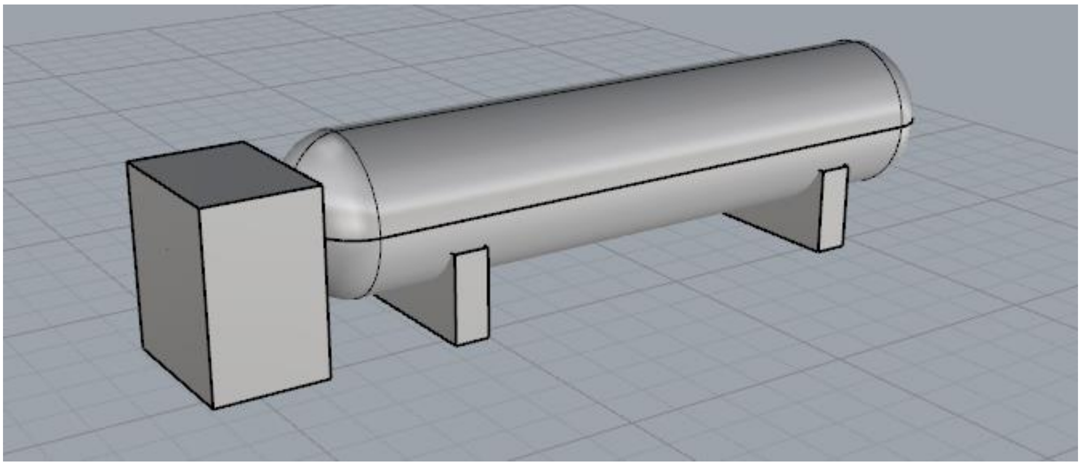


Figure 94. View of the tank in 3D.

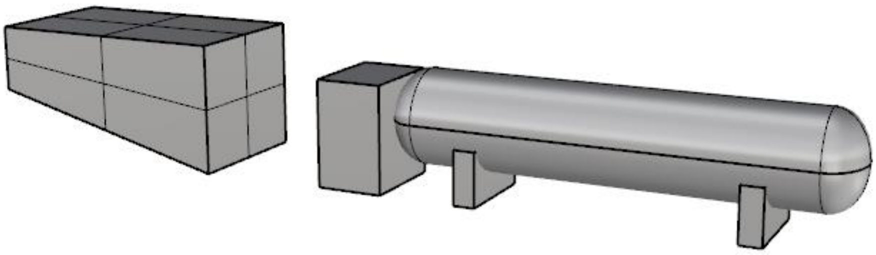


Figure 95. Comparison between tanks.

As can be seen, the volume of the LNG tank is huge comparing to the recoil tank that has to house it. So, in this operational mode is not possible to fit the tank inside this space.

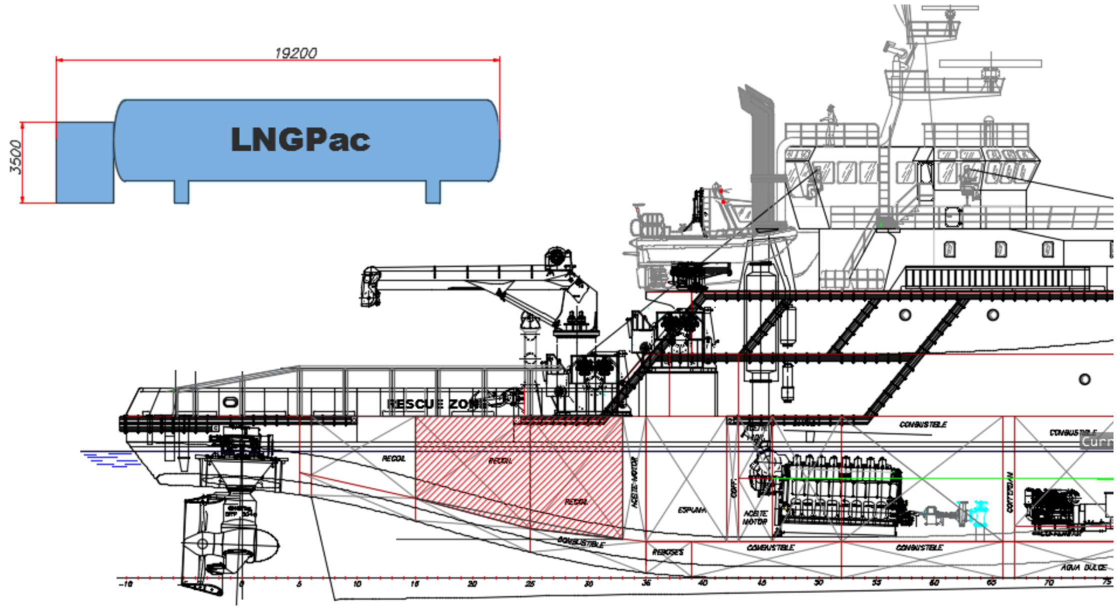


Figure 96. Comparison between the tanks and the recoil tanks (side view).

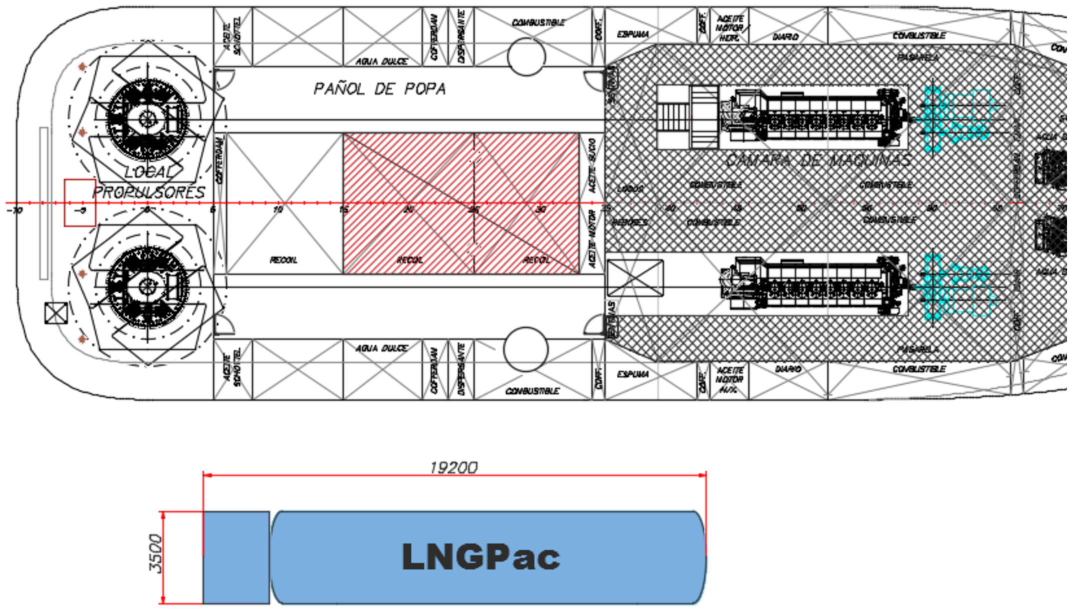


Figure 97. Comparison between the tanks and the recoil tanks (top view).

3.8.3.3 MAN supplier

In this there will be used the same data extracted from MAN:

Volume [m^3]	Diameter [m]	Length including coldbox [m]	Weight [tons]
30	3.6	8.8	26
75	3.6	14.8	40
115	4.2	14.5	50
125	3.6	19.9	55
201	5.3	15.5	80

Table 79. Different characteristics of MAN Cryo tanks.

The smaller tank that fits the best with specifications is the one with 75 m^3 of capacity. So, there will be modelled to check if it is possible to install inside the recoil tanks or on the deck.

The tank dimensions are as shown in the following images:

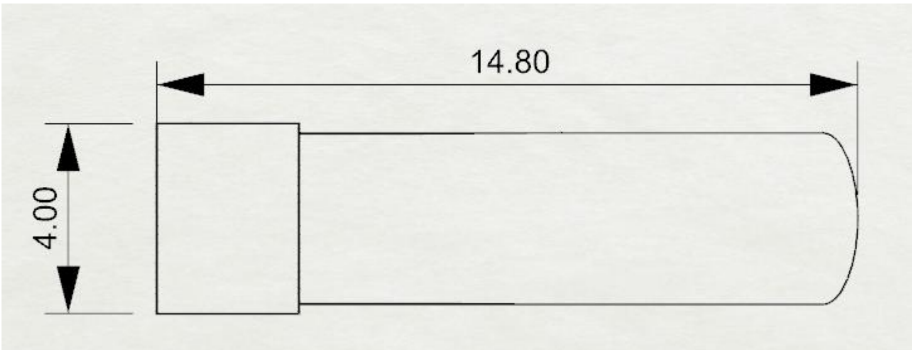


Figure 98. Side view of the tank MAN cryo

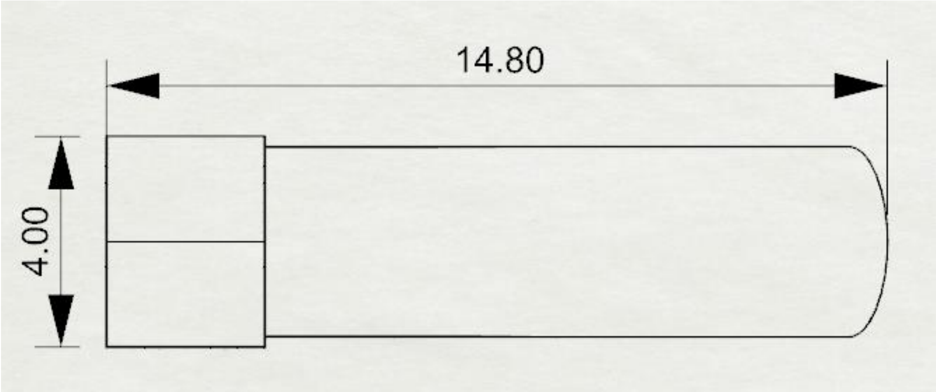


Figure 99. Top view of the tank MAN cryo

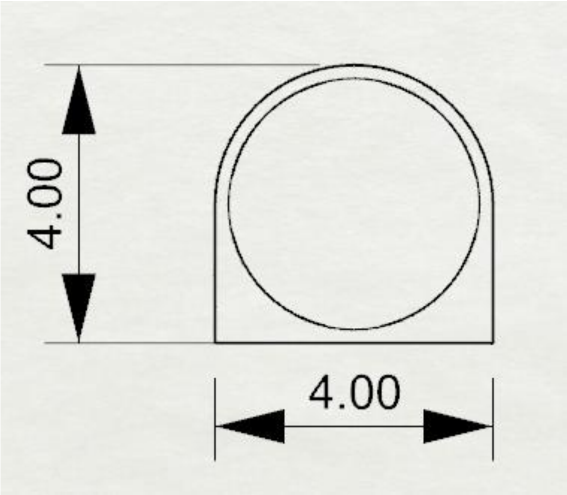


Figure 100. Front view of the tank MAN cryo.

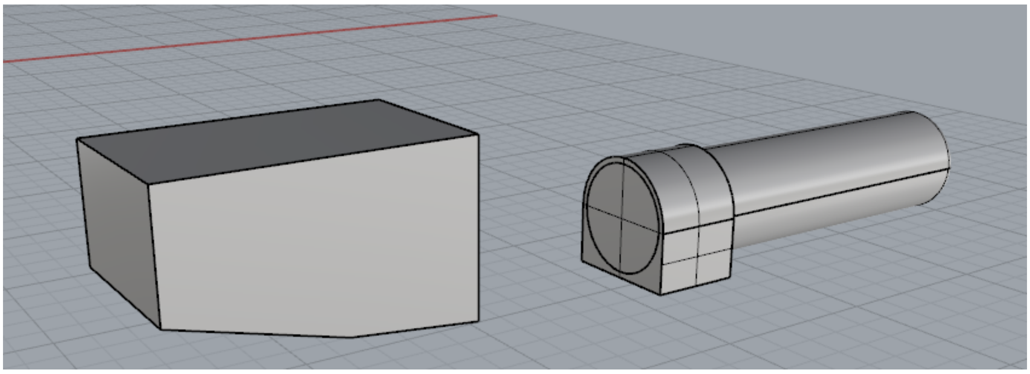


Figure 101. Comparison between tanks.

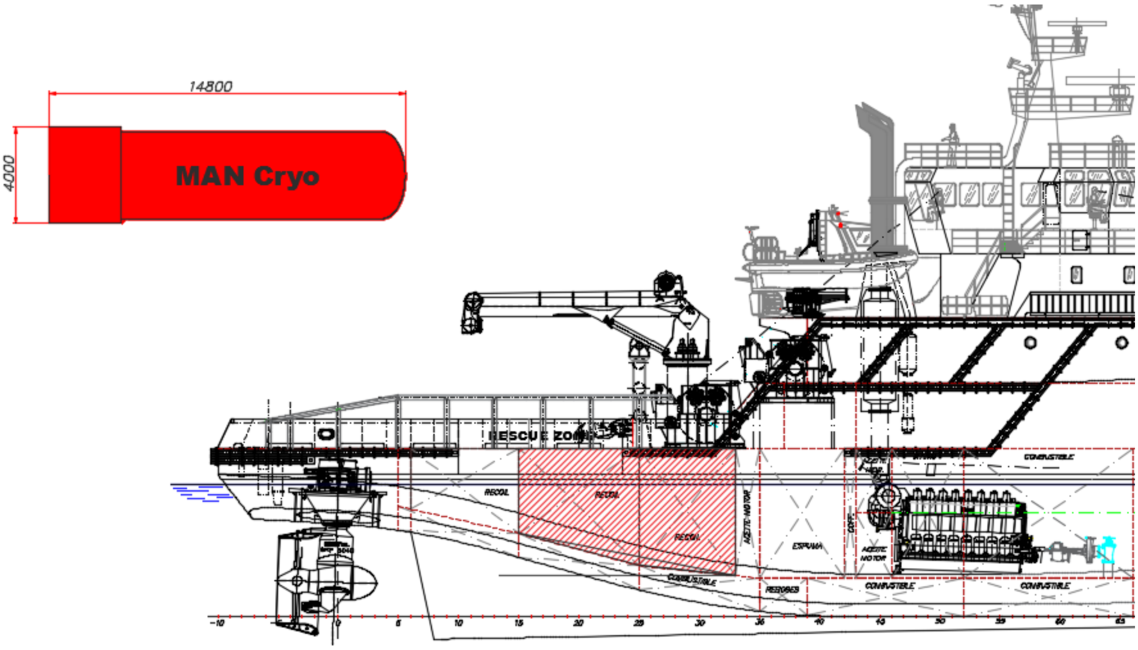


Figure 102. Comparison between MAN cryo tank and recoil tanks (side view).

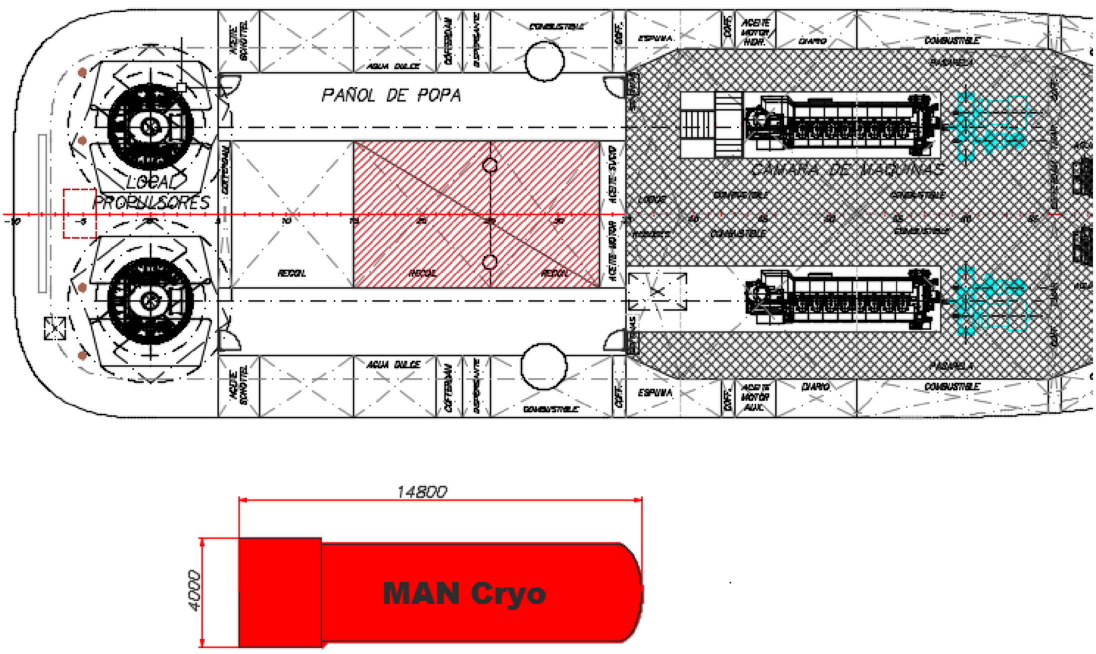


Figure 103. Comparison between MAN cryo tank and recoil tanks (top view).

As it is shown in the images, the tank is very big again to be fitted inside the recoil tanks, for this reason, it is impossible to install them.

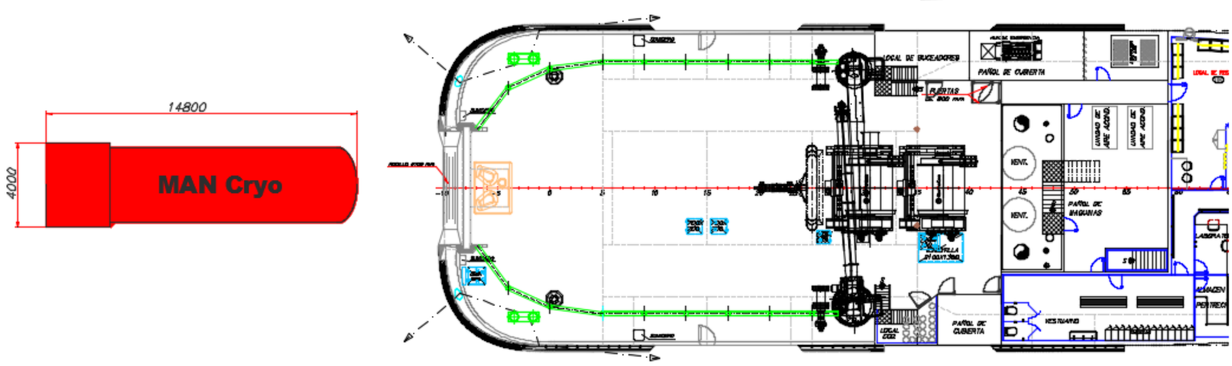


Figure 104. Comparison between MAN cryo tank and main deck (top view).

3.8.4 Calculations for 3rd Operational mode

As the previous operational modes are not feasible regarding tank installations, 3rd operational mode consists in finding a tank that fits inside the recoil tanks and calculate how much autonomy would the ship had in this case and comment the viability of this option.

First, it is necessary to gather the different tank dimensions that suppliers offer, and choose the one that fits the best with the maximum quantity of LNG.

3.8.4.1 Wärtsilä supplier

This company provides tanks of less volume than used in other points of this chapter. In this case, there will be used a tank that is shown below, it includes the tank itself connected with the cold box.

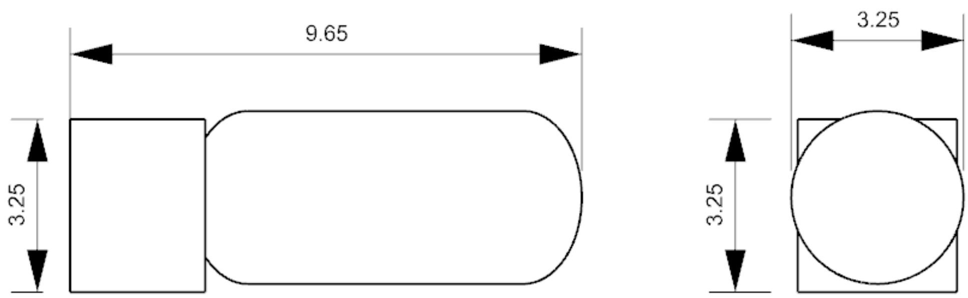


Figure 105. Side and front view of LNGPac.

The aim is the same as in the last points: fit this tanks inside the recoil tanks space to feed the dual motors. It is necessary to put the cold box oriented to the bow, because the closer to the motors it is, the best it will be for gas handling.

This situation has been modelled on Rhinoceros program. The results were as follows:

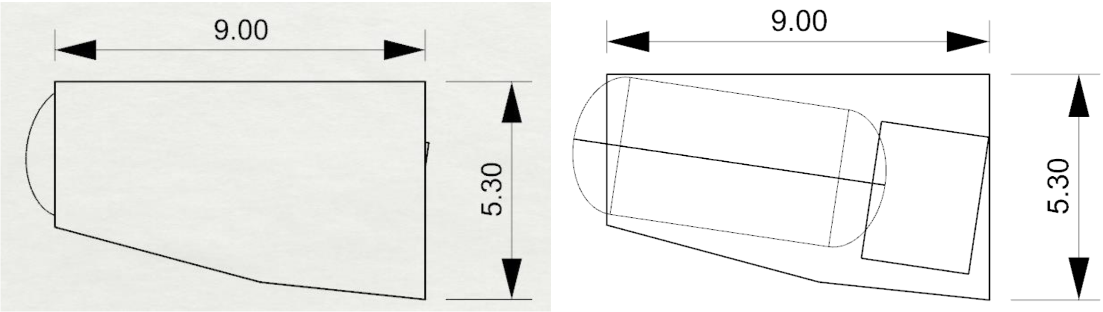


Figure 106. Profile view of the LNG tank inside the recoil tanks space.

As can be seen, this type of tank doesn't fit inside the space, so, it will be necessary to find alternatives, in this case, there are two of them:

1. Choosing a smaller tank
2. Choose a different configuration without cold box.

SMALLER TANK

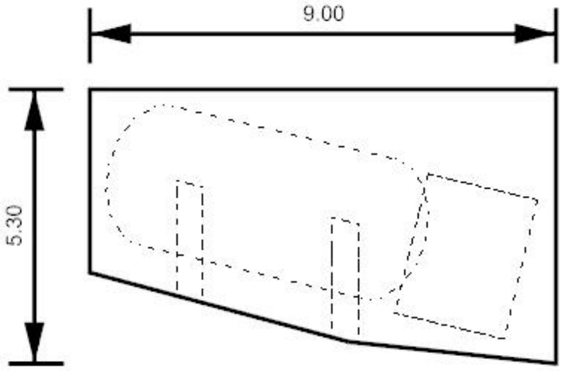


Figure 107. Side view of the LNG tank inside the recoil tanks space.

In this alternative, the tank fits inside the space, and its situation is according the IGF Code.

Navigation situation:

$$Nav.time[h] = \frac{Volume[m^3] \cdot Density\left[\frac{t}{m^3}\right]}{N_{motors} \cdot Consumption\left[\frac{t}{h}\right]} = \frac{22 \cdot 0{,}45}{2 \cdot 0{,}5342} = \boxed{\mathbf{9{,}3[h]}}$$

Port situation:

$$Port\ time[h] = \frac{Volume[m^3] \cdot Density\left[\frac{t}{m^3}\right]}{N_{motors} \cdot Consumption\left[\frac{t}{h}\right]} = \frac{22 \cdot 0{,}45}{1 \cdot 0{,}156} = \boxed{\mathbf{63{,}4[h]}}$$

TANK WITHOUT COLDBOX

In this situation the chosen alternative will be a 30m^3 of capacity tank. It doesn't have a cold box attached to the tank but it shall be installed in a specific enclose location inside the engine room.

The image below shows the tank dimensions:

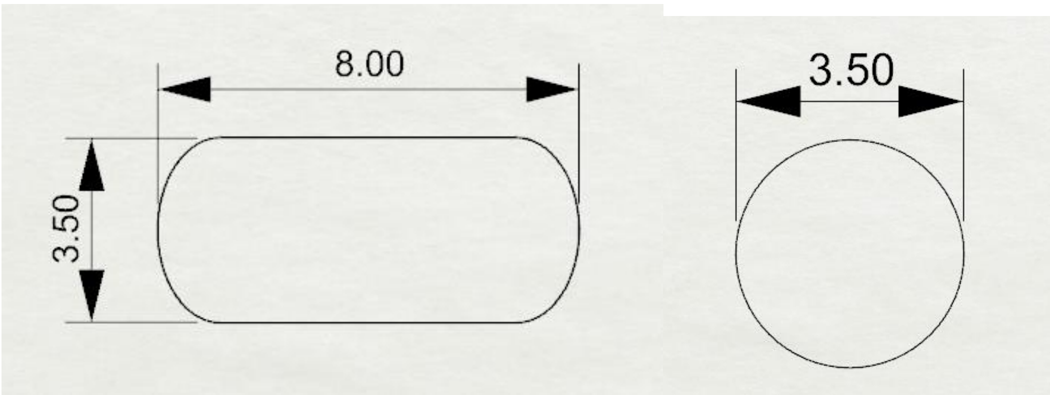


Figure 108. Lateral and front view of the LNG tank without coldbox attached.

And below, this tank inside the recoil tanks:

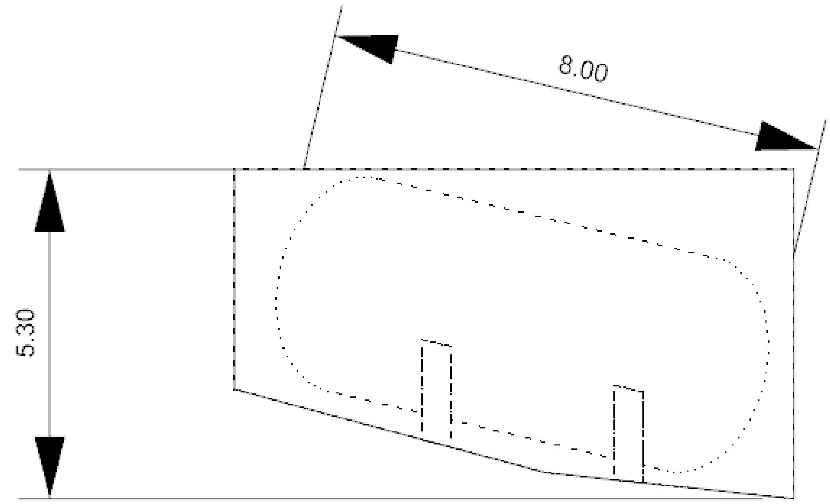


Figure 109. Side view of the Wärtsilä tank inside the recoil tank

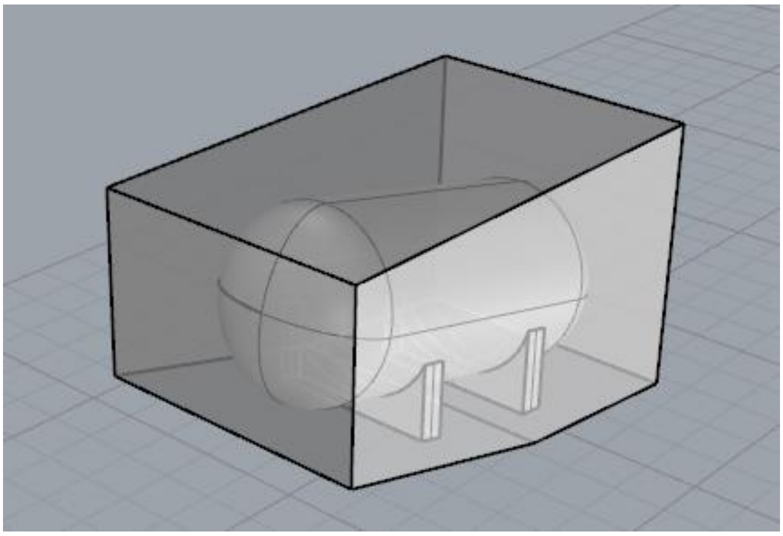


Figure 110. View of the Wärtsilä tank in 3D.

In this case, the tank fits inside the space provided. Then, the next step will be to calculate the amount of gas provided by the tank compared with motors consumption. This motor (as it is said at the beginning of the point) has 38m^3 of gas, so:

Navigation situation:

$$Nav.time[h] = \frac{Volume[m^3] \cdot Density\left[\frac{t}{m^3}\right]}{N_{motors} \cdot Consumption\left[\frac{t}{h}\right]} = \frac{38 \cdot 0{,}45}{2 \cdot 0{,}5342} = \boxed{\mathbf{16[h]}}$$

Port situation:

$$Port\ time[h] = \frac{Volume[m^3] \cdot Density\left[\frac{t}{m^3}\right]}{N_{motors} \cdot Consumption\left[\frac{t}{h}\right]} = \frac{38 \cdot 0{,}45}{1 \cdot 0{,}156} = \boxed{\mathbf{109{,}6[h]}}$$

3.8.4.2 MAN supplier

In this case, the objective is to do the same as in the last point, choosing a tank to fit into the space, and check if it provides enough gas to develop a good operational mode for the ship. In this case, two situations will be taken into account: tank with attached coldbox, and tank without it.

MAN TANK WITH COLDBOX

As it was mentioned some point before, MAN provider gives different sizes for its tanks, the smaller one is the one with the following size:

Type	Volume [m^3]	Diameter [m]	Length [m]
Horizontal	25	3.6	8

Table 80. MAN Cryo tank characteristics.

The image of the tank is as follows:

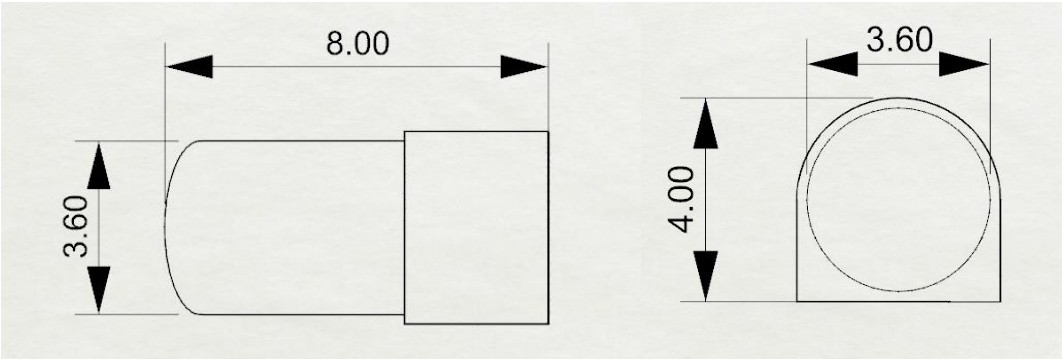


Figure 111. Top and side view of the MAN cryo tank

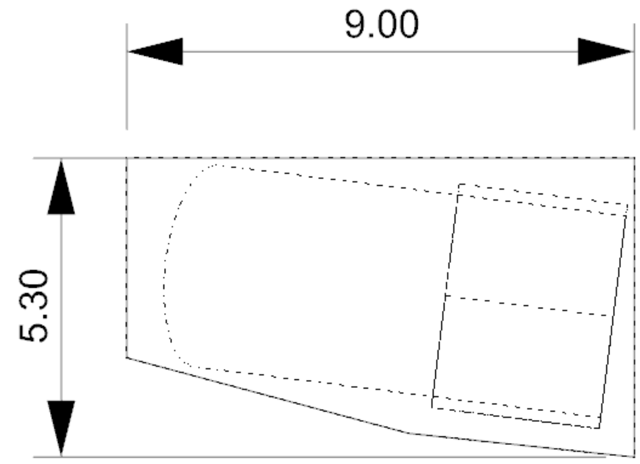


Figure 112. Side view of MAN cryo tank inside recoil tanks.

This tank contains 25 m^3 of LNG, so, the autonomy for each situation would be as follows:

Navigation situation:

$$Nav. time[h] = \frac{Volume[m^3] \cdot Density\left[\frac{t}{m^3}\right]}{N_{motors} \cdot Consumption\left[\frac{t}{h}\right]} = \frac{25 \cdot 0,45}{2 \cdot 0,5342} = \boxed{\mathbf{10,5[h]}}$$

Port situation:

$$Port\ time[h] = \frac{Volume[m^3] \cdot Density\left[\frac{t}{m^3}\right]}{N_{motors} \cdot Consumption\left[\frac{t}{h}\right]} = \frac{25 \cdot 0,45}{1 \cdot 0,156} = \boxed{\mathbf{72[h]}}$$

MAN TANK WITHOUT COLDBOX

As in the last section, now a tank without coldbox will be used to check whether it fits inside the recoil tanks and the volume it can contain, the tank measures are as follows:

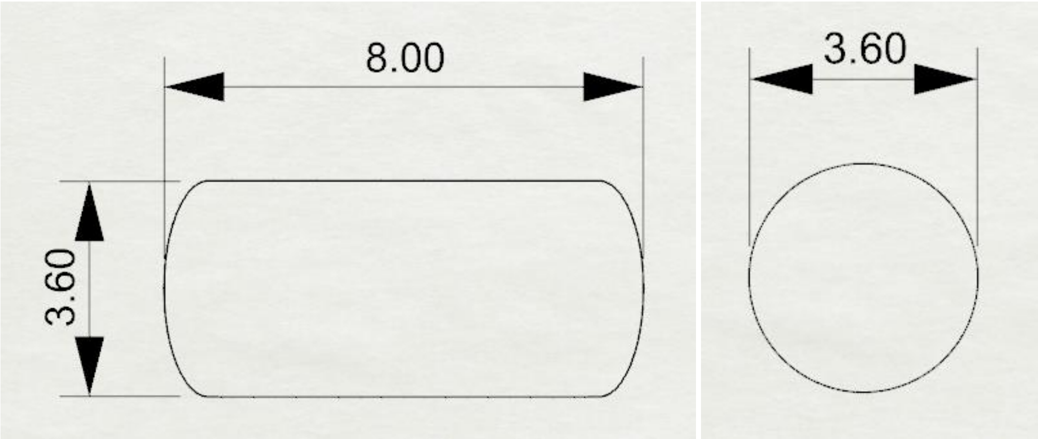


Figure 113. Side and front view of the tank.

And the tank inside the recoil tanks is as follows:

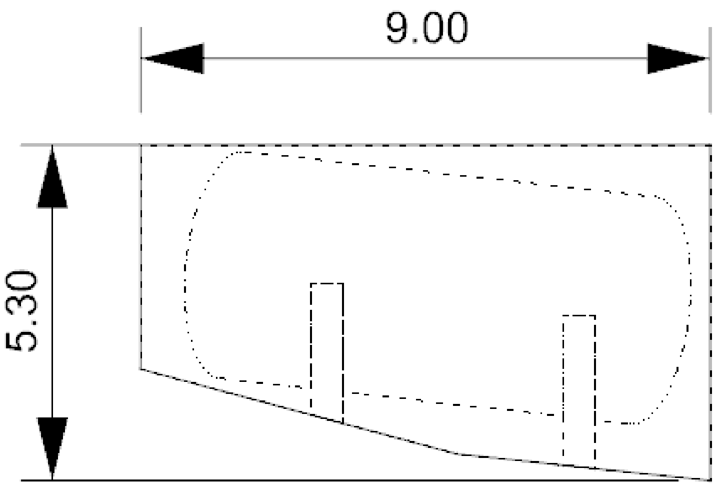


Figure 114. Side view of MAN cryo tank inside recoil tanks.

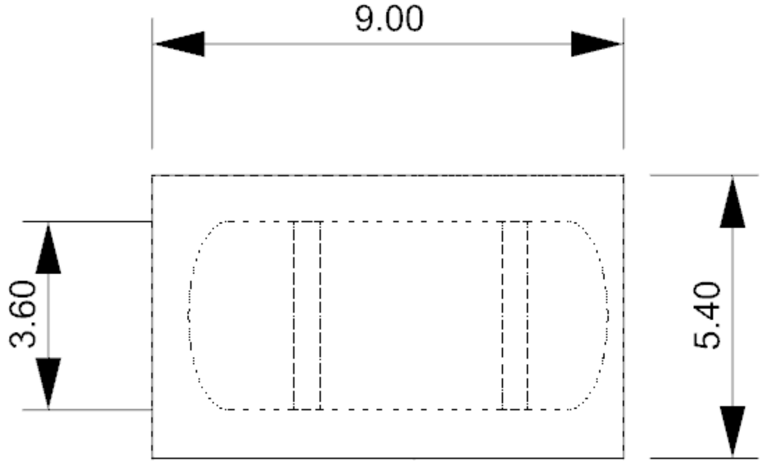


Figure 115. Top view of MAN tank inside recoil tanks.

This tank can contain 40 m^3 of LNG, knowing this, the calculus for the autonomy it would provide to the ship are as follows:

Navigation situation:

$$Nav.\,time[h] = \frac{Volume[m^3] \cdot Density\left[\frac{t}{m^3}\right]}{N_{motors} \cdot Consumption\left[\frac{t}{h}\right]} = \frac{40 \cdot 0{,}45}{2 \cdot 0{,}5342} = \boxed{\mathbf{16{,}8[\boldsymbol{h}]}}$$

Port situation:

$$Port\ time[h] = \frac{Volume[m^3] \cdot Density\left[\frac{t}{m^3}\right]}{N_{motors} \cdot Consumption\left[\frac{t}{h}\right]} = \frac{40 \cdot 0{,}45}{1 \cdot 0{,}156} = \boxed{\mathbf{115{,}4[\boldsymbol{h}]}}$$

3.8.5 Conclusions

The table below, gathers the different data calculated along this point:

Supplier	Coldbox attached	Net volume [m^3]	Nav. Autonomy [h]	Port autonomy [h]
Wärtsilä	YES	22	9,3	63,4
	NO	38	16	109,6
MAN	YES	25	10,5	72
	NO	40	16,8	115,4

Table 81. Different autonomy values from different tanks of Wärtsila and MAN.

As it is shown, the results are very far from SASEMAR objectives (2 days of navigation and 10 days at port), and they not even match with the second operative profile of 50% of these requirements. For that reason, this operational mode, although is plausible because the tanks can be storage inside the space of the old recoil tanks, doesn't provide enough gas to perform a good operational profile, due to it gives a very low autonomy to this ship.

There is no a satisfactory autonomy for each situation, it is very far from the original specifications, and this autonomy is not within an acceptable range.

3.9. DESIGN ALTERNATIVE SELECTION

The aim of this chapter is to select, the best tank or tanks to be installed in the ship. Also, it will be necessary to say whether it is plausible for the ship to use them, giving correct values for ship's operation.

3.9.1 Alternatives to evaluate

The following table gathers the different tanks provided in previous sections. The aim is to show the different tanks evaluated and the main data which will be very important to discard some of them.

Operational mode	Alternative number	Supplier	Net volume [m3]	Coldbox attached	Length [m]	Beam [m]
1	1	Wärtsilä	131	YES	19,4	4
	2	MAN	125	YES	19,9	4
2	3	Wärtsilä	95	YES	19,2	3,5
	4	MAN	75	YES	14,8	4
3	5	Wärtsilä	30	YES	9,65	3,25
	6	Wärtsilä	22	YES	8,8	2,8
	7	Wärtsilä	38	NO	8	3,5
	8	MAN	25	YES	8	3,6
	9	MAN	40	NO	8	3,6

Table 82. Main characteristics of the evaluated tanks.

The operational modes, are as follows:

- **1st operational mode**: In **port** is necessary to use an auxiliary motor during 10 days at 100% of power load. In **navigation** situation, it will be necessary to provide gas to the two main motors to work 2 days at the 85% of the power load.
- **2nd operational mode:** consists in providing gas for the engines for the 50% of the requirements that can be checked in 1st operational mode.
- **3rd operational mode:** consists in finding a tank that fits inside the recoil tanks.

3.9.2 Parameters

To select the tank, it is necessary to define some parameters to check if it is a feasible option and explain the final decisions:

The parameters to be considered will be:

- Autonomy given by the tank compared with the requirements.
- Size of the tank compared with the space inside the ship.
- Free space for coldbox and valves, pipes, etc.
- Relationship between net volume and total length.

Autonomy given by the tank in navigation and port situation:

In the following graphics the different values calculated have been gathered to compare the different values obtained to support the final discussion and the end of this point. Both graphics shows the autonomy given by each alternative, showing the navigation autonomy in hours and the port autonomy in days:

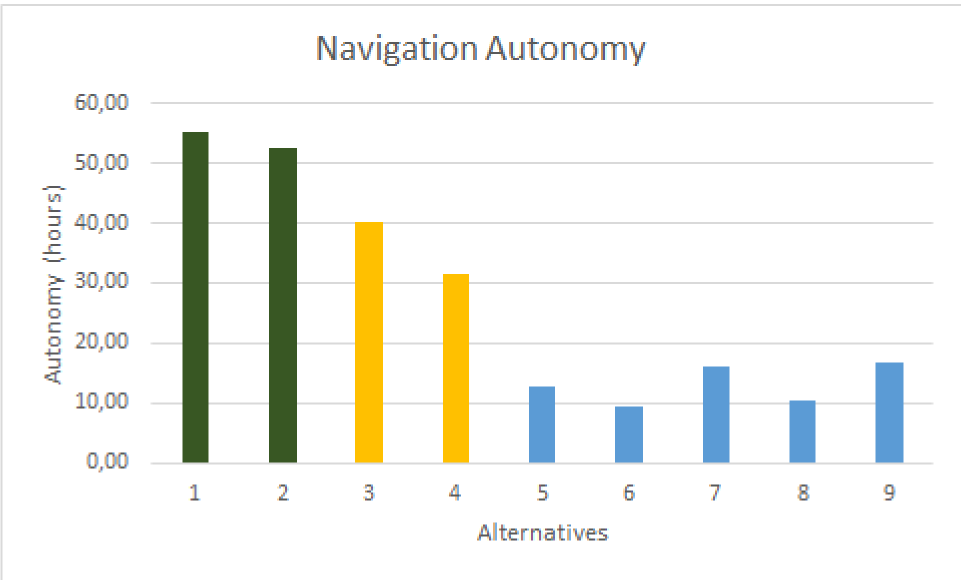


Figure 116. Navigation autonomy of the different alternatives.

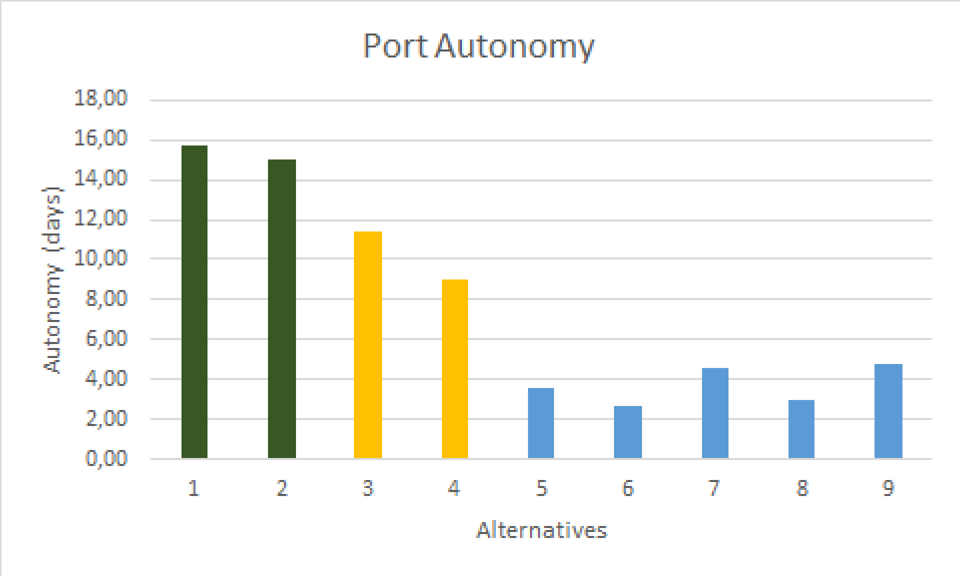


Figure 117. Port autonomy of the different alternatives.

In these figures, the different operational modes have been divided in colours. Being, green colour for the operational mode 1, yellow for the operational mode 2 and blue colours the third mode. It can also be seen that the autonomy for each alternative is expressed in hours, for navigation, and in days for the port.

For the operational mode 1, both alternatives fulfil satisfactorily with the requirements of 2 days in navigation and 10 days in port, being the alternative number 1 the one which more widely satisfy these requirements.

For operational mode 2, also both alternatives bring the navigation autonomy of 1 day and 5 days in port even with a wide margin of hours.

As for the operational mode 3 there is not an autonomy value to satisfy, the best alternatives are those that give the widest number of hours in navigation and port. For this case, the alternatives 7 and 9 are the best options.

It is important to comment that there is an important parameter which has not been taken into account in these considerations, being it, the space required for these alternatives. This fact is considered in the next points, being all of these parameters included in a table where the best option is chosen, at the end of this part.

Size of the tank compared with the space inside the ship.

In this point there will be a discussion about a critical parameter, which is whether the tank fits inside the old recoil tanks or not, because a tank that has a very good performance in lots of areas is not useful if it doesn't fit inside the space provided. For this reason, in the following table the different tanks are gathered, in the right column is write if the tank is able to be install inside the recoil tanks:

Number of alternative	Fits inside the recoil tanks?	Supplier
1	NO	Wärtsilä
2	NO	MAN
3	NO	Wärtsilä
4	NO	MAN
5	NO	Wärtsilä
6	YES	Wärtsilä
7	YES	Wärtsilä
8	YES	MAN
9	YES	MAN

Table 83. Table about the adaptation of the tank inside the recoil tanks

As it is shown, only the last four alternatives are able to be installed inside the recoil tanks. So this is a reason to discard the options 1 to 5, as will be said later in the last point. In the point 6 is possible to see large and concrete explanations about why is it possible or not to fit the different tanks inside the space allowed.

Free space to install coldbox and valves, pipes etc.

This parameter refers to the possibility for the different tanks, that fit inside the recoil tanks (these are alternatives 6, 7, 8 and 9), to let a free space that will be useful to put valves, pipes, and provide and easier installation in the shipyard. In case there would be two or more possible options to be installed, there will be given a priority to these tanks.

To quantify the free extra space that different tanks allow, it has been indicated by the following markers:

- **Lower**: the space is minimum, it will be very difficult to attach the different valves, pipes and sensors. Also, the installation and maintenance operations in the shipyard would be more complicated.

- **Medium**: the space provided is not minimum, but it would still be complicated to make operations with it, although it will be easier to deal with this tank than with lower alternatives.

- **Higher**: it provides more space, giving a higher margin for maintenance and installation of gas handling stuff.

In the following table, there is a comparison between the different tanks that fit inside recoil tanks:

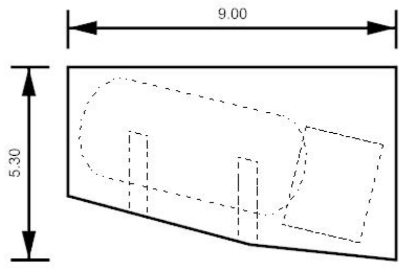
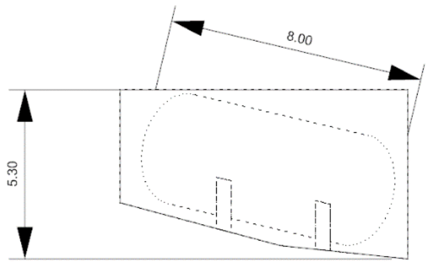
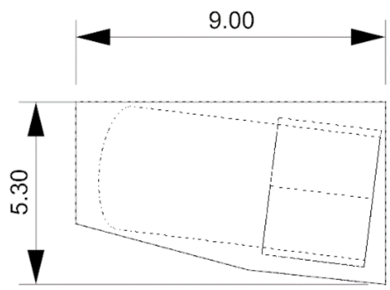
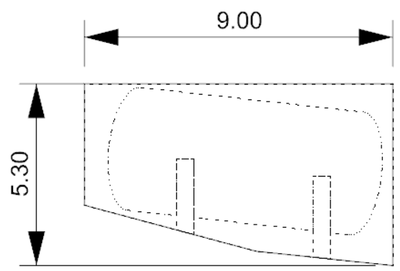
Alternative number	Coldbox attached	Supplier	FREE EXTRA SPACE	TANK FIGURE
6	YES	Wärtsilä	Low	
7	NO	Wärtsilä	Medium	
8	YES	MAN	Low	
9	NO	MAN	Low	

Table 84. Free space inside the recoil tanks.

As it has been shown, there is no alternative that provides free space enough to operate with convenience, but there is an alternative (number 7), that gives more space than the others and has more net volume than alternatives 8 and 6.

Final results in different parameters

In the following table are gathered the different results shown in the last points:

Alternative number	Autonomy		Free extra space
	Navigation [h]	Port [days]	
1	55,2	15,8	NONE
2	52,6	15	NONE
3	40	11,4	NONE
4	31,6	9	NONE
5	12,6	3,6	NONE
6	9,3	2,6	Lower
7	16	4,6	Medium
8	10,5	3	Lower
9	16,8	4,8	Lower

Table 85. Final results of the different parameters.

**The rows marked in red are discarded alternatives because they don't fit inside recoil tanks.*

3.9.3 Conclusions and choosing of alternatives

In the following table, the different alternatives are prioritized in function of the different parameters shown in last points:

Best altertatives according parameters		
	Free extra space	Autonomy
Best alternative	7	9
↓	6	7
Worst alternative	9	8
	8	6

Table 86. Alternatives ordered according different parameters.

It is necessary to remember that the five first alternatives were absolutely discarded because they don't fit inside the recoil tanks, is for this reason that they had not been included in the last decision round.

As it is shown, only two parameters are now taken on account, the best alternative according to them would be the alternative **number 7**. It gives more free space, which would be very interesting for installation and maintenance operations.

The alternative number 7 gives 16 hours of autonomy in navigation situation and 109,6 hours in port situation. This autonomy is a real low value comparing to the initial main requirements given by SASEMAR, which is 2 navigation days and 10 in port.

It doesn't even fit with the requirements of the second operational mode, which are 1 navigation day and 5 port days. For this reason, even though it fits inside the space provided, and it has better results than other tanks according the different parameters. It is not a plausible option to develop such a big change for these poor results of autonomy.

3.10. WORKS TO BE CARRIED OUT

In this section the different works to carry out to install the new gas systems are shown in different work groups.

DISMOUNT MAIN ENGINES

- Separate the starboard engine from all the supplying pipes of each system. Systems: fuel, lube oil, water cooling, compressed air, exhaust, etc.
- Separate the port side engine from all the system supplying pipes. Systems: fuel, lube oil, water cooling, compressed air, exhaust, etc.
- Separate the starboard engine from all the equipment connected: shafts, gearboxes, PTO, FI-FI pump.
- Separate the port side engine from all the equipment connected: shafts, gearboxes, PTO, FI-FI pump .
- Disconnect the electrical and electronic systems from the starboard engine. Separate the starboard engine from the electric, automatization and control systems.
- Disconnect the electrical and electronic systems from the port side engine. Separate the port side engine from the electric, automatization and control systems.
- Remove the fluids inside the engines and fix the moving parts of the starboard engine.
- Remove the fluids inside the engines and fix the moving parts of the port side engine.
- Remove all the equipment and systems from the interior starboard bulkhead between frames 43 and 59.
- Remove all the equipment and systems from the interior port side bulkhead between frames 43 and 59. Dismount the ventilation ducts of the Engine Room.
- Dismount the electrical cable-ttrays of the Engine Room.
- Dismount secondary electric switchboards and starters of the Engine Room.
- Dismount pipes and equipment in the double bottom area between main engines.
- Empty the wing and double bottom tanks in between frames 43 to 59.
- Dismount all floors and outfitting steel elements above the double bottom deck.
- Inert wing and double bottom tanks between frames 43 to 59.
- Starboard hull cutting from 43 + 200 mm to 59 – 200 mm frames. Double bottom +350 mm and -350 mm below the main deck.
- Remove and throw off the main engines.

DISMOUNT AUXILIARY ENGINES

- Separate the auxiliary engine from all the supplying pipes of each system. Systems: fuel, lube oil, water cooling, compressed air, exhaust, etc.
- Disconnect the electrical and electronic systems from the auxiliary engine. Separate the auxiliary engine from the electric, automatization and control systems.
- Remove the fluids inside and fix the moving parts of the engine.
- Remove all the equipment and systems of the bulkheads in frames 66 and 67.
- Dismount the ventilation ducts of the Auxiliary Engine Room.
- Dismount the electrical cable-trays of the Auxiliary Engine Room.
- Dismount secondary electric switchboards and starters of the Auxiliary Engine Room.
- Dismount pipes and equipment in the double bottom area between auxiliary engines.
- Dismount all floors and outfitting steel elements above the double bottom deck.
- Remove and throw off the auxiliary engine.

REMOVE THE RECOIL TANKS OF FRAMES 15 TO 33

- Inert Recoil tanks.
- Disconnect al pipes connected to the tanks (the filling, drain, vent (pressure/vacuum), sounding, inerting and thermal oil heating pipes into recoil tanks.
- Disconnect the instrumentation from recoil tanks.
- Disconnect all the system's pipes below the deck which may affect to the recoil tanks disassembling.
- Remove the electrical raceways which run through the adjacent area to the recoil tanks.
- Remove the recoil tanks bulkheads between frames 15 to 33.
- Move the machinery support beams and add all the required elements below the deck for transferring the surface load.
- Dispose the support beams for the tug machinery installed on the upper deck due to the removal of the recoil tank bulkheads.
- Dismount the cardan shafts for the propellers driving.
- Strengthen the LNG tank support areas below the double bottom deck.

TYPE C LNG TANK

- Install the LNG tank on its position.
- Install below deck the different system pipes which may affect to the disassembling of the recoil tanks.
- Install the electrical cabe-trays which run through the adjacent area to the recoil tanks.
- Fit the cardan shafts for the propellers driving.
- Install the new LNG pipes.
- Install the new ventilation systems.
- Dispose the LNG bunkering stations above deck.
- Modify the space entrances according to the study of the hazardous areas.
- Dispose the separation bulkheads and the accesses between the type C LNG tank space and the other spaces in order to reduce the explosion risks according to the risk assessment.

ASSEMBLY OF THE NEW DUAL FUEL AUXILIARY ENGINE

- Install the new group
- Install all the auxiliary engine supplying pipes. Systems: fuel, LNG, lube oil, water cooling, exhaustion, etc.
- Connect the electrical and electronic systems.
- Install the LNG pipes in the auxiliary engines room.
- Install the equipment and systems of the bulkheads between frames 66 to 67.
- Fit the ventilation ducts in Auxiliary Engines Room.
- Fit the electrical raceways in Auxiliary Engines Room.
- Fit the secondary electric switchboards and starters.
- Fit the equipment and pipes in the double bottom area between auxiliary engines.
- Assemble the floors and the boiler-work above the double bottom deck.
- Adequate the entries, ventilation outlets, etc., according to the hazardous areas assessment.

ASSEMBLY OF THE NEW DUAL MAIN ENGINES

- Install the new dual fuel main engines.
- Connect the starboard main engine to all the supplying pipes. Systems: fuel, LNG, lube oil, water cooling, compressed air, etc.
- Connect the port side main engine to all the supplying pipes. Systems: fuel, LNG, lube oil, water cooling, compressed air, etc.
- Connect the starboard main engine to the shafts, gearbox, etc.
- Connect the port side main engine to the shafts, gearbox, etc.
- Connect the starboard main engine electrical and electronic systems.
- Connect the port side main engine electrical and electronic systems.
- Fit the equipment and systems from the interior starboard bulkhead between frames 43 and 59.
- Fit the equipment and systems from the interior port side bulkhead between frames 43 and 59.
- Fit the ventilation ducts in the Engine Room.
- Fit the electric cable-trays in the Engine Room.
- Install the secondary electric switchboards and starters in Engine Room.
- Fit the pipes and equipment in the double bottom area between the main engines.
- Adequate inlets and ventilation outlets according to the hazardous areas assessment.
- Assemble the floors and the boiler-work above the double bottom deck.
- Assemble the starboard hull from frame 43+200 mm to frame 59-200 mm. Double bottom +350 mm and -350 mm below main deck.

3.11. CONCLUSIONS

In this last chapter, there will be provided the final results about the retrofitting operation, explaining in brief all the points that have been explained in the last pages, unifying the conclusions that were taken according the different data, calculations and comparatives exposed.

It is clear that the Natural gas engines have a lot of advantages relating with environmental aspects, reducing emissions of CO_2 and even almost making disappear others like SO_X and particulates. This aspect could be very beneficial for the environment, and was the main reason to think about making this change in the ship of SASEMAR, because it could be a flag project to be an example to others, in accordance with the international trends of looking for solutions to reduce emissions, (not only in maritime environment).

Other very important aspects to go for LNG system is that there are some very developed rules at different stages like IMO and different Class Societies. Indeed, along the document have been explained that these systems are widely known, and the main maritime engineering supplier brands also have different solutions to provide for any type of ship which had been exposed along this document (specially from MAN and Wärtsilä). These solutions have been utilized by many shipyards along the world, and have a proven efficiency and performance, making them suitable for the project exposed.

Also, it is necessary to add that there are different forms of bunkering that are safe, and Spain has a correct infrastructure to provide gas to these ships, and, in this aspect it could be plausible to use dual motors, even more when the LNG gas is becoming an option to a lot of ships to comply with the rules about emissions.

Also, it was decided to develop the analysis taking into account the type C tanks to storage LNG gas, because is widely use in the maritime field, and is an advanced technology that has proven a good efficiency in maritime systems.

For the reasons outlined above, the LNG was a good alternative focusing in environmental aspects but the main problems found along this project are mainly technical aspects. Different criteria were exposed at the beginning of each part; their size, autonomy given by the net volume of gas, and the complexity of installing and maintaining them in the future.

As exposed previously, the biggest disadvantage of LNG in the current project is that it needs a huge space to provide enough autonomy. This made impossible to install the tank inside the recoil tanks at the stern of the ships and it was not possible to change the length and beam of these tanks. In the alternative analysis, there were explored the tanks of suppiers MAN and Wärtsilä, trying to check if it would be possible to install tanks reducing the operative requirements given at the beginning. Even with lower requirements, the problem persisted; the tanks were too large to be introduced inside the recoil tanks.

To install the LNG tanks in the main deck was not a feasible option, because it would conflict the normal operation of the ship, fact that would become the vessel useless.

In addition to what has been outlined above, some smaller tanks (smaller enough to fit inside recoil tanks) were studied to calculate the autonomy that could give to the ship. The results were far away from initial requirements, and they were not in acceptable range.

In these terms, it should be emphasized the logistic problem of the size of the LNG tanks, and it must be taken into account in every retrofitting project of the same characteristics, although other parameters could be quite positive in different ranges.

Another interesting aspect shown along this document is the relevance of the different compulsory works needed for the effective retrofitting, which is necessary to comply with valid regulations, such as IGF code. This is very important and makes it necessary to study and check if the costs of this aspects make it profitable comparing with the final result obtained.

There is an important disadvantage affecting to the propulsion. Dual fuel main engines run in a different speed that the current main engines do. This difference affects to all the components and systems which are powered by the engines shafts, as the propellers, the gearbox, the PTOs and the FI-FI system in their properly operation. So, in these terms, the retrofitting implies an operation mode out of the optimized designed range values of all these equipment.

Estimations provided by the shipyard indicate that there would be a speed loss between 0,5-0,75 knots and between 10-12 tons of bollard pull.

In the following table the different advantages and disadvantages are gathered:

RETROFITTING COMPARISON	
ADVANTAGES	**DISADVANTAGES**
less emissions during short period of time	Increase fuel consumption due to the higher MDO specific consumption of the new engines
	More contamination in MDO operational mode
	High retroffiting cost compared to the residual value of the vessel
	Loss of recoil capacity
	Oversized boiler
	Loss of ship speed due to new dual main engines characteristics.
	Loss of ship bollard pull due to new dual main engines characteristics.

Table 87. Comparison of advantages and disadvantages.

4. MANOEUBRAVILITY STUDY COMPARING DIESEL TUGBOAT TYPE "LUZ DE MAR" AND DUAL FUEL DIESEL-LNG TUGBOAT

The main objective of this study is to compare the operation in emergency towing of a maritime rescue unit with the current diesel propulsion and a possible dual propulsion LNG - Diesel. These ship manoeuvres have been carried out using the most advanced tools in this field.

To do this we have used the set of Polaris simulators: Simulator ship manoeuvring Jovellanos Integral Maritime Center for being the tools that offer more realism and reliability available today.

Given the diversity of the types of accidents that can occur to a ship in emergency situations, the severity of the consequences that the management of them can cause on the lives of people on board and on the environment, the variability of the coast and changing both its ocean-weather and its terrain, it has proceeded to study a simulated ship damaged and requires rescue is intact, drifting without propulsion or government and it is towed with a ¨Luz de Mar¨ type unit. In case the vessel had limited propulsion or reduced government the conditions of handling of it would be less demanding and would improve the manoeuvrability of the vessel-tug boat.

The multipurpose ships modelled have been the Luz de Mar and the Luz de Mar LNG propulsion. They have been handled with the maximum level of realism that the simulator allows and has had the experience of one of the Captains of the SASEMAR Fleet that was are responsible of the unit Miguel de Cervantes twin of Luz de Mar. The developed models correspond to specific numerical models with six freedoms degrees that integrate not only the movements of the tugboat but also the behaviour of the towing cable and the propulsive system of the afore mentioned units.

The basic difference between both tugs has been exemplified taking into account the variation of the response time of the main engines in the face of a demand for variable power, as can be deduced from the manufacturer's project guides.

To compare both tugs, the shunting have been repeated twice in each weather condition and assisted vessel, the first towing with the current engine and the second towing with the model of dual fuel engines operating with LNG onwards.

Figure 118 – Luz de Mar model

The development of these models has been possible thanks to the development of the company ENRED that was responsible of do it, with the collaboration of Armón Shipyards, constructor of the twin multi-purpose ships Miguel de Cervantes and Luz de Mar and that are operated by Maritime Rescue, and the manufacturer of the engines of the MAK units, which have provided all the technical information necessary to model the possible dual fuel engine for manoeuvring behaviour.

The towed vessels have consisted of very large vessels chosen after the study of the current trends of the world fleet, the result of the collaboration between Maritime Rescue, Armón Shipyards and SOERMAR.

4.1. SIMULATOR OF MANOEUVRING

4.1.1 APPROACH OF THE MANOEUVRES

Of all the extensive casuistry of incidents that could happen to a needy ship of help, it has been chosen that the ship is adrift without propulsion or government, as a very demanding case within the possible ones, with the ship intact and upright.

Firstly, and on the high seas, the approach of the salvage vessel to the drifting vessel is simulated so that the captain can evaluate the best way to give the tow. When the approach makes it possible to pass the towing rope of the rescue vessel to the drifting vessel, the connection of the towing cable is simulated. The towing unit moves away from the drifting vessel to be able to run the trailer safely. Once the trailer is made firm, the rescue unit must hold the towed vessel, understanding to hold the trailer as the operation of reducing its drift speed. In the next phase of the manoeuvre, the viability of the offshore towing manoeuvre is evaluated. If it can be counteracted, it will be towed to a safer area and where the sea allows its repair or towing by port units to a secure dock.

Therefore, the general program of manoeuvres proposed consists basically in the performance of various type manoeuvres executed in different meteorological conditions. Specifically the manoeuvres are those described below:

MANOEUVRE	TUG	TOWED VESSEL	WIND Speed(knots)	WAVE H(m)	DESCRIPTION
1	LUZ DE MAR	TANKER	25	3	Approach to towed vessel, hitch, start of towing and towing
2			37	4	
3			48	6	
4		GAS CARRIER	25	3	
5			37	4	
6			48	6	
7		CRUISER	25	3	
8			37	4	
9			48	6	
10		CONTAINER SHIPS	25	3	
11			37	4	
12			48	6	
13	LUZ DE MAR GAS	TANKER	25	3	
14			37	4	
15			48	6	
16		GAS CARRIER	25	3	
17			37	4	
18			48	6	
19		CRUISER	25	3	
20			37	4	
21			48	6	
22		CONTAINER SHIPS	25	3	
23			37	4	
24			48	6	

Figure 119 - Manoeuvres

4.1.2 CONDITIONS OF HIGH SEA SIMULATIONS

The simulations conditions are the following:

4.1.2.1 BATHTIMETRY

The bathymetry considered in all simulations of the high seas corresponds to a flat bottom at the level -100 m, since from the point of view of the manoeuvrability of the ships; this is representative of deep waters.

4.1.2.2 METEOROLOGICAL CONDITIONS

The studied meteorological conditions coincide with severe sea conditions from the point of view of the tugboat, waves of 3, 4 and 6 m of maximum wave height have been simulated with winds of the same direction of 25, 37 and 42 knots respectively , and they are those specified in Table 2.

WIND			WAVE		
DIRECTION	DISPERSION	SPEED (knots)	High max (m)	Peak period Tp (s)	DIRECTION
360º	+/- 10 º	25	3	13	360º
360º	+/- 10 º	37	4	13	360º
360º	+/- 10 º	48	6	15	360º

Table 88 - Meteorological conditions.

In all the simulations it has been considered that the wind and the waves came from the same direction. The waves of the simulator are irregular and reproduce at each point a spectrum of Pierson-Moskowitz. The significant height of the upper range has been considered to leave manoeuvres on the side of safety. The modelled wind has a random directional dispersion of 10 ° with respect to the central direction.

4.1.3 ASSISTED VESSELS AND TUGS

The vessels analysed in the present study have been two Luz de Mar type tugboats, the first modelled in their behaviour to the use of diesel and the second analogous to the previous one but modifying their behaviour to diesel-LNG propulsion. In all simulation conditions it has been assumed that this second tug was operating by feeding the main engines with LNG.

Figure 120 – Luz de Mar

The towed units correspond to 4 types of very large boats of different types to be able to study the behaviour of vessels of volume or weight, which will affect the wind or wave component, respectively.

The model´s data used can be seen below in the following table.

NAME	IMAGE	TYPE	LENGTH	BEAM	DRAUGHT	PROPULSION
VLCC07F FULL LOAD		TANKER	342	53	11,4	FIXED PITCH PROPELLER
GAS 05 L		GAS CARRIER QMAX	333	54	12	2 FIXED PITCH PROPELLER
CNTNR28L		CONTAINER SHIP	332	43	14,5	FIXED PITCH PROPELLER
EUROPA		CRUISER	225,3	26,7	6,5	AZIPOD
LUZ DE MAR		OCEAN GOING TUG VESSEL DIESEL ENGINE	56	48	5,9	2 SCHOTTEL
LUZ DE MAR GAS		OCEAN GOING TUG VESSEL DUAL DIESEL LNG ENGINE	56	48	5,9	2 SCHOTTEL

Table 89 - Models used

4.2. SIMULATOR OF MANOEUVRING AND NAVIGATION

POLARIS ship´s bridge simulator, built by the Norwegian leader in marine simulation KONGSBERG, has been installed in December 2009 in the Center Jovellanos. The Simulator has a classification Class A from the DNV, which means it can simulate navigation environments and realistic manoeuvres to all competition rules prescribed by the table relating to navigation training IMO code (STCW-95).

The movements of the image correspond to a mathematical model that calculates the trajectory of the vessel, course, speed, etc., through resolution of the equations of movement longitudinal, transverse and torque of the ship with the six freedom degrees. The model takes into account the influence of the wind, waves and currents. Environmental data are stored along with the stage and cover the entire geographical area of exercise.

Orders shipped from the navigating bridge to the rudder and the machine are input to the computer during the simulation. Hydrodynamic forces acting on the vessel depend only on the relative movements of the same with respect to water. The calculated forces result in corresponding changes in the position of the vessel on the stage and in readings of instruments.

During the simulation it is recorded and prints the path of the ship in real time. Take samples of significant variables and stored on disk for recording data, graphic representations and analysis.

The Simulator works in real time and its main components are:

Jobs instructor: located in the control room from where ships in transit are handled and tugs that interact with the model, programmed environmental conditions and the data are collected for further treatment.

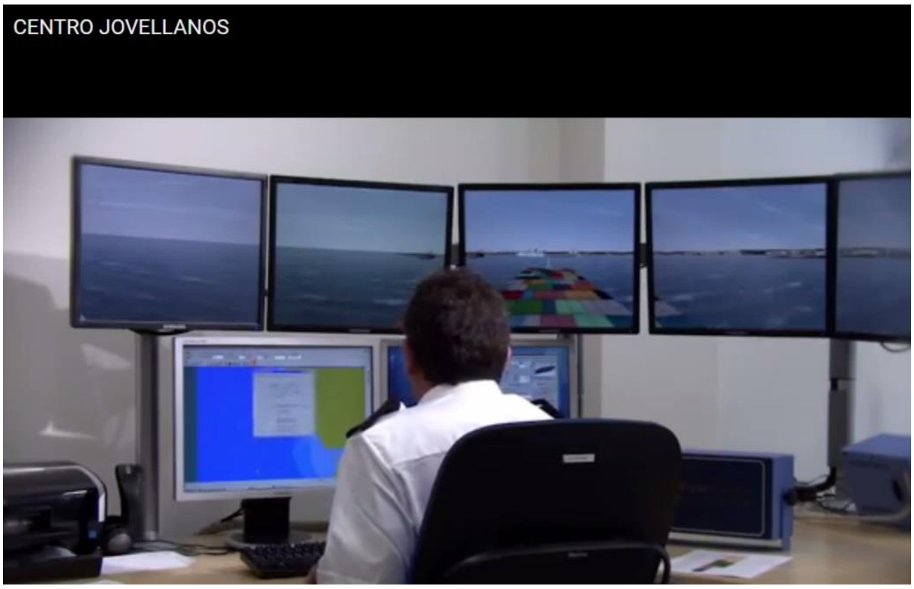


Figure 121 – Control room

A main bridge: a full navigation bridge (Full Mission Bridge) with current equipment of navigation and government, including controls for Azi-Pods, Navtex, and Doppler systems among others. It has a visual system of 360 ° which are projected onto a space circular of 8 meters in diameter.

Figure 122 - Bridge

Two tugboat bridges: with 360 ° display and all navigation and towing, teams prepared to simulate both azimuth propulsion and Voith-Schneider, as well as work with tug wire.

Figure 123 - Tugboat bridge

Two small bridges: can be used also with own hydrodynamic model.

RADAR Simulator: capable of generating digital signals from radar that interact with interference and environmental and meteorological distortions.

Debriefing room: for further analysis to the realization of the exercise, complete with projector and printing equipment.

Main components simulator "Polaris"	• Wheel house controls • Wheel house bracket • Instrument panels • Radar ARPA • ECDIS • Visual system • Debriefing room • 2 Tugs bridge • 1 Puente de nave de gran velocidad • 2 Puentes reducidos
Software applications	• Escenarios (Multigen) • Parameters manoeuvre (SetGet/OCTOPUS) • Hydrodynamic models (HDMT) • Evaluation systems
Resources to training and research	• Planning and making a journey • Maintaining a safe navigation guard • Using the radar and ARPA to safely navigate • Responding to emergencies • Responding to messages and distress signals at sea • Manoeuvre to other vessels • Determine position and its precision with all types of media • Determine and correct needle errors • Coordinate search and rescue operations • Establish procedures for wheel house guards • Maintain safe navigation with the use of radar, ARPA and modern Navigation systems that facilitate correct decision making • Manoeuvre and handle a ship in any condition
Equipment of navigation bridge	The Polaris Simulator's navigation bridge has a similar design and equipment of a current vessel, taking into account the latest requirements in this regard as well as a modern and professional design. The Training Agreement (STCW) requires that the simulators used for training and evaluation of competition must be approved by a maritime administration Det Norske Veritas (DNV) established the requirements for such approval. The Polaris Simulator is a DNV approved model for A, B, C and X category simulators.

Table 90 – Simulator equipment

4.3. DEVELOPMENT OF THE MANOEUVRES

The set of manoeuvres was carried out at the Jovellanos Maritime Rescue Integral Center, on May 18 and 19 to review the numerical models and prepare the manoeuvring scenarios. After carrying out the modifications of the numerical models by the company ENRED, which was in charge of the development of the same, all the simulations were carried out on July 11, 12 and 12, 2017.

All of the manoeuvres were carried out by an expert captain in emergency towing and who served as captain of the unit Miguel de Cervantes, twin of Luz de Mar, and is currently Captain of tugboat SAR Mesana.

The manoeuvres have been developed using the vessels and tugboats with the maximum realism that the Polaris manoeuvring simulator allows. The Luz de Mar tugboat has been manoeuvred in real time with the implementation of the bridge with azimuthal instrumentation (Schottel) while the towed vessel was being modelled on the main bridge. The towed vessels have assumed no propulsion or government and with the rudder to the road. In total, 24 simulations of manoeuvres were considered as a result of the combination of the storms with the different tug configurations used.

At the start of the manoeuvres, the tugboats set off on the approach course to the ships drifting without propulsion or government, as already indicated.

Annex I shows the graphs of the trajectory followed by the tugboat and the towed classified according to the manoeuvre number. In section 5 the tables of the results of the manoeuvres in terms of their viability and based on the expert criteria of the Captain are shown, adding in the field of observations any peculiarity of the manoeuvre considered to be reviewed.

4.4. RESULTS OF THE MANOEUVRES

1. The results of the manoeuvres are those that are reflected below in the following table in terms of viability:
2. **HITCH**: in the first phase of the manoeuvre the approach and hooking of the tug to the towed is made.
3. **HOLD**: the second phase of the manoeuvre consists of reducing the drift speed of the towed vessel.
4. **REVOLVING AND TOWING**: the third phase of the manoeuvre consists in checking the possibility of turning the vessel and towing it to take it to the shelter zone.
5. **RESULT**: In the last column we can observe the joint result of the manoeuvre, that is to say it will be viable in those cases in which it has been in all the phases previously described.

MANOEUVRE	TUG	TOWED VESSEL	WIND Speed(knots)	WAVE H(m)	DESCRIPTION	CAPTAIN´S COMMENTS	HOOK	MAINTAINING	TURN AND TOWING	OVERALL RESULTS
1	LUZ DE MAR	TANKER	25	3	Approach to towed vessel, hitch, start of towing and towing	Not necessary for being viable in a higher condition	*feasible*	*feasible*	*feasible*	*feasible*
2			37	4		Viable manoeuvre, in hook, maintaining the boat and change course	*feasible*	*feasible*	*feasible*	*feasible*
3			48	6		For the hold it would be necessary to throwing, with projectile. The sea sweeps the bow of the tanker, making it difficult to manoeuvre in the bita´s tug. With this condition of sea the tanker derives between 1 and 3 of a knots towards earth. The approach is risky. The movements of both units are abrupt. By the existing swell the approximation and separation must be quick and precise, to avoid the collision of the tugboat with the tanker. After getting the hook if this is feasible, and against the wind the tug is able to stop the starting from 1 to half a knot, with tensions of up to 106 ton and full machine. The turn of the tanker is not viable, it a lot the tension with all the picht and the tanker does not follow the tug but it drags it, so you can´t running the manoeuvre safely and is terminated.	*feasible*	*feasible*	*Unfeasible*	*Unfeasible*
4		GAS CARRIER	25	3		feasible the hook and mainting gas carrier. Not possible to turn it.	*feasible*	*feasible*	*feasible*	*feasible*
5			37	4		feasible	*feasible*	*Unfeasible*	*Unfeasible*	*Unfeasible*
6			48	6		The reaction to the wind of the LNG is more noticeable than with the tanker the approximation is very complex. The tug is not able to drag the gas carrier or carry out the turn.	*Unfeasible*	*Unfeasible*	*Unfeasible*	*Unfeasible*
7		CRUISER	25	3		Not necessary for being viable in a higher condition	*feasible*	*feasible*	*feasible*	*feasible*
8			37	4		feasible	*feasible*	*feasible*	*feasible*	*feasible*
9			48	6		feasible the hook and mainting gas carrier. If possible to turn it.	*feasible*	*feasible*	*Unfeasible*	*Unfeasible*
10		CONTAINER SHIPS	25	3		Not necessary for being viable in a higher condition	*feasible*	*feasible*	*feasible*	*feasible*
11			37	4		feasible	*feasible*	*feasible*	*feasible*	*feasible*
12			48	6		feasible the hook and mainting gas carrier. If possible to turn it.	*feasible*	*feasible*	*Unfeasible*	*Unfeasible*

MANOEUVRE	TUG	TOWED VESSEL	WIND Speed(knots)	WAVE H(m)	DESCRIPTION	CAPTAIN´S COMMENTS	HOOK	MAINTAINING	TURN AND TOWING	OVERALL RESULTS
13	LUZ DE MAR GAS	TANKER	25	3	Approach to towed vessel, hook, start of towing and towing	Not necessary for being viable in a higher condition	feasible	feasible	feasible	feasible
14			37	4		Viable manoeuvre, in hook, maintaining the boat and change course	feasible	feasible	feasible	feasible
15			48	6		For the hook it would be necessary to throwing, with projectile. The sea sweeps the bow of the tanker, making it difficult to manoeuvre in the bita´s tug. With this condition of sea the tanker derives between 1 and 3 of a knots towards earth. The approach is risky.The response of this gas-engine unit is slower. However this can be saved by climbing the PICTH to 100% and manoeuvring with the rotation of the thrusters. In this case it decreases the safety margin of the manoeuvre by having less angle availability. It should be noted that in case of failure of the gas plant, during the change to diesel both boats would be adrift. The movements of both units are abrupt. By the existing swell the approximation and separation must be quick and precise, to avoid the collision of the tugboat with the tanker. After getting the hitch if this is feasible, and against the wind the tug is able to stop the starting from 1 to half a knot, with tensions of up to 106 ton and full engine. The turn of the tanker is unfeasible, it raises a lot the tension with all the picht and the tanker does not follow the tugboat but it drags it., so you can´t running the manoeuvre safely and is terminated	Unfeasible	feasible	Unfeasible	Unfeasible
16		GAS CARRIER	25	3		feasible the hook and mainting gas carrier. If possible to turn it.	feasible	feasible	feasible	feasible
17			37	4		feasible	feasible	Unfeasible	Unfeasible	Unfeasible
18			48	6		This manoeuvre isn´t feasible for sure. The approximation for the hold requires greater agility of response. It continues manoeuvre simulating hold and turn is unfeasible neither	Unfeasible	Unfeasible	Unfeasible	Unfeasible
19		CRUISER	25	3		Not necessary for being viable in a higher condition	feasible	feasible	feasible	feasible
20			37	4		feasible	feasible	Unfeasible	Unfeasible	Unfeasible
21			48	6		Viable but with many reserves, first to proceed to hook. You miss speed from the machine. Once hooked you can maintening the position of the towed ship and even change the bow and carry it towed. The problem arises when making the turn because the effect of wind and sea which would lead to undesirable situations for the tug.	Unfeasible	feasible	Unfeasible	feasible
22		CONTAINER SHIPS	25	3		Not necessary for being viable in a higher condition	feasible	feasible	feasible	feasible
23			37	4		feasible	feasible	feasible	feasible	feasible
24			48	6		feasible the hook and mainting gas carrier. Not possible to turn it.	feasible	feasible	Unfeasible	Unfeasible

Table 91 – Summary table of manoeuvres

4.5. CONCLUSIONS

The present study reflects very realistic conditions from the point of view of the manoeuvrability of ships, since each of the boats involved responds to a mathematical model of six specific freedom degrees and has been manoeuvred, in real time, by a Captain with great experience in the real tugboat.

The tugboat´s towing manoeuvre to tugged has been assumed to be effective from the moment the captain has given a towing order. This aspect would be desirable if the simulator was more adjusted to reality since in real manoeuvres while passing the ropes to make the wire firm, the tugboat must be held very close to the towing and avoiding over stresses in this first part of the tow line to prevent breakage of the connecting bridge until the wire is firmly in the towing towboat. These details can´t be modelled at present.

In the major storms with winds of 48 knots in reality it would be necessary to use auxiliary means to pass the tow line as rocket launchers.

In the event of a fall of the Gas plant due to emergency, the tug would remain without propulsion for an indefinite period of time until it was rearmed with diesel. This aspect can´t be modelled realistically in the ship manoeuvre simulator.

4.5.1 GENERAL CONCLUSIONS

The potential response to the effective tugboat´s pull once the trailer is delivered does not differ between the operation with engines powered by diesel, or natural gas.

The conditions of simulation have been very harsh although they contemplate the casuistry of tow in emergency from the aspect of the limitation of the viability of the rescue for this type of unit.

The change of fuel type has not affected the manoeuvres of drag and revolt although it has affected at the time of coupling. Although the way to manoeuvre the propulsion has varied in this cases between having diesel fuel or Natural Gas. In the first case, the pitch of the propellers was modified, and in the second case, the propellers were rotated at an angle of rotation.

With winds of 25 knots coupled to 3 meter waves, the result of all the manoeuvres is positive regardless of the type of propulsion.

With winds of 37 knots coupled to waves of 4 meters, there are differences that affect the operation of the tugboats analysed during the rescue operation.

With winds of 48 knots coupled to 6-meter waves, there are also differences that affect the operation of the tugboats analysed during the rescue operation.

For tougher storms the manoeuvres are not considered operationally viable, so they have not been analysed.

4.5.2 CONCLUSIONS APPROACH AND TOWING MANOEUVRES

The approach and towing manoeuvres are one of the most critical phases of the towing manoeuvre of ships in emergency, since the connection operation between tug and towed forces the tugboat to keep its stern very close to the towed unit while the tow line passes and it becomes firm. In these conditions, the tugboat needs an agile and powerful response from its propulsion system to avoid collision with the ship in emergency.

The change in the response time of engines powered by natural gas to variable power demands has negatively affected the approach and towing manoeuvre.

In the manoeuvres of approach and engagement with the toughest storms the Captain has accused the lack of speed of response of the unit to avoid undesirable situations from the point of view of safety.

With winds of 48 knots coupled to waves of 6 meters in theory you can hook the cruise ships and the tanker with the tugboat operating with diesel but the viability of the coupling is very doubtful operating with LNG. In the case of the gas carrier, the coupling is not feasible. Although if in the case of the container ship.

4.5.3 CONCLUSIONS OF THE MANOEUVRES OF HOLD THE VESSEL TO DRIFT

Once the trailer is towed and with the vessel at a sufficient distance from the towing, no differences in the type of propulsion are observed with respect to the effect of holding the towing.

With winds of 37 knots coupled to waves of 4 meters, the gas ship can´t stand, although the rest of the ships do.

With winds of 48 knots coupled to waves of 6 meters, the gas ship can´t stand, although the rest of the ships do.

4.5.4 CONCLUSIONS OF THE MANOEUVRES OF THE REVIVING THE VESSEL TO THE DRIFT AND TOWING IT WITH SECURITY TO A SAFE AREA

With winds of 37 knots coupled to waves of 4 meters you can´t turn the gas ship but the rest of the ships do.

With winds of 48 knots coupled to 6 meter waves, none of the studied vessels can be turned independently of the propulsion. In these conditions it would be advisable to hold the towed waiting for the storm to subside in cases where this has been viable, or wait for a towing unit of greater size and power.

4.5.5 COMPARING THE TUGS

As previously shown, the only differences that have been observed that affect the operation of the two tugboat models have been in the phase of towing and for storms greater than 25 knots of wind.

TUG	TOWED VESSEL	WIND SPEED (kn)	WAVE HEIGHT (m)	HOOK	MAINTAINING	TURN AND TOWING
LUZ DE MAR	CRUISE	25	3	feasible	feasible	feasible
LUZ DE MAR GAS	CRUISE	25	3	feasible	feasible	feasible
LUZ DE MAR	GAS CARRIER	25	3	feasible	feasible	feasible
LUZ DE MAR GAS	GAS CARRIER	25	3	feasible	feasible	feasible
LUZ DE MAR	OIL TANKER	25	3	feasible	feasible	feasible
LUZ DE MAR GAS	OIL TANKER	25	3	feasible	feasible	feasible
LUZ DE MAR	CONTAINER SHIP	25	3	feasible	feasible	feasible
LUZ DE MAR GAS	CONTAINER SHIP	25	3	feasible	feasible	feasible
LUZ DE MAR	CRUISE	37	4	feasible	feasible	feasible
LUZ DE MAR GAS	CRUISE	37	4	feasible	feasible	feasible
LUZ DE MAR	GAS CARRIER	37	4	feasible	Unfeasible	Unfeasible
LUZ DE MAR GAS	GAS CARRIER	37	4	Unfeasible	Unfeasible	Unfeasible
LUZ DE MAR	OIL TANKER	37	4	feasible	feasible	feasible
LUZ DE MAR GAS	OIL TANKER	37	4	feasible	feasible	feasible
LUZ DE MAR	CONTAINER SHIP	37	4	feasible	feasible	feasible
LUZ DE MAR GAS	CONTAINER SHIP	37	4	feasible	feasible	feasible
LUZ DE MAR	CRUISE	48	6	feasible	feasible	Unfeasible
LUZ DE MAR GAS	CRUISE	48	6	Unfeasible	feasible	Unfeasible
LUZ DE MAR	GAS CARRIER	48	6	Unfeasible	Unfeasible	Unfeasible
LUZ DE MAR GAS	GAS CARRIER	48	6	Unfeasible	Unfeasible	Unfeasible
LUZ DE MAR	OIL TANKER	48	6	feasible	feasible	Unfeasible
LUZ DE MAR GAS	OIL TANKER	48	6	Unfeasible	feasible	Unfeasible
LUZ DE MAR	CONTAINER SHIP	48	6	feasible	feasible	Unfeasible
LUZ DE MAR GAS	CONTAINER SHIP	48	6	feasible	feasible	Unfeasible

Table 92 – Tugs feasibility summary table

4.5.6 GRAPHICS RESULTS OF MANOEUVRES

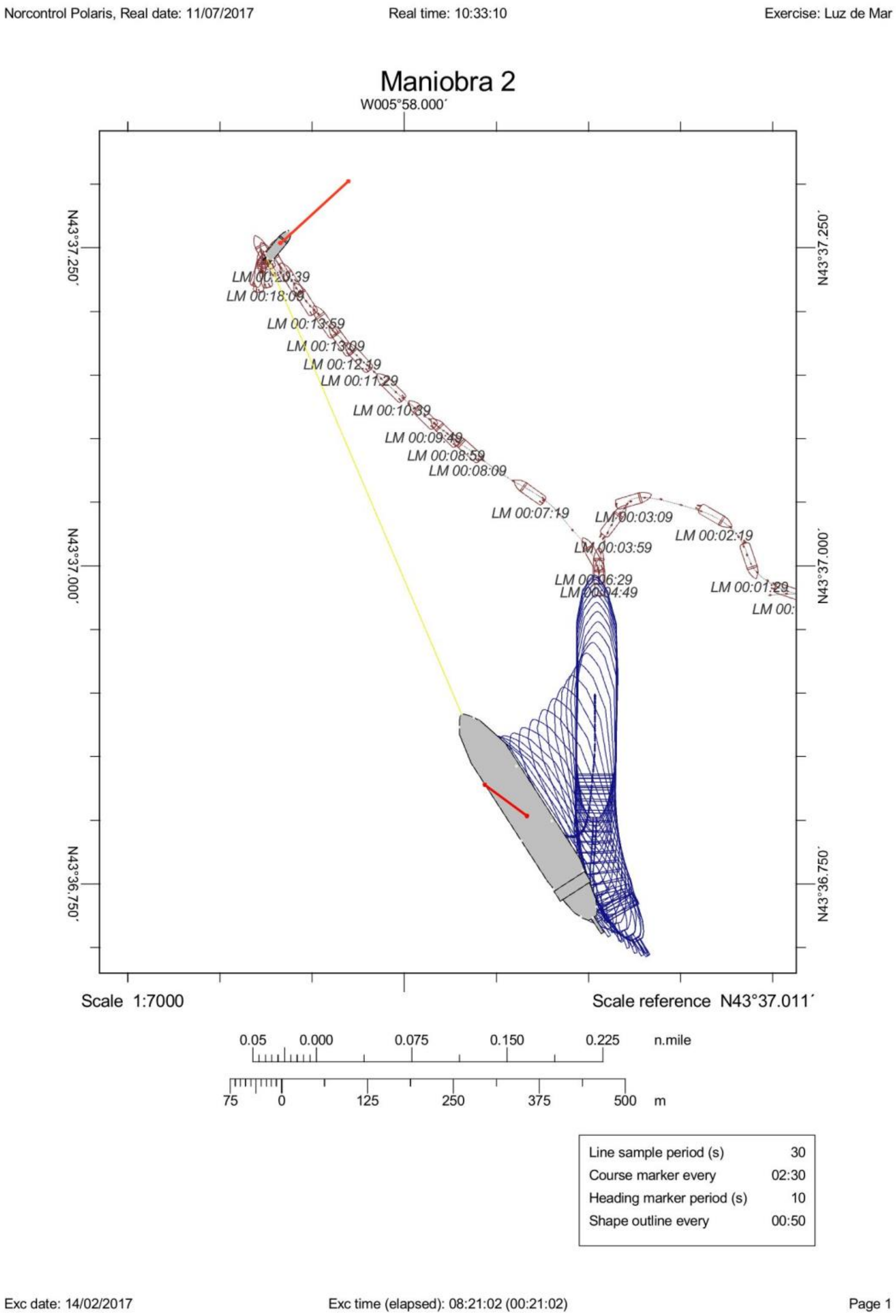


Figure 124 – Manoeuvre 2

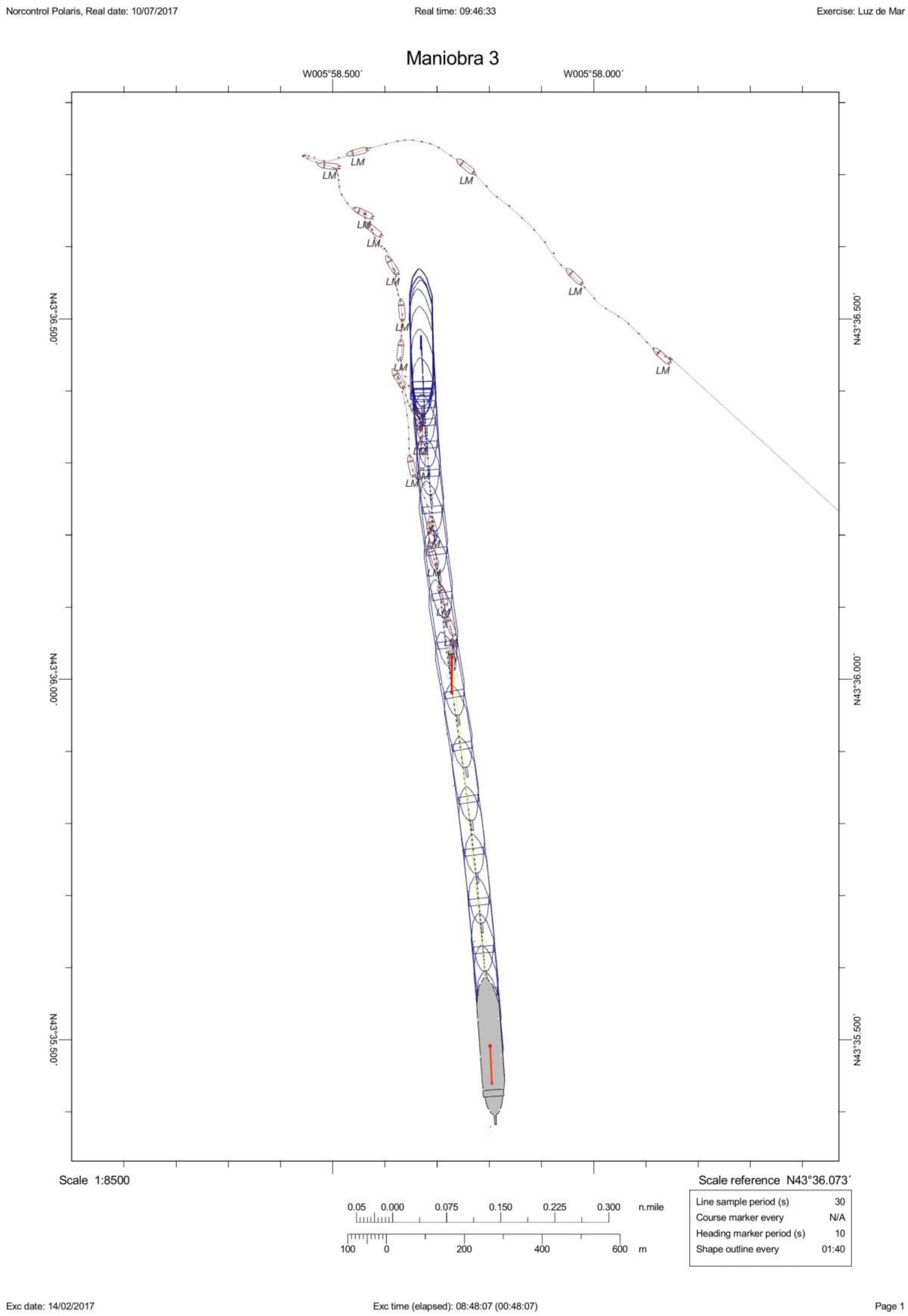


Figure 125– Manoeuvre 3

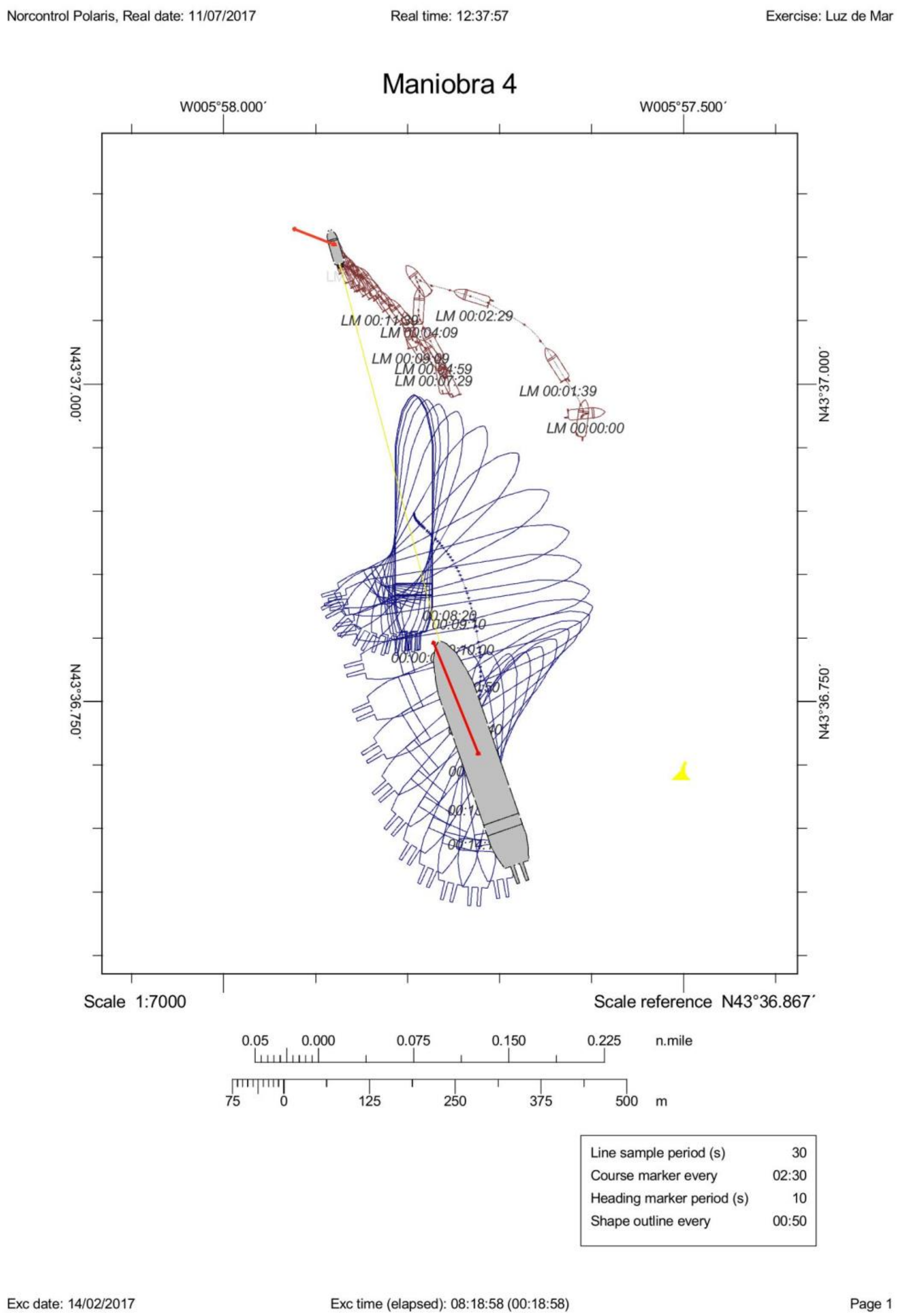


Figure 126– Manoeuvre 4

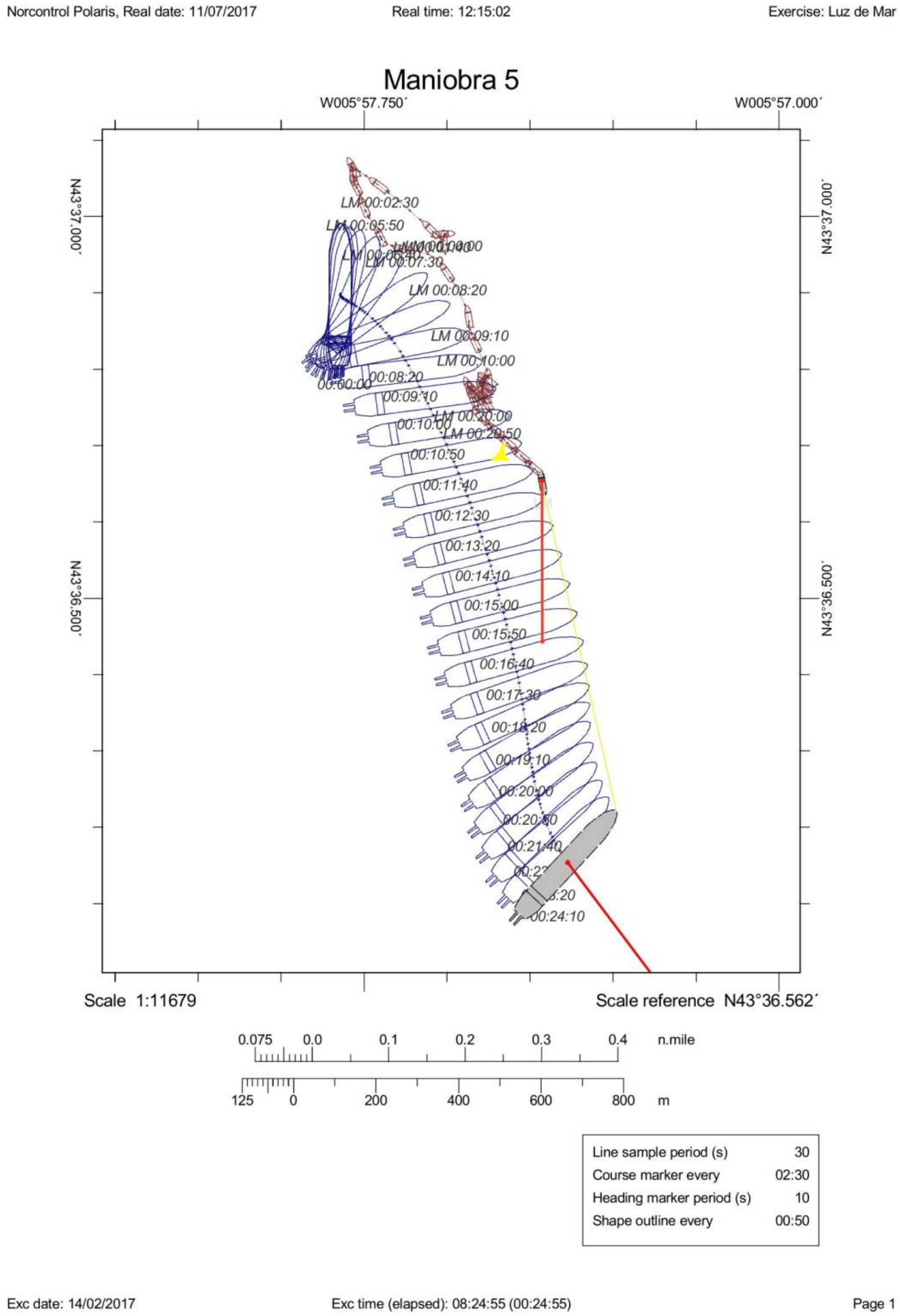


Figure 127– Manoeuvre 5

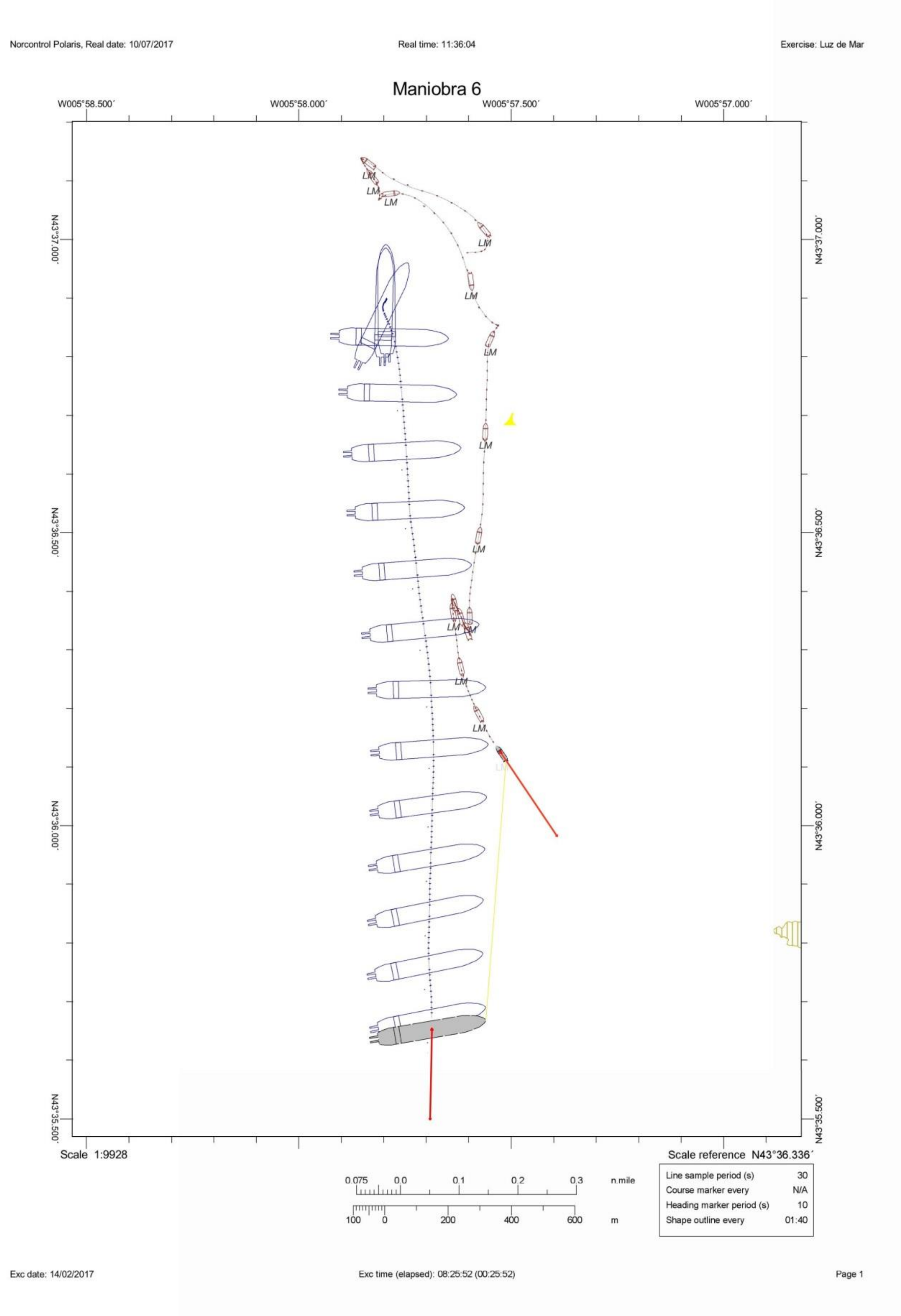


Figure 128– Manoeuvre 6

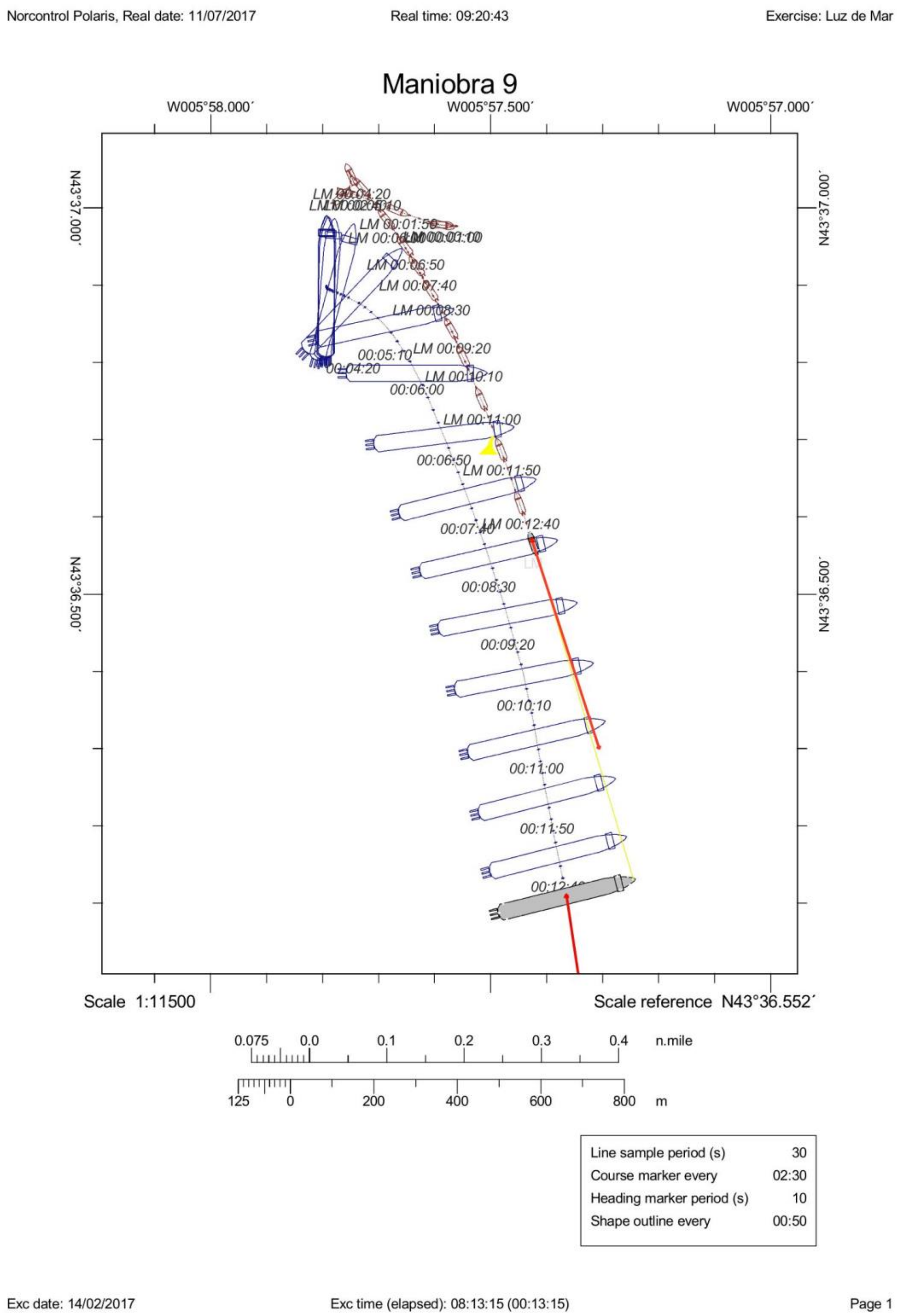


Figure 129– Manoeuvre 9

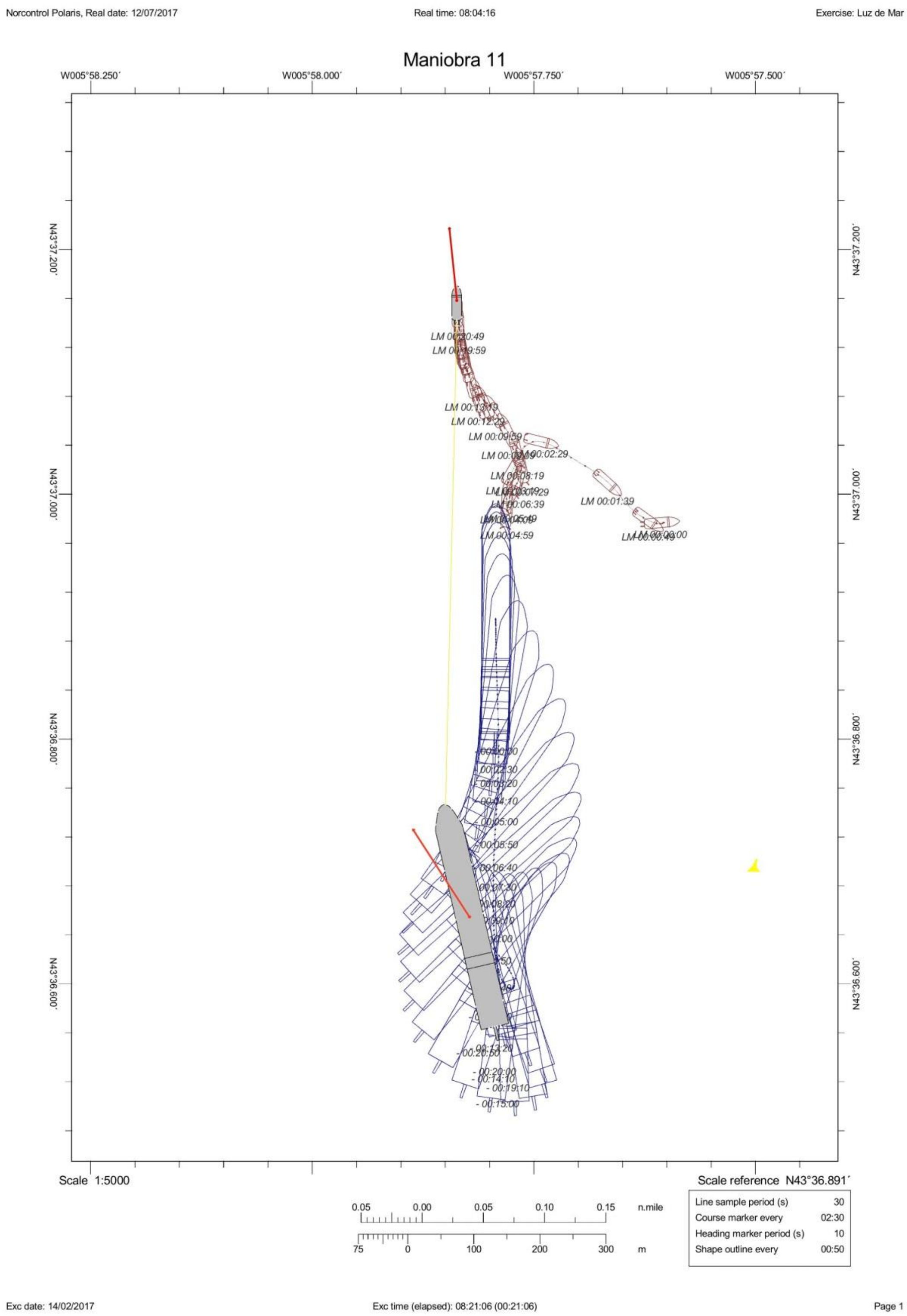


Figure 130– Manoeuvre 11

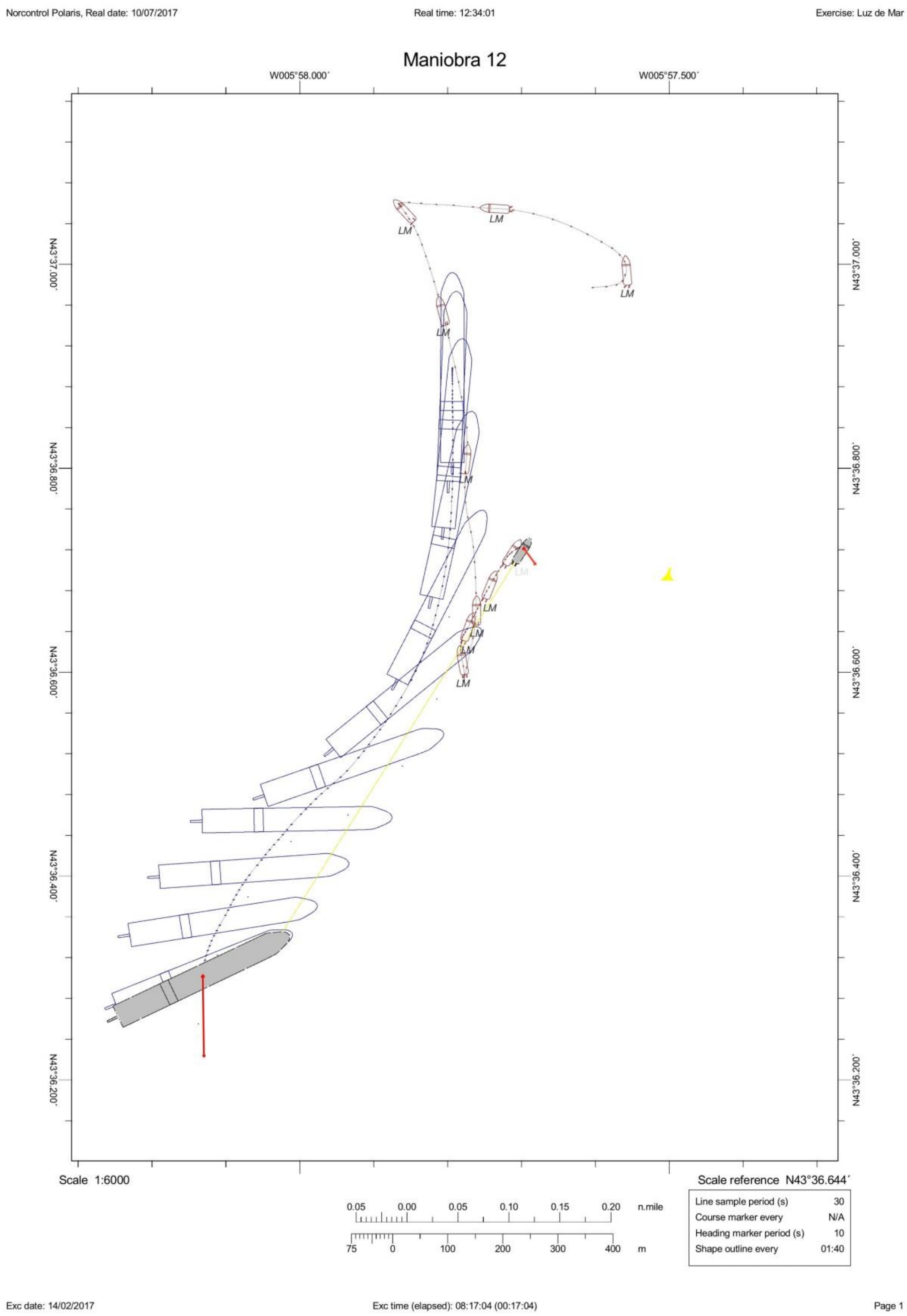


Figure 131– Manoeuvre 12

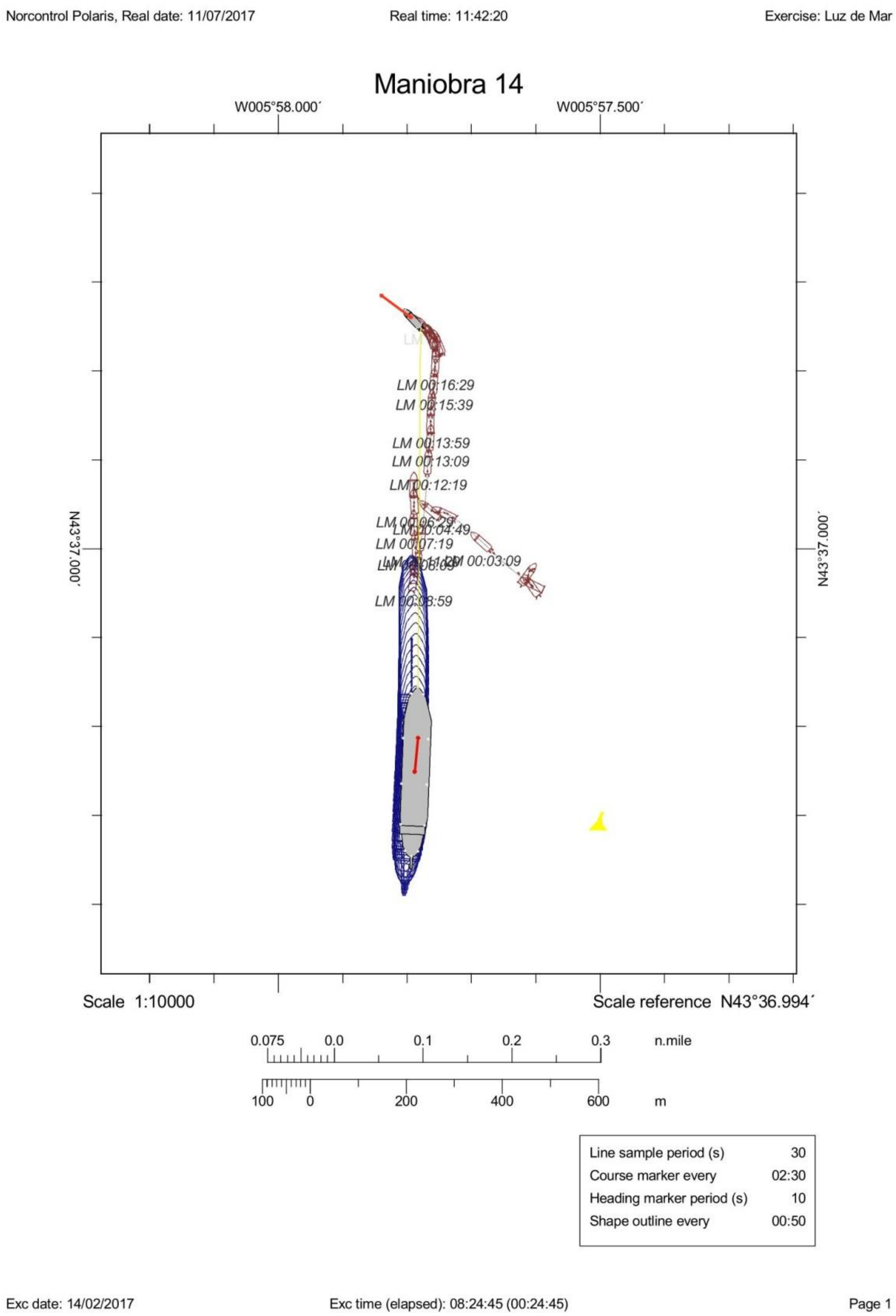


Figure 132– Manoeuvre 14

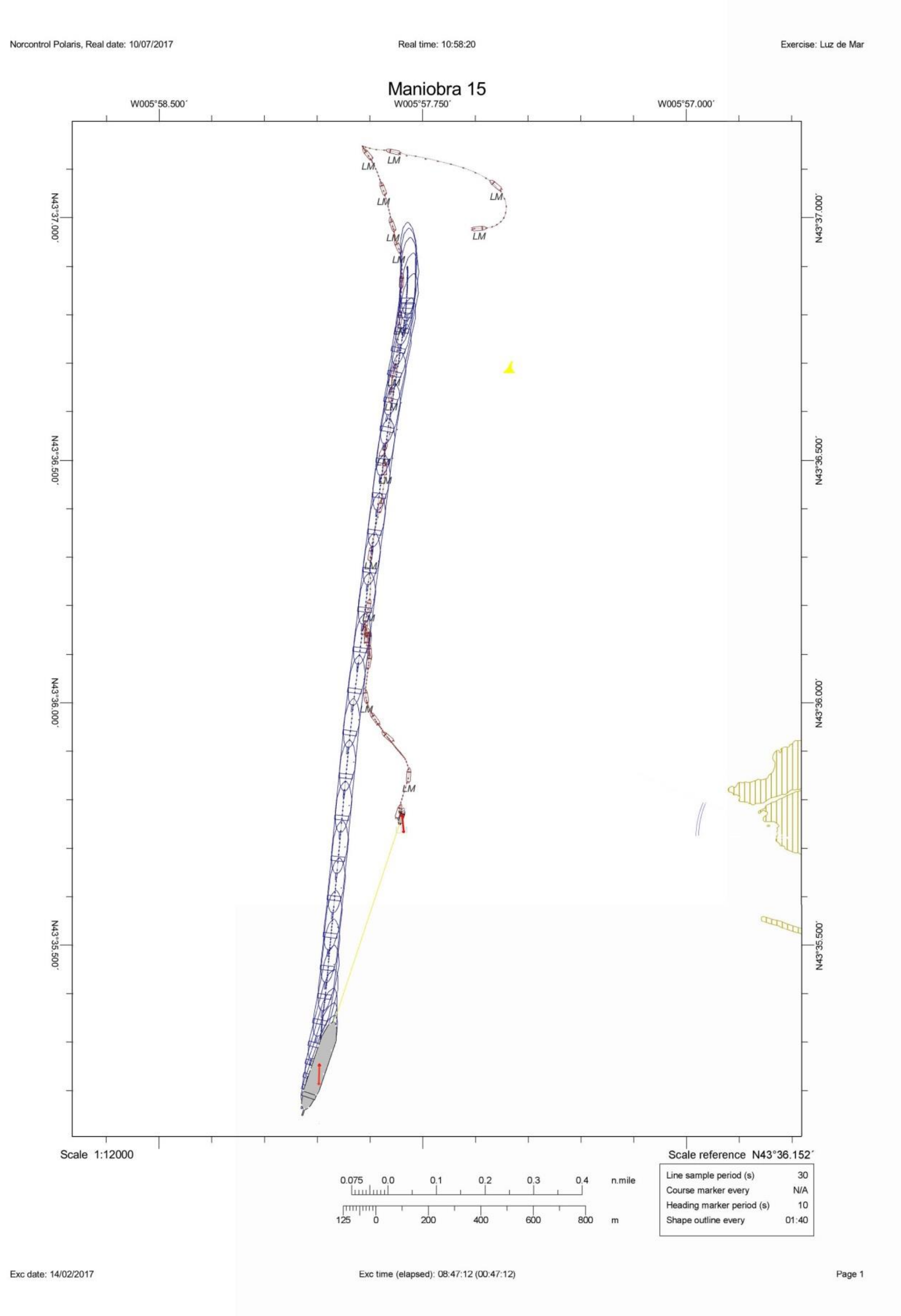


Figure 133– Manoeuvre 15

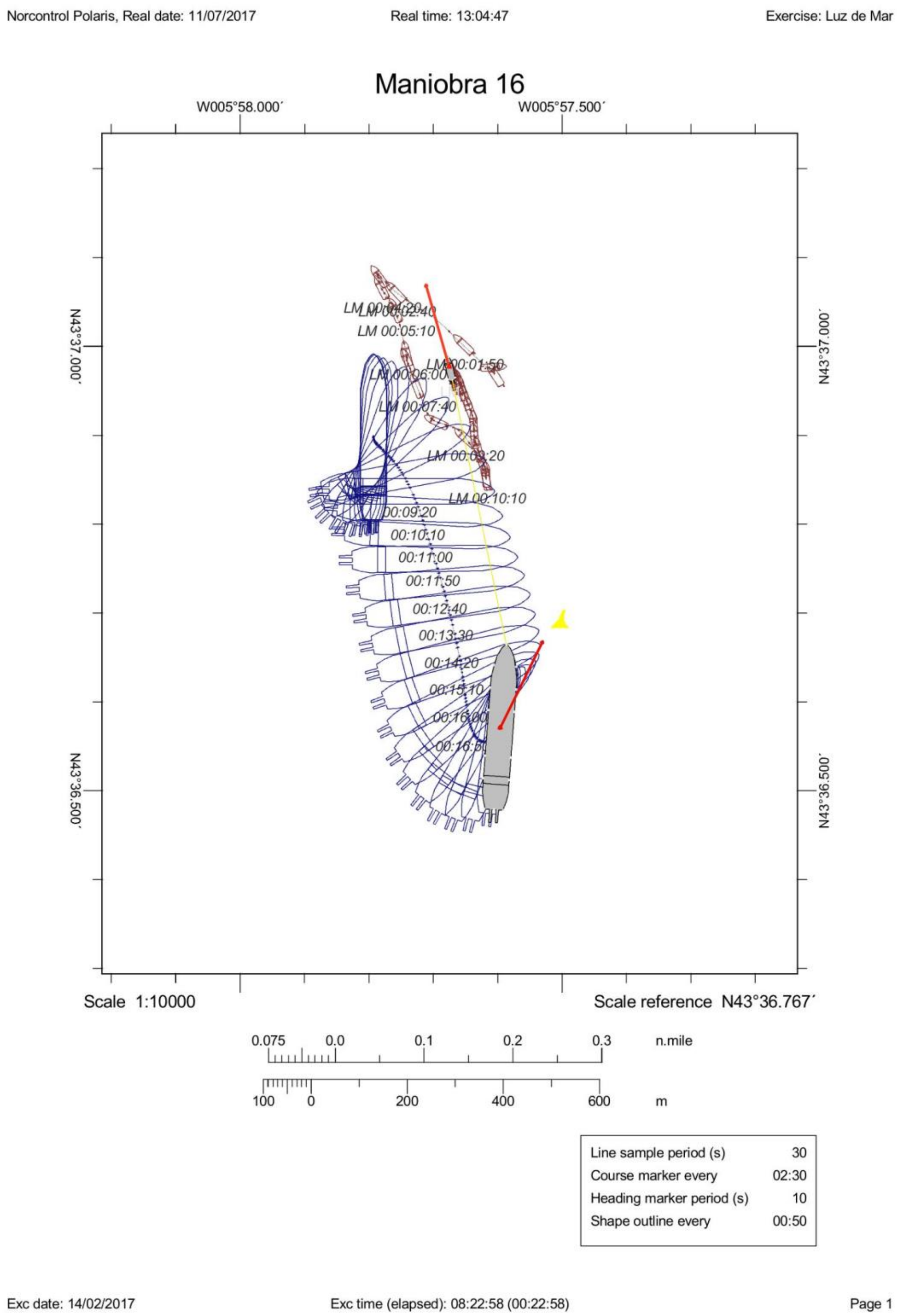


Figure 134– Manoeuvre 16

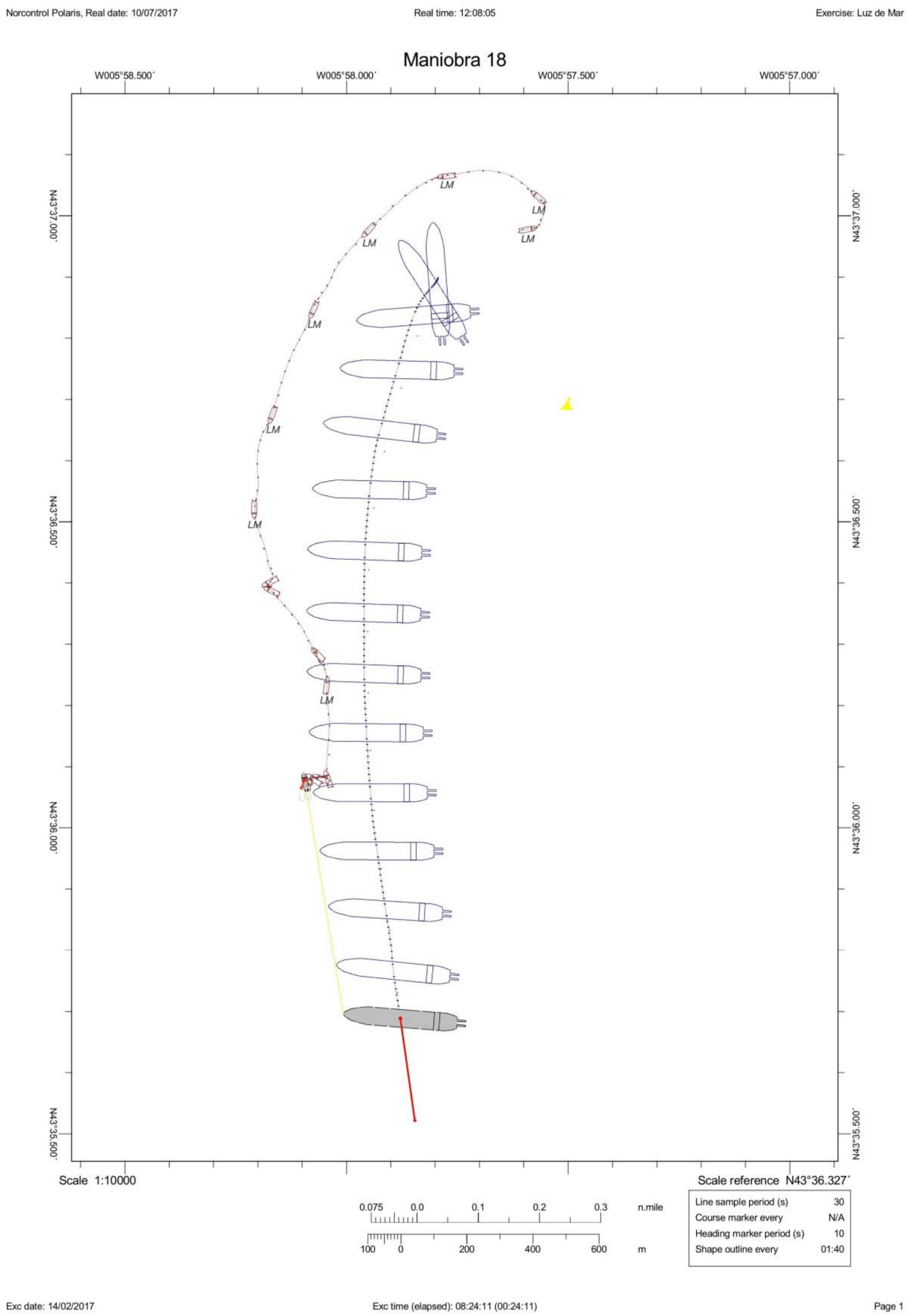


Figure 135– Manoeuvre 18

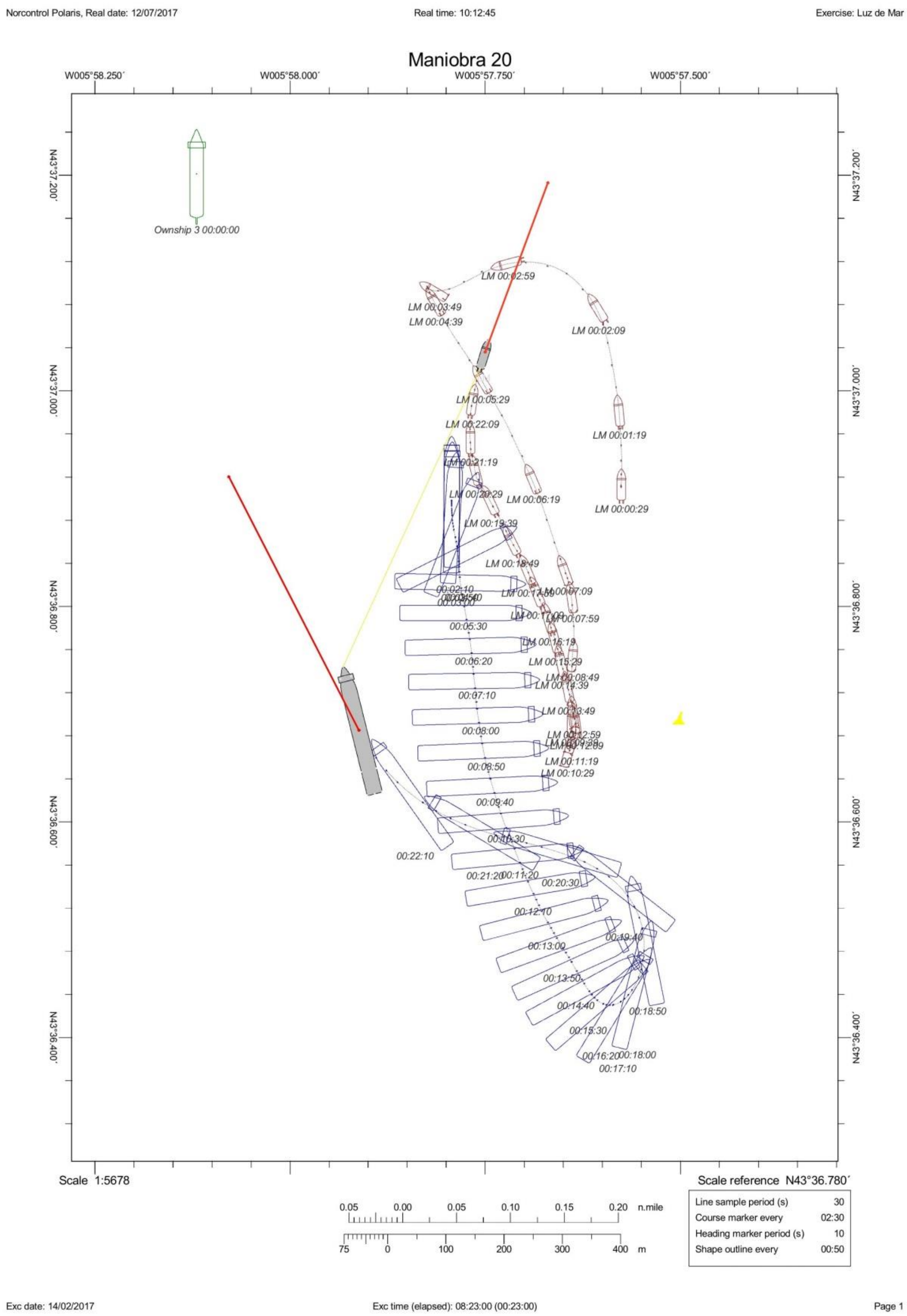


Figure 136– Manoeuvre 20

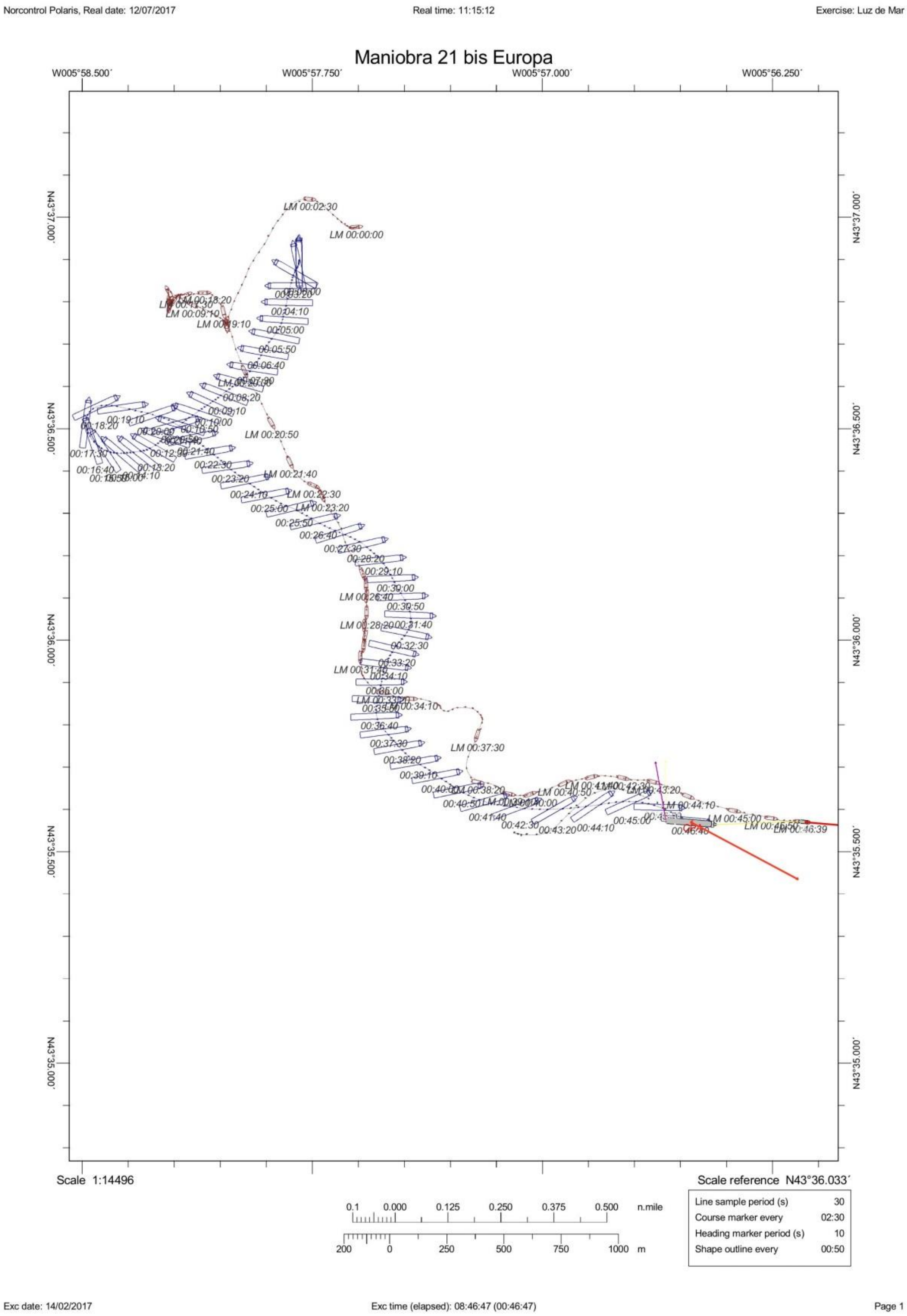


Figure 137– Manoeuvre 21 bis

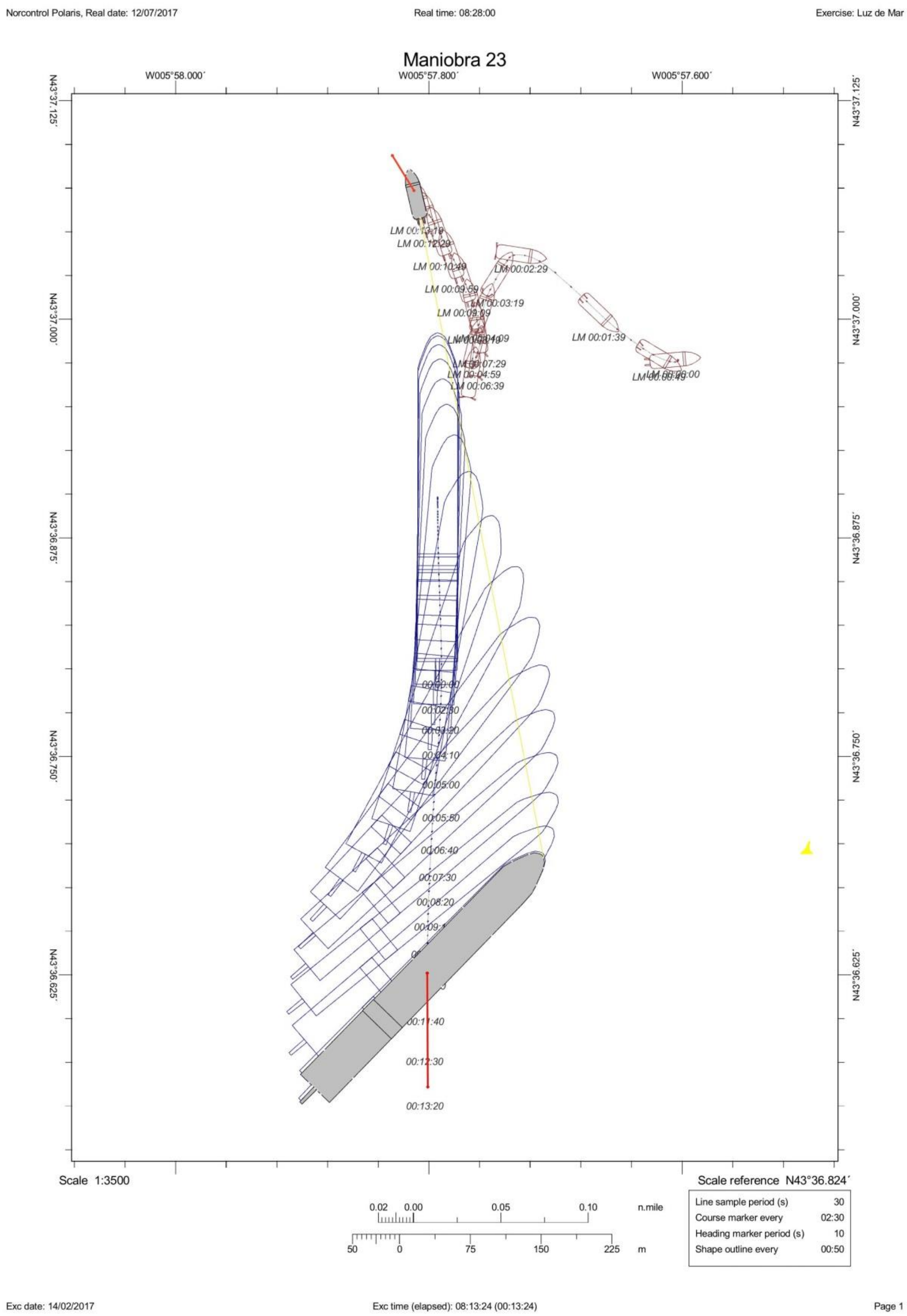


Figure 138– Manoeuvre 23

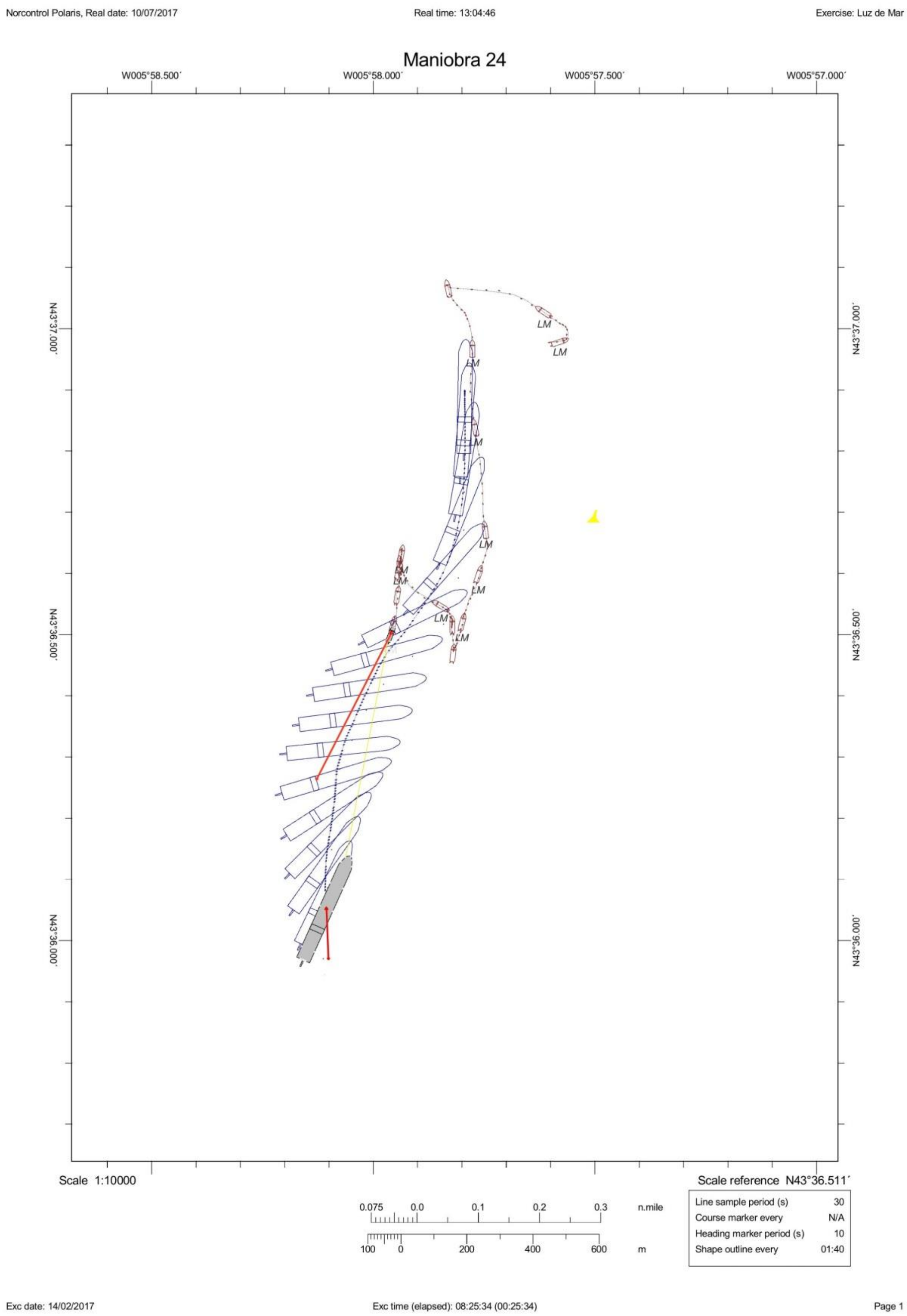


Figure 139– Manoeuvre 24

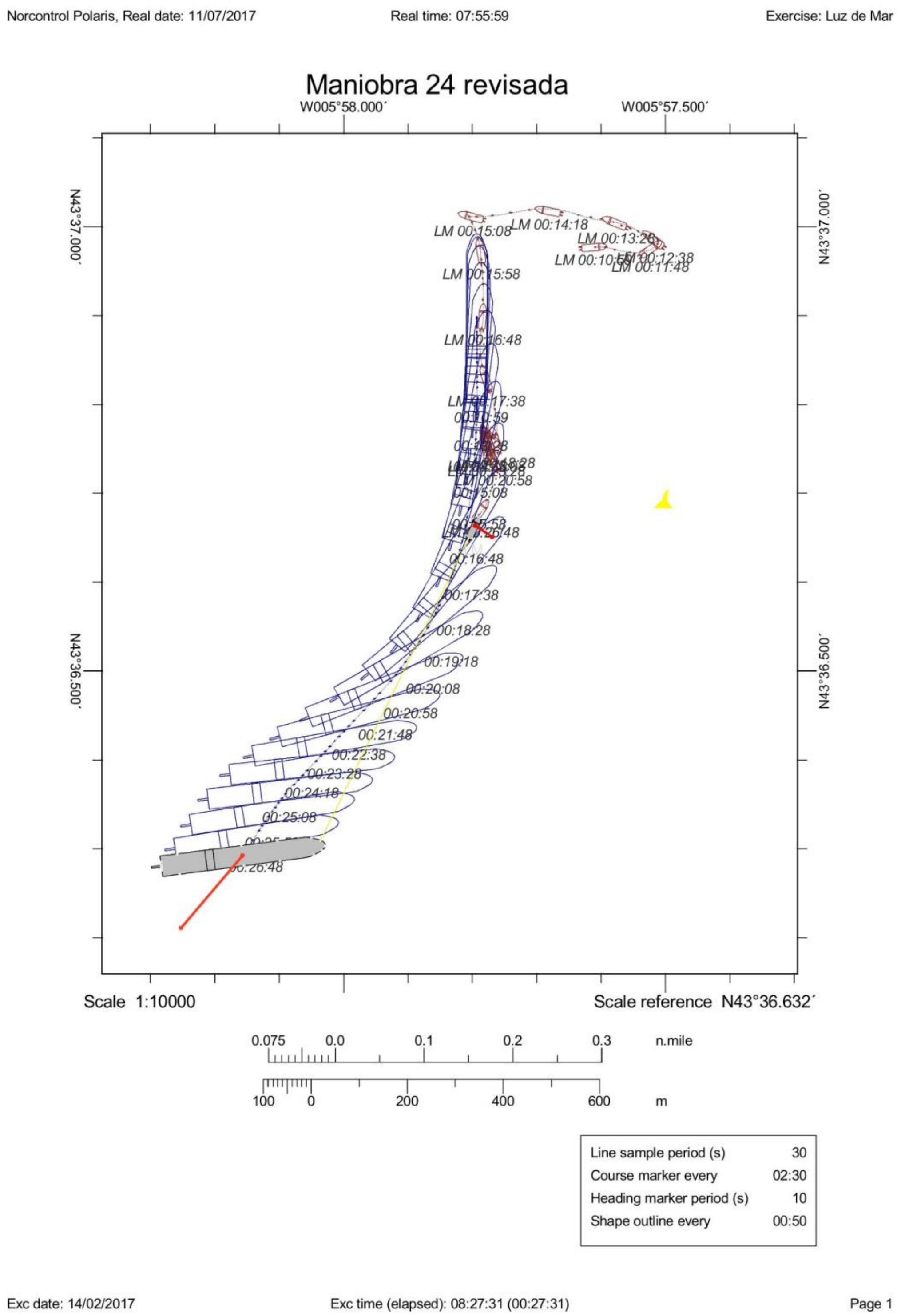


Figure 140– Manoeuvre 24

5. NEW BUILDING DEFINITION

The purpose of the present section is to develop the technical requirements of a new building vessel using gas as fuel. As mentioned at the beginning of the document, LNG have several environmental advantages in comparison with traditional fossil fuels, therefore ships using gas as fuel fulfill new regulations in Emission Control Areas (ECA). On the other hand, the storage and handling of a cryogenic fluid presents several challenges to be taken into account during the design phase.

5.1. GENERAL

The scope of the definition of the New Building will contain several technical and operational requirements that will define the feasibility of the unit.

- Selection of the reference unit to be defined. Base case scenario
- Requirements and operational profile
- Preliminary dimensioning of the vessel
- Technology review for the present unit
- Rules and regulations
- New Building feasibility

5.1.1 Reference ship definition

The reference ship to be considered is the MULTIPURPOSE CATEGORY 2 of the SASEMAR fleet. In this case the vessels are Clara Campoamor and her sistership Don Inda. This two vessels are the largest in SASEMAR fleet and their versatility is focused in three main operational scenarios:

- Salvage, tugging and fire fighting
- Diving support operations
- Oil recovery

The new unit must fulfill the same operational scenarios implementing the new technological developments allowing the improvement and optimization of the operative.

5.1.2 New building main particulars

The new building ship must fulfill, as a mínimum, with the same operational capabilities of the present ships from SASEMAR fleet. The following characteristics shall be considered:

- Speed 100%: 18 knots
- Bollard pull (stern): 235 tons
- Range (80%): 9.000 nm
- DP2 (DYNAPOS AM/AT R)
- Oil recovery: Approx. 50% of Clara Campoamor capacity (about 875m³). Portable equipment to be fitted on main deck
- FIFI-II + Water Spray
- Natural gas as fuel
- Helideck
- Moonpool
- Clean Design

5.1.3 Reference units

Prior to the unit definition, and initial survey of the world fleet is done, with similar characteristics to the unit to be developed. At present, only k/v Turva has a similar operational profile. k/v Turva is a coastguard vessel from the Finish Army which main operations are patrol, salvage, oil recovery and diving operations. The ship uses gas as fuel and is provided with Helideck. Unfortunately there is limited available information of this ship.

On the other hand, with conventional propulsion (diesel), there is a vast amount of designs and vessels than can be used as starting point of the new unit. In the following pages, it is shown the main particulars of some of them that fits with the requirements of our unit.

Clara Campoamor / Don Inda:

Length overall: 80,00 m

Length between perpendiculars: 69,30 m

Beam: 18,00 m

Height to main deck: 8,25 m

Design draft: 6,00 m

Speed 100%: 18 kn

Aft bollard pull: 234 t

Fwd bollard pull: 100 t

Range (80%): 9.000 nm

Crew: 18 + 7

Rescue people on board: 29 personas

Propulsion:

Main Engines: 4 x 4.000 kW a 750 rpm

Electrical power:

Gensets: 2x1265 kW

PTO: 2x2200 kW

Port genset: 1x425 kW

DP2 (DYNAPOS AM/AT R)

Oil recovery: 1.748,40 m3

FIFI 2 + Water Spray

Rescue boat: 34 kn

Working boat: 2 t – 15 kn

Aux. cranes: 2 x 20 t @ 15 m

k/v Turva:

Length overall: 95,90 m

Beam: 17,40 m

Design draft: 5,00 m

Speed 100%: 18 kn

Aft bollard pull: 100 t

Range (80%): 9.000 nm

Crew: 18 + 7

Rescue people on board: 29 personas

Propulsion:

Main engines:	3 x Wärtsilä 34DF
	1 x 12V34DF (6400 kW)
Gensets:	2x6L34DF (2x3000 kW)

Two azimuth thrusters (diesel –electric) + main engine coupled to a central shaft

DP2 (DYNAPOS AM/AT R)

Oil recovery: 1.000 m3

FIFI 2

Rescue boat

Helideck

Figure 141 - k/v Turva

MAERSK MASTER

Length overall: 95,00 m

Length between perpendiculars: 81,5 m

Beam: 25,00 m

Height to main deck: 11 m

Scantling draft: 8,7 m

Accommodation 52

Bollard pull: 252 t

Propulsion:

Main engines: 2 x 4.000 kW más 2x 3000 kW

Gensets: 1x1800 kW

DP2

FIFI 1

Oil Recovery 1500 m³

Moonpool: No

Helideck: No

Figure 142 - MAERSK MASTER

AKER AH12 - KL SALTFJORD

Length overall: 95,00 m

Length between perpendiculars: 84,8 m

Beam: 24,00 m

Height to main deck: 9,8 m

Draft: 7,8 m

Bollard pull: 350 t

Propulsion:

Main engines: 2 x 8.000 kW Wartsila 16v32

Gensets: 5x2200 kW

PTI: Hybrid propulsion

DP2

Moonpool: No

Helideck: No

Figure 143 - KL SALTFJORD

AKER AH04 – AYA707

Length total: 108,00 m

Length between perpendiculars: 99 m

Beam: 24,00 m

Height to main deck: 9,8 m

Draft: 7,8 m

Speed 100%: - kn

Bollard pull: 170 t

Accommodation: 90 people on board

Propulsion:

Main engines: 2 x 16v32 (2X7680Kw)

Gensets: 4x8L26 (4x2600 kW)

Port Generator: 1x220 kW

DP3 (DYNAPOS AUTRQ)

Rescue boat

Moonpool: Yes

Helideck: Yes

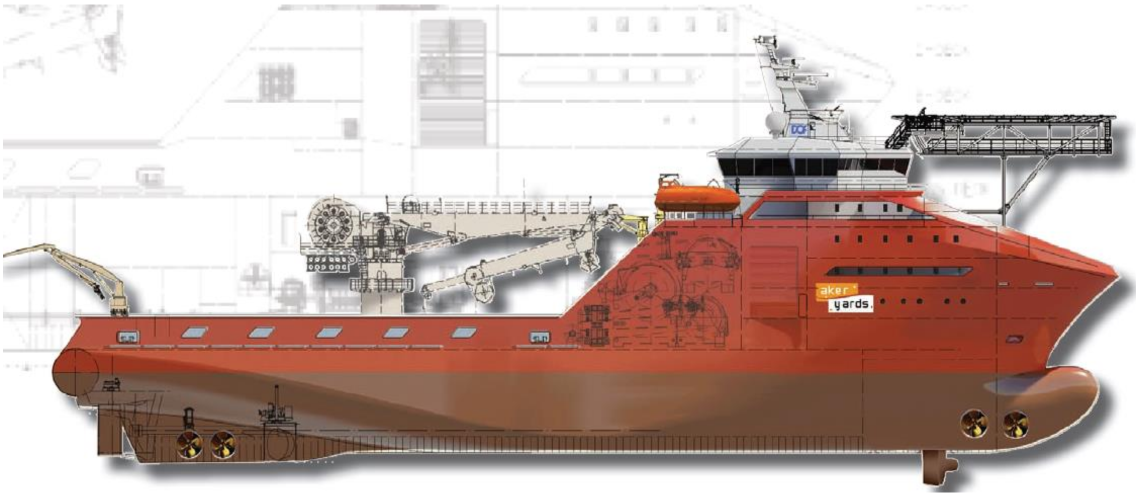


Figure 144 - AYA707

DAMEN AHTS 200

Length overall: 89,10 m

Beam: 22,00 m

Height to main deck: 9,1 m

Draft: 7,0 m

Speed: 16,4 kn

Bollard pull: 200 t

Crew: 21 people

Rescued people on board: 60 personas

Propulsion:

Main engines: 4 x MAN9L27/38 (

Gensets: 2Xcat c32 (2x715 kWe)

PTO: 2x1600 ekW

Port genset: 1x238 kWe

DPAA (DP2)

FIFI 2

Oil recovery

Moonpool: No

Helideck: No

Figure 145 - AHTS 200

ASSO TRENTUNO

Length overall: 79,90 m

Beam: 19,20 m

Height to main deck: 8,30 m

Draft: 6,30 m

Speed 100%: 17,5 kn

Bollard pull: 220 t

Crew: 32 personas

Propulsion:

Main engines: 2 x 4.000 kW Wartsila 8L32

Gensets: 2x515 kW

PTO: 2x3000 kva

Port genset: 1x515 kW

DP2

Oil recovery: 910,0 m3

FIFI 2

Figure 146 - ASSO TRENTUNO

BOA JARL

Length overall: 91,00 m

Length between perpendiculars: 81,93 m

Beam: 22,00 m

Height to main deck: 9,60 m

Draft: 7,00 m

Speed 100%: 18 kn

Bollard pull: 267 t

Crew: 39 personas

Propulsion:

Main engines: 2 x 8.000 kW Wartsila w32V16

Gensets: 2x2335Kva

PTI: 2x1500 kW

PTO: 2x3335 kva

Port genset: 1x5131kva

Dynpos-AUTR (DP2)

ORO Prepared for NOFO 2006 oil recovery equipment

FIFI 2

Moonpool: No

Helideck: No

Figure 147 - BOA JARL

LOKE VIKING

Length overall: 85,20 m

Length between perpendiculars: 76,20 m

Beam: 22,00 m

Height to main deck: 9,60 m

Draft: 7,60 m

Speed 100%: 17 kn

Bollard pull: 220 t

Crew: 45 personas

Propulsion:

    Main engines: 2 x 4.000 kW + 2x 3000 kW

    Gensets: 2x720 Kw

    PTO: 2x2700 kw

    Port genset: 1x501 kw

Dynpos-AUTR (DP2)

Oil recovery: 1650,0 m3

Moonpool: No

Helideck: No

Figure 148 - LOKE VIKING

ABEILLE BOURBON

Length overall: 80,00 m

Length between perpendiculars: 68,60 m

Beam: 16,50 m

Height to main deck: 8,00 m

Draft: 5,60 m

Speed 100%: 19,80 kn

Bollard pull: 201 t

Accommodation: 14+ 8 personas

Propulsion:

Main engines: 4 x 4.000 kW

Gensets: 3x615 Kw

PTO: 2x2400 kw

Dynpos-AM/AT

FIFI 2

Moonpool: No

Helideck: No

Figure 149 - ABEILLE BOURBON

SKANDI ATLANTIC

Length overall: 75,00 m

Length between perpendiculars: 68,00 m

Beam: 17,40 m

Height to main deck: 8,50 m

Draft: 7,00 m

Speed 100%: 15 kn

Bollard pull: 180 t

Crew: 27 personas

Propulsion:

Main engines: 2 x 6.000 kW

Gensets: 2x370 Kw

PTO: 2x2400 kw

DP2

FIFI 2

Moonpool: No

Helideck: No

Figure 150 - SKANDI ATLANTIC

SIEM PEARL

Length overall: 91,00 m

Length between perpendiculars: 79,35 m

Beam: 22,00 m

Height to main deck: 9,60 m

Speed 100%: 18 kn

Bollard pull: 285 - 310 t

Accommodation: 60 personas

Propulsion:

Main engines: 2 x 8.000 kW Wartsila 16V32

Gensets: 2x2100 Kw cat 3516

PTI: 2x1600 kW

PTO: 2x3400 kw

DP2

Oil recovery: 973,4 + 1296,5 m3

FIFI 2

Moonpool: No

Helideck: No

Figure 151 - SIEM PEARL

Among the different ships of the database, the following characteristics are highlighted:

Only k/v Turva use Gas as fuel

Lengths around 90 m

Beams around 20 m

No moonpool

No helideck

For the new building, the LNG tank(s) will impact significantly to the main dimensions.

5.2. NEW BUILDING MAIN PARTICULARS

5.2.1 Operational profile

Based on the operational requirements and characteristics of the new unit, it is defined the following operational profiles operating in Natural gas:

Salvage: Due to the specific requirements during tug and considering the safety measures that are considered in an emergency tug, the use of natural gas in salvage is limited. Tugging will be done in Diesel mode[3]

Transit: Natural gas

Port: Natural gas

Diving support: Natural gas

Oil recovery: Natural gas

[3] Ref. Section 4 "Manoeuvrability study comparing diesel tugboat type "luz de mar" and dual fuel diesel-lng tugboat

5.3. SHIP CONFIGURATION

Along the following sections, it is going to be developed the main configuration of the ship that will define the unit:

- Propulsion plant
- Bollard pull
- Propellers
- LNG tank
- Moonpool
- Helideck
- Active Heave Compensated Crane
- Towing winch

5.3.1 Propulsion plant

The propulsion plant shall be dimensioned according to the requirements of the unit. The present ship has three main power requirements:

Bollard pull: 235 t

Speed: 18 kn

DP2

Three configuration of the propulsion plant are considered:

a) Standard configuration AHTS with large bollard pull: Main engines directly coupled to shaft and control pitch propellers with kort nozzle. Transversal propellers at bow and stern with the potential installation of retractile thrusters to improve the DP operation.
b) Diesel-electric propulsion plant with three azimuth thrusters at stern. Transversal tunnels fore where retractile thrusters could be installed to improve the DP operation.
c) Diesel electric propulsion plant with two azimuth thrusters at stern and one main engine directly coupled to shaft and propellers. The main engine could be electric or diesel. Tunnel thrusters fore where retractile thrusters could be installed to improve the DP operation.

Among the different configurations, only the first one is already installed on an existing ship complying with the minimum bollard pull requirements. B and C options, even already operational on existing ships, do not provide enough bollard pull (B configuration installed in the Seven Atlantic 3x2950kW / Bourbon Evolution 800 with 70 tons of bollard pull. C configuration installed in the k/v turva with maximum bollard pull of 100 tons and in the skandi aker))

The operational profile of the new building shall be defined. The following operational modes are considered:

Transit: The vessel sails between ports or operational areas. Transit is done at economical speed.

Tugging: The vessel has all the power available during tug operation

DP: The vessel is able to maintain position under certain environmental conditions

FIFI: The vessel is operating as firefighting ship

Low speed: The vessel sails at a very low speed

Port maneuvering: The vessels enters in port areas and berthing operations

Port: The vessels is moored, electrical power is used for hotel

5.3.2 Bollard pull

Bollard pull is dependent on the thrust of the propellers, such thrust vary with the diameter, type of propeller (FPP or CPP) and power delivered.

At the conceptual design, the bollard pull can be estimated using the following formulae for tugs:

Vessel equipped with fix pitch propeller: BHPx0.9x1.10/100= (t)

Vessel equipped with fixed pitch propeller and kort-nozzle: BHPx0.9x1.20/100= (t)

Vessel equipped with controllable pitch propeller: BHPx0.9x1.25/100= (t)

Vessel equipped with controllable pitch propeller and kort-nozzle: BHPx0.9x1.40/100= (t)

As the bollard pull requirement is 234 tons, the power requirements are around 14.000 kw for controllable pitch and kort-nozzle.

As per the database, vessels with similar bollard pull capacity have between 15.000 and 17.000 kw installed.

5.3.3 Propellers

Propellers definition is done according to two main characteristics:

Bollard pull

DP operation

The bollard pull will define the dimension and characteristics of the propulsion propellers. Based on the reference unit and the above section, the vessel will be fitted with two propulsion propellers of 4,1 m of diameter.

The propellers related with DP operation are the transverse tunnels (bow and stern). Taken into account that the vessel will be a DP2, there is no need to include redundancy as it will be required in a DP3.

DP requirements are dependent on the environmental design conditions and the size of the vessel. Increase in length and draft have huge impact in the power requirements, on the other hand increment in beam have less impact.

The base case for the new unit at concept design stage will be the installation of 4 transversal propellers (two fore and two aft) each of them with 900 kw of power. One of the fore propellers will be retractile allowing sailing at a very low speed without using aft propellers (or even safe return to port operation in emergency). In further design phases, the power shall be reviewed and calculated according the environmental forces in order to validate the initial estimation

5.3.4 FIFI

FIFI-II requirements implies the installation of two pumps with the following capacity: 3.900 m^3/h @ 16 bar (approx.. 2.000 kW each). The power plant configuration of the vessel allows two different configurations of the FIFI pumps:

a) FIFI pumps directly coupled to the auxiliary engines. In this case the alternator will be driven at one end of the engine and the FIFI pump at the other end. The present configuration has some limitations / requirements: The minimum power of the auxiliary engines shall be 2.000 kW as per FIFI requirement, additionally electrical generation on board shall be done by other mean or increase the power.
   Similar to the describe arrangement, FIFI pumps could be attached to the main engines. Having in mind that the selected configuration is PTO driven fore and PTI aft with gearbox, the implementation of a FIFI pump will overload the area, the operation and the failure mode will be critical in case of main engine maintenance.
b) FIFI pumps attached to electrical engines. Electrical power could be provided by any genset or PTO on board. This configuration provides flexibility in the auxiliary engines power, number and location.

Considering both alternatives, it is selected the first one as the elements on board is lower with the same operational redundancy and simplifying the power plant.

5.3.5 Power plant configuration

Based on the above mentioned operational profile, and taken into account the vessel requirements, the following power plant configuration is selected:

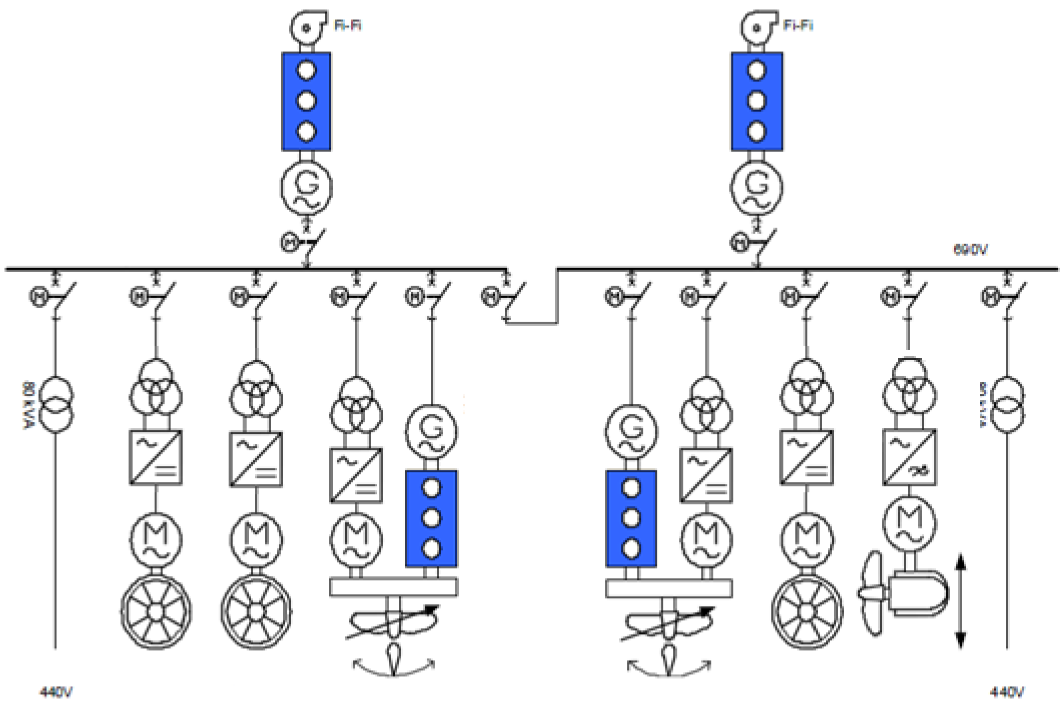


Figure 152 – Propulsion plant configuration

The propulsion plant configuration is as follows:

Two main engines directly coupled through gearbox to two shafts attached to two control pitch propellers. Two alternators driven fore of the main engines. Two electric engines (PTI) coupled to the gearbox.

Two auxiliary engines for electrical generation, each with a FIFI pump attached.

Based on the operational modes, the operation of the vessel, from the power plant point of view is as follow:

Transit: The main engines provide the propulsion power and the electrical power through the fore alternators. If sailing at low speed, the power can be generated by the auxiliary engines and the propellers will be moved through the PTI.

Tug operation: Main engines and PTI providing propulsion power. Auxiliary engines providing electrical power to the ship and to the PTI.

DP: Transversal thrusters in operation. The vessel has available power to maintain position.

FIFI: FIFI pumps directly coupled to the auxiliary engines. Electrical power generated through the main engines alternators

Low speed navigation: Auxiliary engines supplies the electrical power for the vessel and for the retractile thruster fore. As an alternative, the main propellers can be used through the PTI.

Port manoeuvring: Auxiliary engines provides enough power to the PTI and to the transversal thrusters

Port: The port generator supplies electric power for the electrical load. In case that higher electrical demand, an auxiliary engine could be used.

Power requirements of the propulsion plant are as follows:

2 main engines 5.500 kW each

2 PTO 2.000 kW each

2 PTI 3.000 kW each

2 Auxiliary engines of 3.000 kW each

Port generator of 600 kW

Regarding the available manufacturers, it is revised the different alternatives in the market. The only criteria to exclude a manufacturer / technology is the pure gas engines. Due to the characteristics of the vessel and the operational profile it is considered that the unit has to have two fuels (Gas plus diesel). This requirement not only maximizes the operational flexibility and also guarantee the availability of the vessel in emergency tug and salvage operations independent of the fuel used.

The following manufacturers have been reviewed:

- Wärtsilä
- MAN
- Caterpillar / Mak
- Mitsubishi
- ABC
- Rolls Royce
- MTU

In the following pages, the selection of the different equipment is done:

Main engines:

Wärtsilä:

8V31DF – 4.880 kW

10V31DF – 6.100 kW

6L50DF – 5.850 kW

MAN:

9L35/44DF – 4.770 kW

10L35/44DF – 5.300 kW

MaK:

6M46DF – 5.400 kW

Rolls Royce:

B35:44V12PG – 5.700 kW *

Auxiliary engines:

Wärtsilä:

6L34DF – 3.000 kW

MAN:

6L35/44DF – 3.180 kW

MaK:

6M34DF – 3.000 kW

Port generator:

MAN:

5L23/30DF – 625 kW

Mitsubishi:

GS12R-MPTK – 676 kW *

ABC:

6DZD – 750 kW

* These engines uses pure gas technology, therefore based on the criteria, are not going to be considered.

The power plant selected is as follows:

Main engines: MaK 6M46DF - 5.400 kW

Modelo	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)	H1 (mm)	H2 (mm)	H3 (mm)	W1 (mm)	W2 (mm)	Peso (t)
6 M 46 DF	8330	1086	1255	1723	3734	1396	750	2961	2961	96

Figure 153- Dimensions MaK 6M34DF

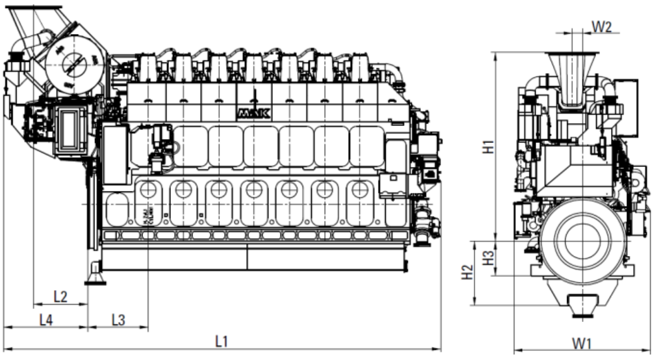


Figure 154 – Dimensiones MaK 6M46DF

Modelo	Potencia (kW)	RPM	PME (bar)	Velocidad pistón media (m/s)	Consumo específico Fuel 100% (g/kWh)	Consumo específico Fuel 85% (g/kWh)	Consumo energético total gas 100% (kJ/kWh)	Consumo energético total gas 85% (kJ/kWh)
6 M 46 DF	5400	500/514	21.3/20.7	10.2/10.5	186	185	7441	7524

Table 93 - Characteristics MaK 6M 46DF

Auxiliary engines:

Option 1: MaK 6M34DF - 3.000 kW

Modelo	L1 (mm)	L2 (mm)	L3 (mm)	H1 (mm)	H2 (mm)	W1 (mm)	W2 (mm)	Peso (t)
6 M 34 DF	9566	9094	8672	2749	1800	2600	127	71

Table 94- Dimensions MaK 6M34DF

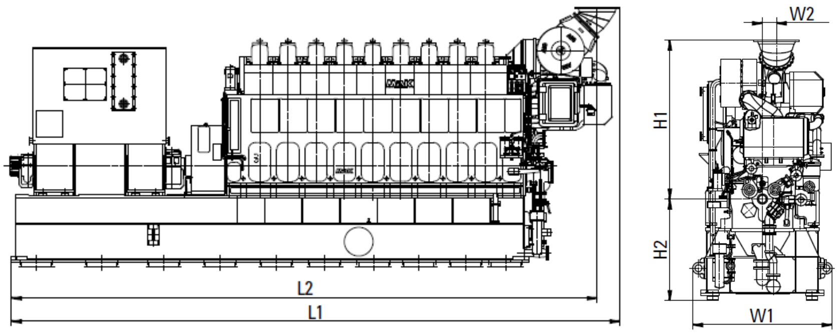


Figure 155– Dimensions MaK 6M34DF

Modelo	Potencia (kW)	Potencia eléctrica (kVA)	PME (bar)	RPM	Velocidad pistón media (m/s)	Consumo específico Fuel 100% (g/kWh)	Consumo específico Fuel 85% (g/kWh)	Consumo energético total gas 100% (kJ/kWh)	Consumo energético total gas 85% (kJ/kWh)
6 M 46 DF 60 Hz	3060	3672	20.3	720	11.0	188	187	7520	7680
6 M 46 DF 50 Hz	3180	3816	20.2	750	11.5	188	187	7520	7680

Table 95– Characteristics MaK 6M34DF

Option 2: Wärtsilä 6L34DF – 3.000 kW

Modelo	LA1 (mm)	LA2 (mm)	LA3 (mm)	WA1 (mm)	WA2 (mm)	WA3 (mm)	HA1 (mm)	HA2 (mm)	HA3 (mm)	HA4 (mm)	Peso (t)
6L34DF	8765	6900	1215	2290	1910	1600	4000	2345	1450	1055	60

Table 96 - Dimensions 6L34DF

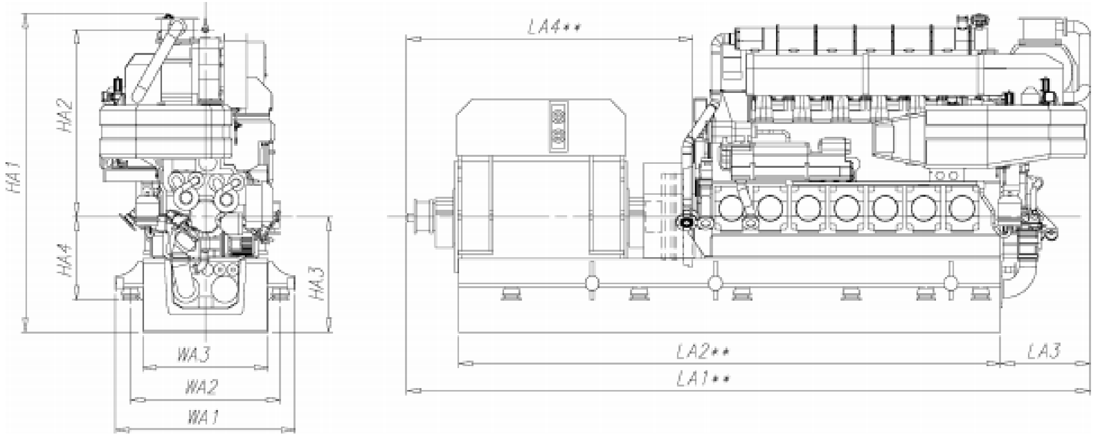


Figure 156 - Dimensions 6L34DF

Modelo	Potencia (kW)	Potencia eléctrica (kVA)	PME (bar)	RPM	Velocidad pistón media (m/s)	Consumo específico Total 75% (kJ/kWh)	Consumo específico Fuel 50% (g/kWh)
6L34DF	3000	3600	22	750	11.0	7850	8600

Table 97 - Characteristics 6L34DF

<u>Alternativa 3</u>: MAN 6L35/44 DF – 3.180 kW

Modelo	A (mm)	B (mm)	C (mm)	W (mm)	H (mm)	Peso (t)
6L35/44DF	6270	3900	10170	2958	4631	85

Table 98 - Dimensions 6L34DF

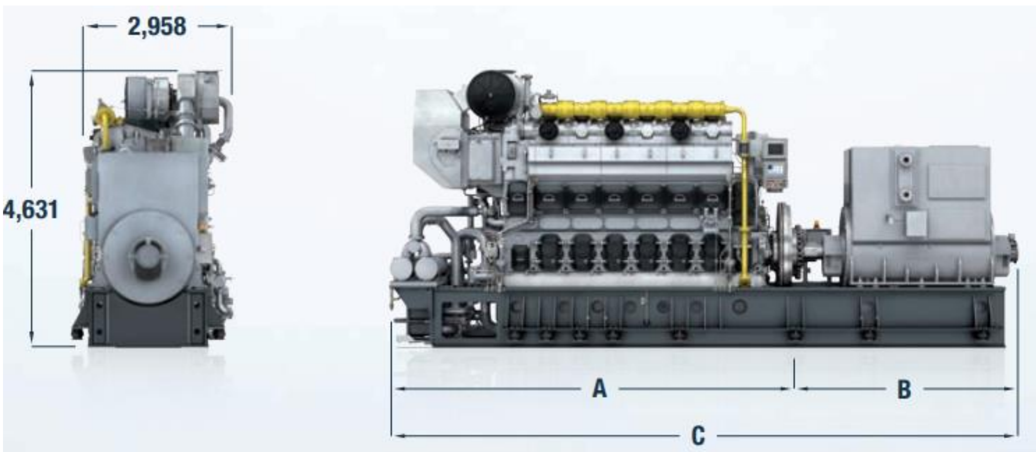


Figure 157 - Dimensions 6L35/44DF

Modelo	Potencia (kW)	RPM	PME (bar)	Consumo específico Gas 100% (kJ/kWh)	Consumo específico Gas 85% (kJ/kWh)
6L35/44DF	3180	750	20	7470	7515

Table 99 - Characteristics 6L35/44DF

Grupo de puerto: MAN 5L23/30DF – 625 kW

Modelo	A (mm)	B (mm)	C (mm)	H (mm)	Peso (t)
5L23/30DF	3469	2202	5671	2685	17.4

Table 100 - Dimensions 6L34DF

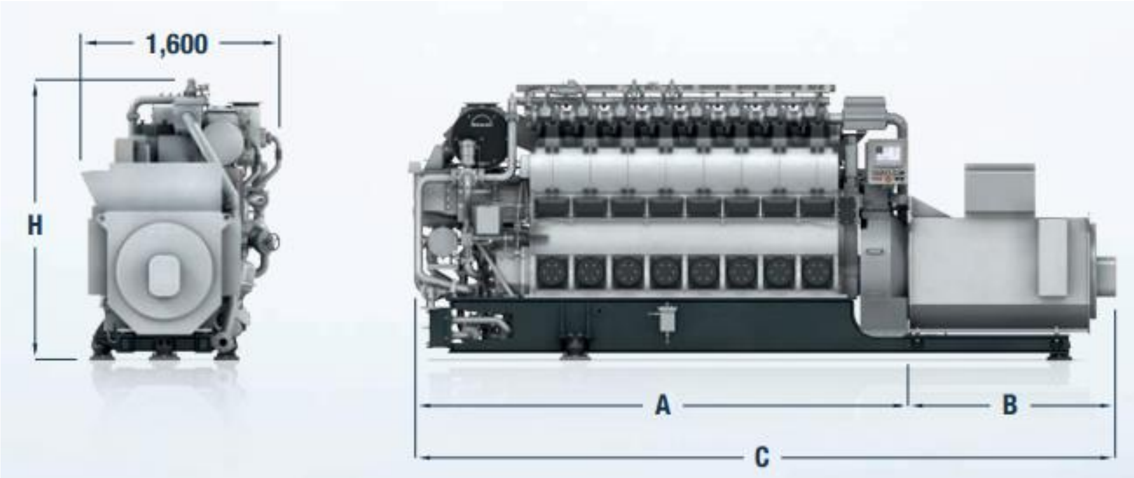


Figure 158 - Dimensions 5L23/30 DF

Modelo	Potencia (kW)	RPM	PME (bar)
6L35/44DF	625	750	17.1

Figure 159 - Characteristics 6L35/44DF

The use of Natural Gas in engines requires the installation of a control unit providing (gas ramp) that the gas supply is done at a defined pressure and temperature (as per manufacturer's specifications). These units also have safety operation allowing the system to vent and purge

In the following figures, the control unit of two different manufacturers is shown and the arrangement of another manufacturer:

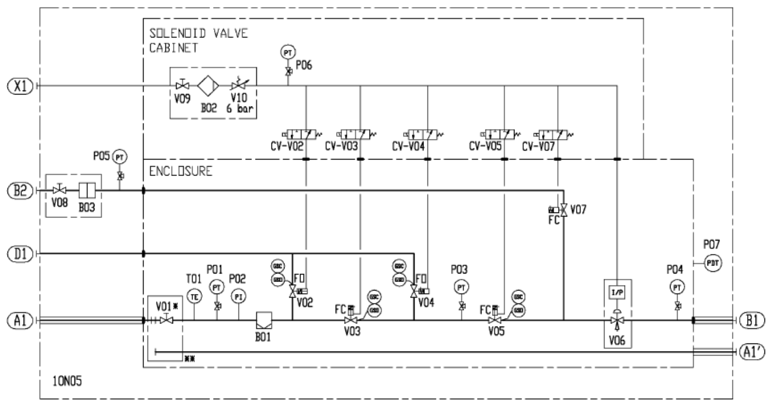


Figure 160 – Gas ramp Wärtsilä (GVU)

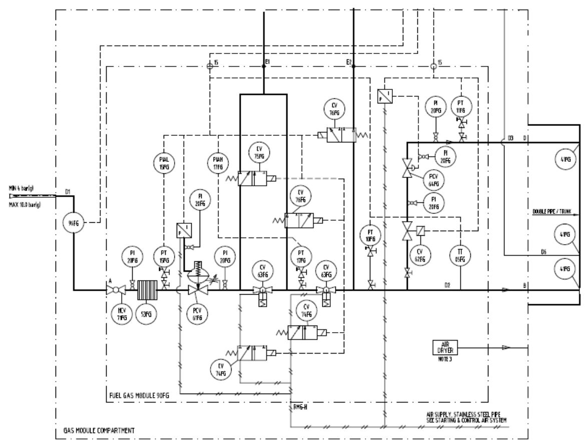


Figure 161 - Ramp gas Rolls-Royce (GRU)

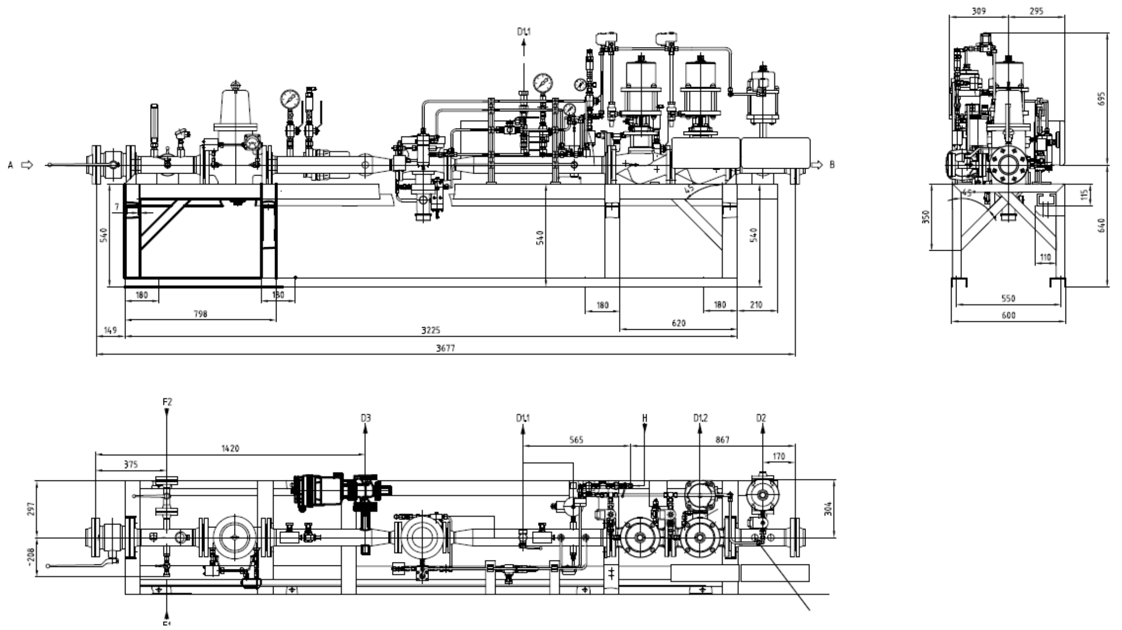


Figure 162 – Ramp gas arrangement MAN

The dimensions of the ramp gas are dependent on the manufacturers technology and the power of the engines (gas supply flow and pressure)

Based on the manufacturers technologies, two different configurations are considered for the gas ramp. The standard one extrapolated for large gas carriers are equipment installed in a specific room. The other configuration is the installation of the gas ramp inside a gastight equipment. The last configuration has the same operability of the first one and the advantage of the reduction of a dedicated room on board. In the following figures, two manufacturers technology are shown:

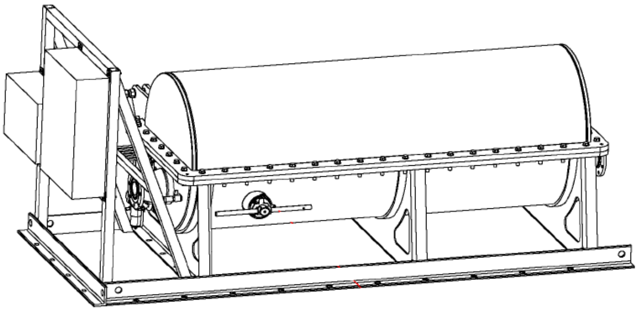


Figure 163 - GVU Wärtsilä

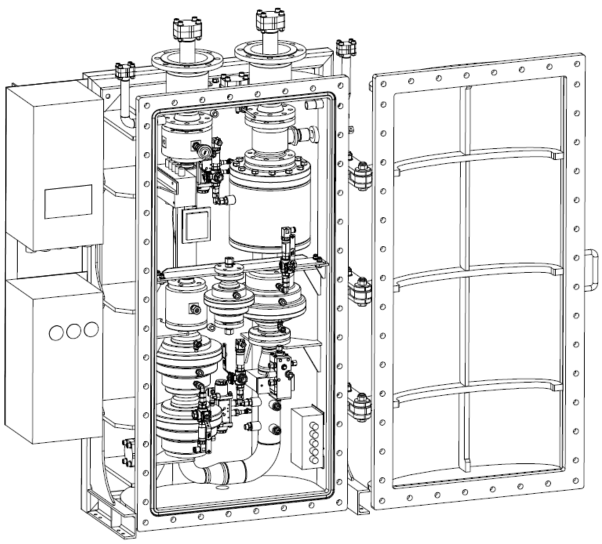


Figure 164 - GRU RMG

The gas ramps shall be installed one per engine. The configuration selected on board is to bundle two ramps per room (one main engine and one auxiliary engine). The arrangement on board of the ramp gas is critical due to the limitation of the pipe length between the gas ramp and the engines (less than 10 m).

5.3.6 Moonpool

One of SASEMAR additional requirement to be consider for the conceptual design is the implementation of a moonpool to improve the diving operations. The diving operation in the present fleet is done on the side of the ship and the moonpool allows a shelter area safer for the operation.

The size of the moonpool is dependant on the equipment to be deployed. The preliminary size selected is 4.2mx4.2m

To be taken into account that the open moonpool implies an increase in the overall drag of the vessel between 5% to 10%.

The arrangement of the moonpool clashes with the longitudinal arrangement of the LNG tank (considered the most suitable arrangement).

In case of installation, the moonpool will be fitted with a upper cover allowing the stow of cargo on deck. A lower cover (dismountable) can be fitted.

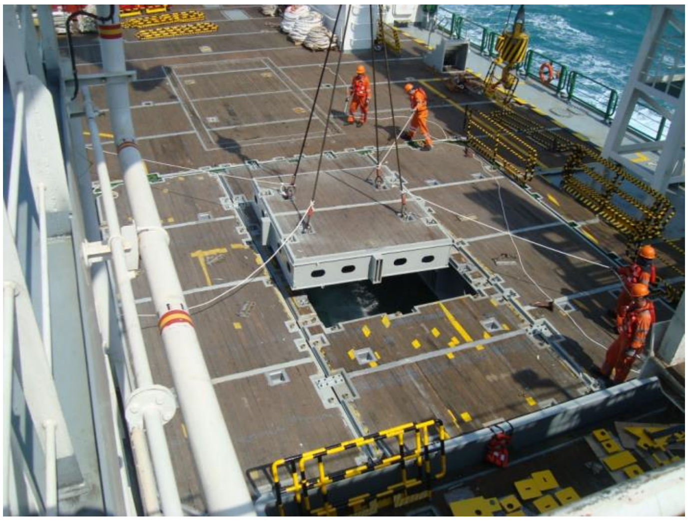


Figure 165 – Moonpool upper cover

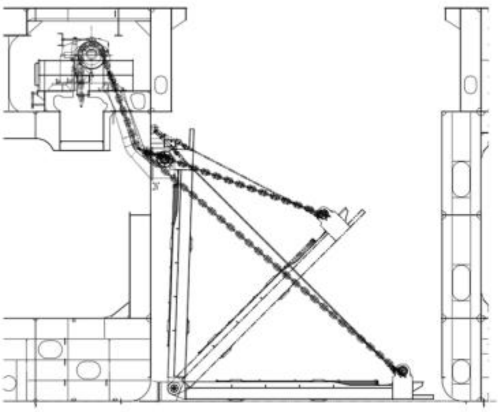


Figure 166 – Lower cover operation

5.3.7 Helideck

The present fleet of SASEMAR do not have a helideck available. It is considered for the new building the installation of a Helideck. The Helicopter fleet of SASEMAR that could operate in the helideck is shown in the following table:

Base	Modelo	Zona de influencia
Santander	AW139	Cantábrico Oriental
A Coruña	EC225	Galicia
Cee *	AW139	Galicia
Jerez	AW139	Estrecho
Valencia	AW139	Mediterráneo Central
Las Palmas	S61N	Canarias Oriental
Palma de Mallorca	AW139	Baleares
Almería	AW139	Alborán/Mediterráneo Sur
Reus	AW139	Mediterráneo Norte
Tenerife	AW139	Canarias Occidental
Gijón	AW139	Cantábrico Occidental

Table 101 - SASEMAR Helicopter fleet

Taking into account the helicopters, and knowing that the helideck sizing is dependent on the maximum capacity of the helicopter that could operate, it is consider reasonable the use of the AW139 helicopter as base case.

At conceptual design is not consider helicopter refuelling.

According to CAP 437, the following table show the main characteristics of the helidecks associated to the helicopter fleet of SASEMAR:

TYPE	D-Value (m)	Perimeter mark "D"	Rotor diameter (m)	Maximum weight (kg)	"t" value	Net diameter
AW139	16,66	17	13,8	6400	6,4	Medium
EC225	19,5	20	16,2	11000	11	Medium
S61N	22,2	22	18,9	9298	9,3	Large

Table 102 – Helideck characteristics

Taking into account the required dimensions for AW139 helideck, in the following figure it is shown the installed helideck:

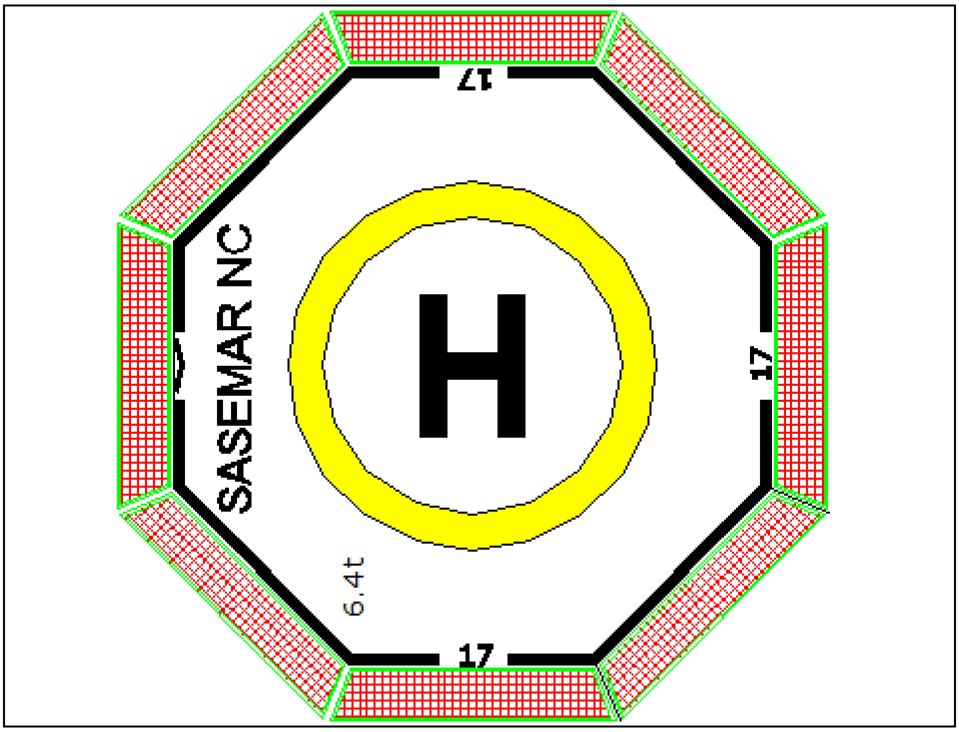


Figure 167 – Helideck

5.3.8 Cranes

In order to improve the vessel capabilities in operation, the vessel is provided with an Active Heave Compensated crane. This crane can be used not only during load transfer between vessels but also in diving support operations widen the operational envelope.

When operating in compensation mode, the crane compensates for relative vertical movement between the crane vessel and secondary vessel regardless of where the crane or load is positioned. The system calculates the necessary winch compensation to minimise hook movement in relation to the load or landing zone on the secondary vessel.

The main benefits of the AHC are:

- Safe transfer of loads between vessels
- Widened operational envelope
- Time-saving for complete lift operations
- Precise and accurate motion-compensation
- Maximum use of load capacity

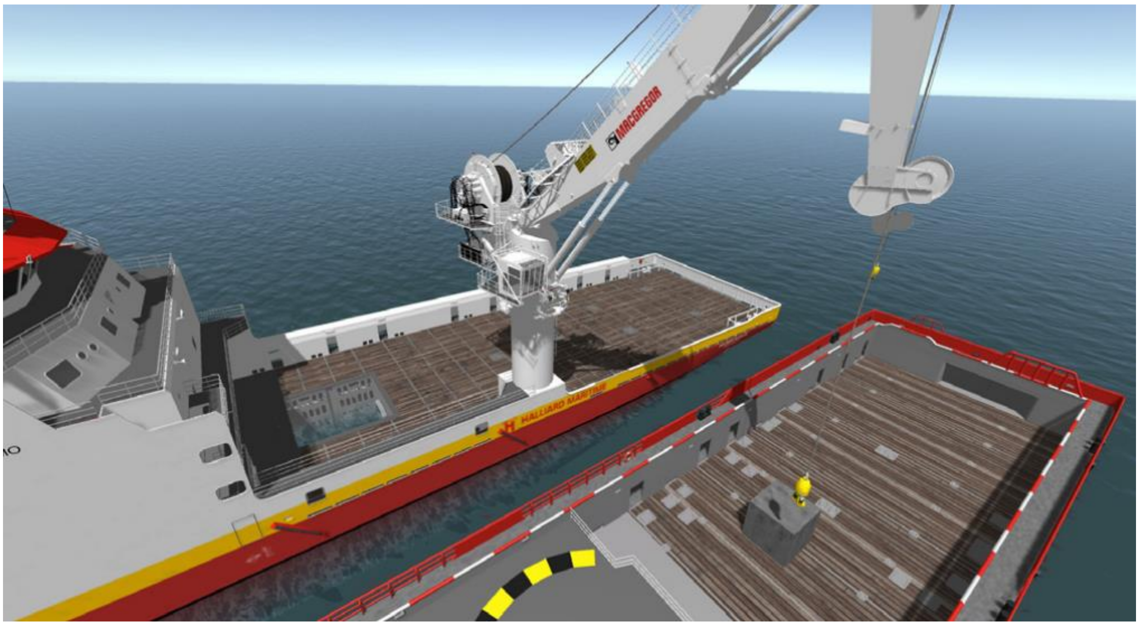


Figure 168 – AHC operation. Source: MacGregor

Regarding the capacity required, the preliminary lifting capacity will be around 200 t. Based on that, according to MacGregor product sheet the lifting capacity could be of 150 tons @15 m or 250 tons @ 19 m.

Additional to the lifting capacity, there are other parameter that is paramount in the selection of the crane that is the winch location. The Winch can be located on the crane or under deck. Considering both alternatives, and having in mind the space limitation under deck, the winch will be located on crane.

The main characteristics of the selected crane are.

Crane type: MacGregor 3568

Shipboard Capacity: LKO 30T-35m (150T -15m)

Offshore capacity: LKO 25T-35m (150T-11m)

List/Trim: 5/2

Outreach: 35 m

Wire diameter: 77mm

Power consumption: 4x550 Kw

Foundation height: 5m

Total Weight: 370 ton

Winch type: On crane

Hook travel: 3000 m

Hoisting Speed 1 (Stepless on middle layer): 0-50T // 0-80m/min

Hoisting Speed 2 (Stepless on middle layer): 50-100T // 0-80-40m/min

Hoisting Speed 1 (Stepless on middle layer): 100-150T // 0-40-20m/min

5.3.9 Towing Winch

One of the main particulars of the vessel is the towing capacity. As the towing capacity of the New Building is the same as the reference ship, similar towing winch is considered. The main elements to be considered in the towing operation are:

Towing Winch: 310 tons @ 8 m/min

Brake holding: 550 tons 1st layer

Tugger Winch: 2x 10 tons @ 16,5 m/min

Towing pins: 300 tons

One of the potential limitations of the use of the towing winch is the compatibility with the moonpool arrangement and the diving support operation on deck.

In the following figures it can be seen that the moonpool shall be located aft the towing hook. As the moonpool will have a deck cover, no additional space is required.

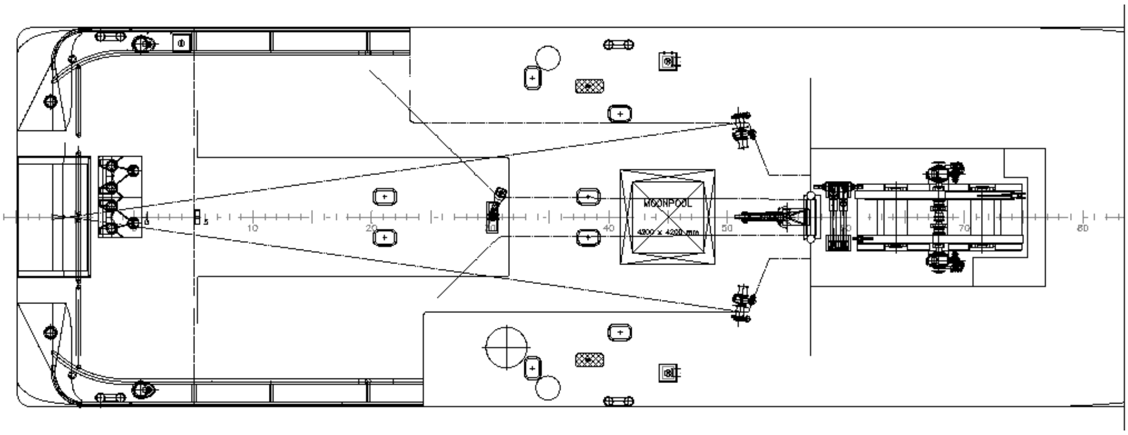


Figure 169 – Towing winch and moonpool deck arrangement

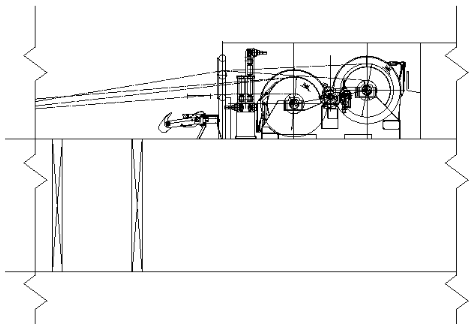


Figure 170 – Towing winch and moonpool profile arrangement

5.3.10 LNG storage tank

In order to define the minimum LNG volume on board, it is calculated the fuel consumption in the reference power plant (Clara Campoamor) and the energy requirement is extrapolated.

	Transit	Tug / salvage	DP	FIFI	Low speed sailing (Retractile)	Port manoeuvring	Port
MMPP (kW)	6800	13600	3840	7840		600	
MMAA (kW)		800	700	700	1340	1900	
Port (kW)							380
Weekly operation (h)	20	4	10	6	40	6	82
Estimated fuel consumption (ton)	29.44	12.53	9.97	11.25	12.67	3.48	7.84

Table 103 – Estimated weekly fuel consumption for the reference vessel

According to the operational profile, the weekly fuel consumption is about 87 tons[4] that mean an equivalent energetic value of 145 m³ of LNG.

Taking into account the vessel power plant described in section 4.3.5, similar operational profile implies the following LNG requirements:

	Transit	Tug / salvage	DP	FIFI	Low speed sailing (Retractile)	Port manoeuvring	Port
MMPP (kW)	6800	8500	4685	4585			
MMAA (kW)		5900		4135	1340	2200	
Puerto (kW)							380
Weekly operation (h)	20	4	10	6	40	6	82
Estimated consumption LNG (m^3)	40.89	17.37	14.09	15.814	16.24	4.55	10.61

Table 104 – Estimated LNG requirements for the new building

According to the operational profile and the installed power plant, the LNG requirements on board will be about 120 m³[5].

[4] 85 tons per week shall be compared with real consumption. Annual average of 330 days of operation mean 4.000 tons of fuel per year

[5] Calculations have been simplified as the specific fuel consumption is considered constant.

In order to compare the LNG volume requirements suitability, it is compared with the LNG installed in existing units. The comparison will provide a third input.

As the k/v turva has limited available information there is no input from this vessel. On the other hand it is known some information of the gas fuel Offshore patrol boats Barentshav class (KV Barentshav, KV Bergen y KV Sortland) similar in size as the k/v turva. The Barentshav class have installed one LNG tank of about 200m^3 (net – 90%)

Additionally to the Barentshav class patrol boats, it is used as reference the gas fuel offshore supply vessels:

Vessel name	Type	Owner	Building year	Main particulars
Stril Pioneer	OSV	Simon Møkster	2003	LOA 94.9 m / B= 20.4
Viking Energy	OSV	Eidesvik Offshore	2003	LOA = 94.9 m / Lpp = 83 m / B=20.4 LNG 1 x 234 m3
Viking Lady	OSV	Eidesvik Offshore	2008	LOA = 92.2 m / Lpp = 84.8 / B=21
Viking Queen	OSV	Eidesvik Offshore	2008	LOA 92.2 / Lpp = 84.8 / B=21 LNG 1 x 234 m3
Normand Artic	OSV	Solstad Offshore	2011	L=94.3 / B=20 LNG 213 m3
Skandi Gamma	OSV	DOF ASA	2011	LOA=94.9 m / B=20 m
MV Island Crusader	PSV	Island Offshore	2012	L=96 / B=20 2 x LNG Capacidad total neta 200m³
MV Island Contender	PSV	Island Offshore	2012	L=96 / B=20 2 x LNG Capacidad total neta 200m³
Rem Eir	OSV	Remoy Shipping	2014	L=92.5 m
Viking Prince	OSV	Eidesvik Offshore	2012	LOA=89.6 / Lpp = 79.2 / B=21 233 m3LNG
Viking Princess	OSV	Eidesvik Offshore	2012	LOA=89.6 / Lpp = 79.2 / B=21 LNG 233 m3
Harvey Energy	PSV	Harvey Gulf	2015	L=94.5 m / B= 19.5 m / T=7.5 m LNG 295.3 m³
Harvey Power	PSV	Harvey Gulf	2015	L=94.5 m / B= 19.5 m / T=7.5 m LNG 295.3 m³
Siem Symphony	PSV	Siem offshore	2014	L=89 / B=19 LNG 230 m³
Siem Pride	PSV	Siem offshore	2015	L=89 / B=19 LNG 230 m³
Stril Barents	PSV	Simon Møkster Shipping	2015	L=94 m / B=20 m LNG 200 m³

Table 105 – Gas fuelled offshore supply vessels

As can be seen in the previous table, the LNG tank capacity for the units of that size is around 200 m³.

Taken into account the operational profile and the reference vessels, it is established a minimum LNG capacity requirement of about 120 m³, being the target LNG capacity of 200m³. The arrangement of the LNG tank will maximize the amount of LNG on board.

It shall be highlighted that all the LNG tanks of the reference vessels are cylindrical Type C tanks. Taken into account the operation of the vessel, type C tank is considered the most suitable option as it provides with operational flexibility.

Regarding the insulation technologies (vacuum and polyurethane foam), vacuum insulation is selected as it provides higher holding time and therefore there is margin in case of low gas consumption on board (i.e. long port stays)

At present, several manufacturers in the market are available able to supply the LNG tank: Chart Ferox, Furiase, MAN Cryo LNG, Wärtsilä, Viafin V7, etc

Among the different options, it is used for the present study the type c vacuum insulated LNG tanks from Chart Ferox. The manufacture is able to supply tanks of standard size but also specific sizes according to the project requirements. In the following table the standard tank sizes are shown. The conceptual design of the vessel will consider different tank lengths but maintaining the standard diameters as it is considered a critical dimension.

Type	Unit	LNGTank 105	LNGTank 145	LNGTank 194	LNGTank 239	LNGTank 284	LNGTank 280
Geometric Volume	[m³]	105,00	145,00	194,00	239,00	284,00	280,00
Net Volume (90%)	[m³]	94,50	130,50	174,60	215,10	255,60	252,00
External diameter (D)	[m]	3,50	4,00	4,30	4,30	4,30	4,80
Tank Length (A)	[m]	16,70	16,90	19,10	23,10	27,10	21,30

Table 106 - Chart Ferox LNG tank

Type	LNGTank 308	LNGTank 339	LNGTank 402	LNGTank 440	LNGTank 465	LNGTank 520	LNGTank 527
Geometric Volume	308,00	339,00	402,00	440,00	465,00	520,00	527,00
Net Volume (90%)	277,20	305,10	361,80	396,00	418,50	468,00	474,30
External diameter (D)	4,80	5,00	5,00	5,60	5,00	5,60	5,00
Tank Length (A)	23,40	23,50	27,50	23,80	31,50	27,80	35,50

The reference tank to be considered will be the LNGTank 239 for dimensional purposes. Extrapolating the dimensions of the standard tanks, it is calculated the different tanks dimensions with 200 m³ of capacity. In the following table it is shown a preliminary sizing of the tank including length, external diameter and net volume.

Characteristics	Units	LNGTank 239	Alt. 1 239	Alt. 2 239	Alt. 1 200	Alt. 2 200
Geometric volume	[m3]	239	239	239	200	200
Net volume (90%)[6]	[m3]	215.1	215.1	215.1	180	180
External diameter[7]	[m]	4.3	5	5.6	5	5.6
Tank length	[m]	23.1	16.3	12.5	13.6	10.7

Table 107 – Sizing alternatives based on target volume

As a reference, it is included in the following table the LNG tanks supplied by MAN Cryo LNG. As can be seen, the geometry is similar for both manufacturers.

[6]Net volume is dependent of the tank maximum pressure (MAWP)
[7]Maximum external diameter shall be checked with the manufacturer

Geometrical volume [m³]	Net filling volume (95%) [m³]	Outer diameter [m]	Tank length (without TCS) [m]
76	73	3.6	10.9
100	95	3.6	13.9
124	118	3.6	16.9
142	135	4.2	14.0
175	167	4.2	17.0
209	199	4.2	20.0
249	237	5.3	16.4
300	285	5.3	19.4
352	335	5.3	22.4
385	366	6.0	19.8
450	428	6.0	22.5
516	491	6.0	25.8
600	570	6.9	23.2

Table 108 – MAN LNG Cryo, LNG type C Tanks

Based on the LNG tank size, several arrangements of the LNG tank on board will be assessed. To be taken into account that length/diameter ratio can be adjusted according to the requirements.

Taken into account the low volumetric efficiency of the tank on board, only one tank will be installed on board maximizing the LNG volume.

Minimum holding time of the tank per rules is 15 days. The selection of vacuum insulated tanks implies that the holding time is significantly increased fulfilling regulations requirements.

Once the target volume is defined, different tank arrangements shall be considered. Taking into account the ship geometry, the operational profile and other ships used as reference, it must be highlighted that the most used arrangement is horizontal – longitudinal aft the engine room. In the following figure it is shown the arrangement:

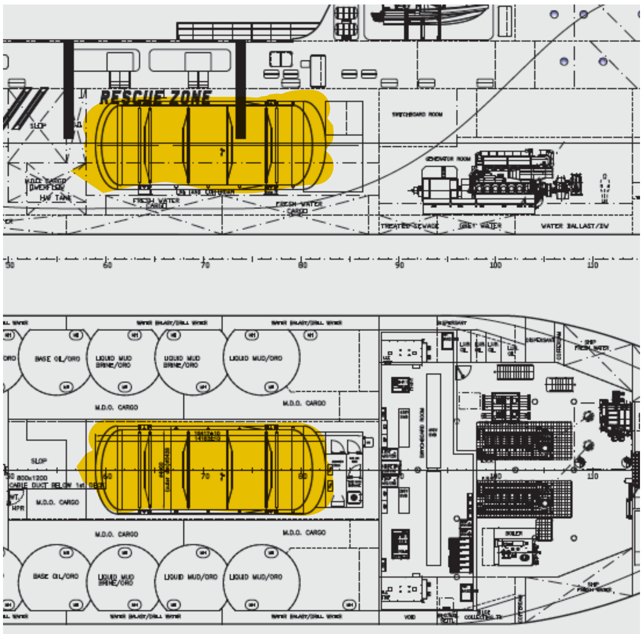


Figure 171 – LNG tank arrangement VS 489 design (Wärtsilä)

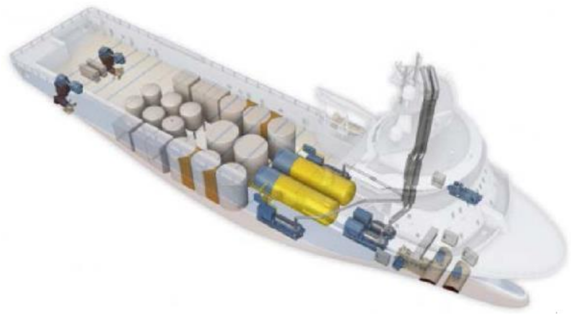


Figure 172 – LNG tank arrangement UT 776 design (Rolls Royce)

Considering the size of the LNG tank and the target volume of 200m³, the following configurations are considered:

- Vertical located forward
- Horizontal – transverse aft
- Horizontal - longitudinal centre

5.3.10.1 Vertical located forward

The arrangement of the LNG tank vertical forward, has the following considerations:

- The arrangement of the LNG tank vertical implies the movement of the auxiliary engines aft reducing the free space in the engine room
- The significant weight increase mean that it shall be compensated with ballast aft
- The vertical arrangement implies the modification on the arrangement of the accommodation block backwards
- The location of the tank allows the installation of a moonpool. The dimensions of the moonpool are 4.8x4.8 m, allowing the use of diving bells
- Aft the moonpool specific tanks for oil recovery are considered. In the present arrangement the maximum oil recovery capacity will be about 930 m^3 (complying with the minimum capacity required of 875 m^3)

In the following page it is shown the vertical tank arrangement.

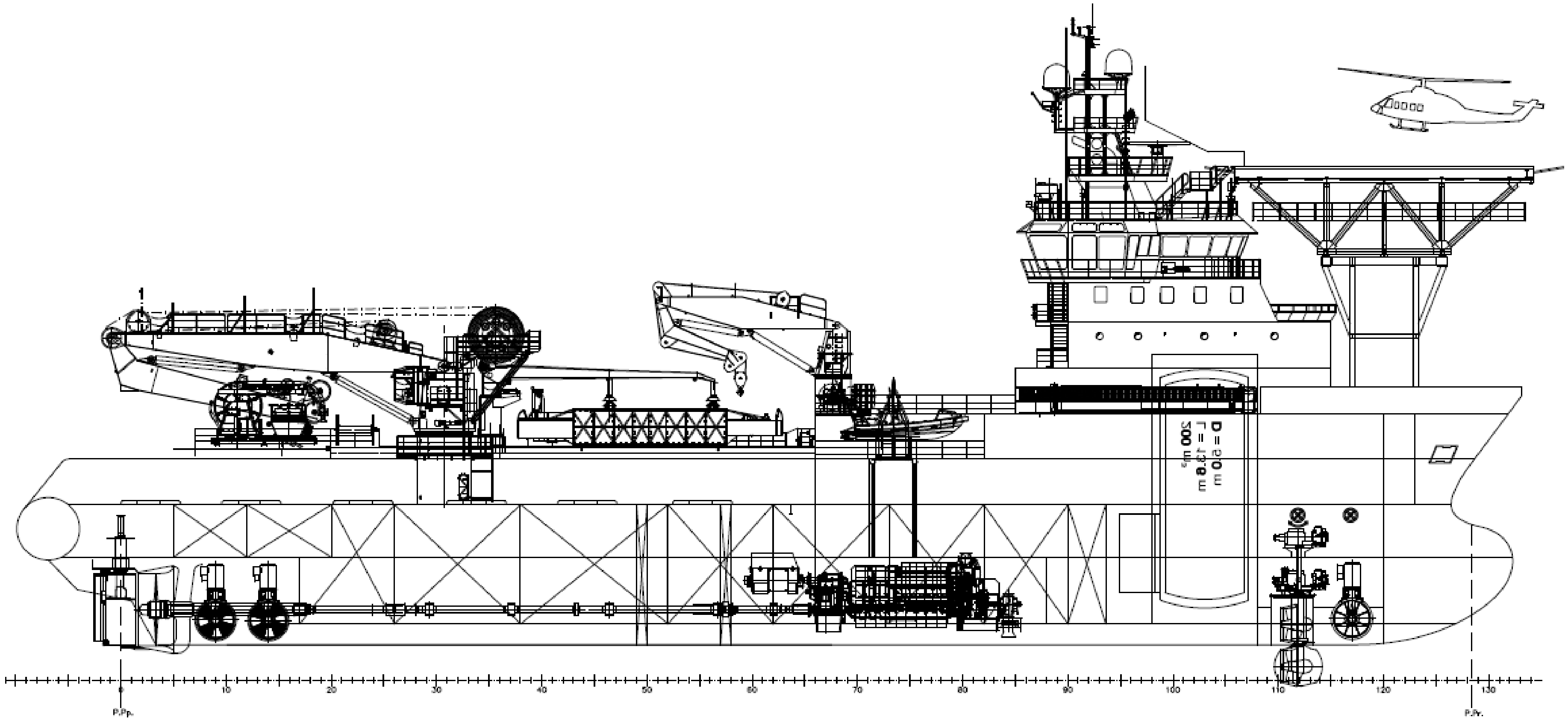


Figure 173 – Vertical tank arrangement - Profile

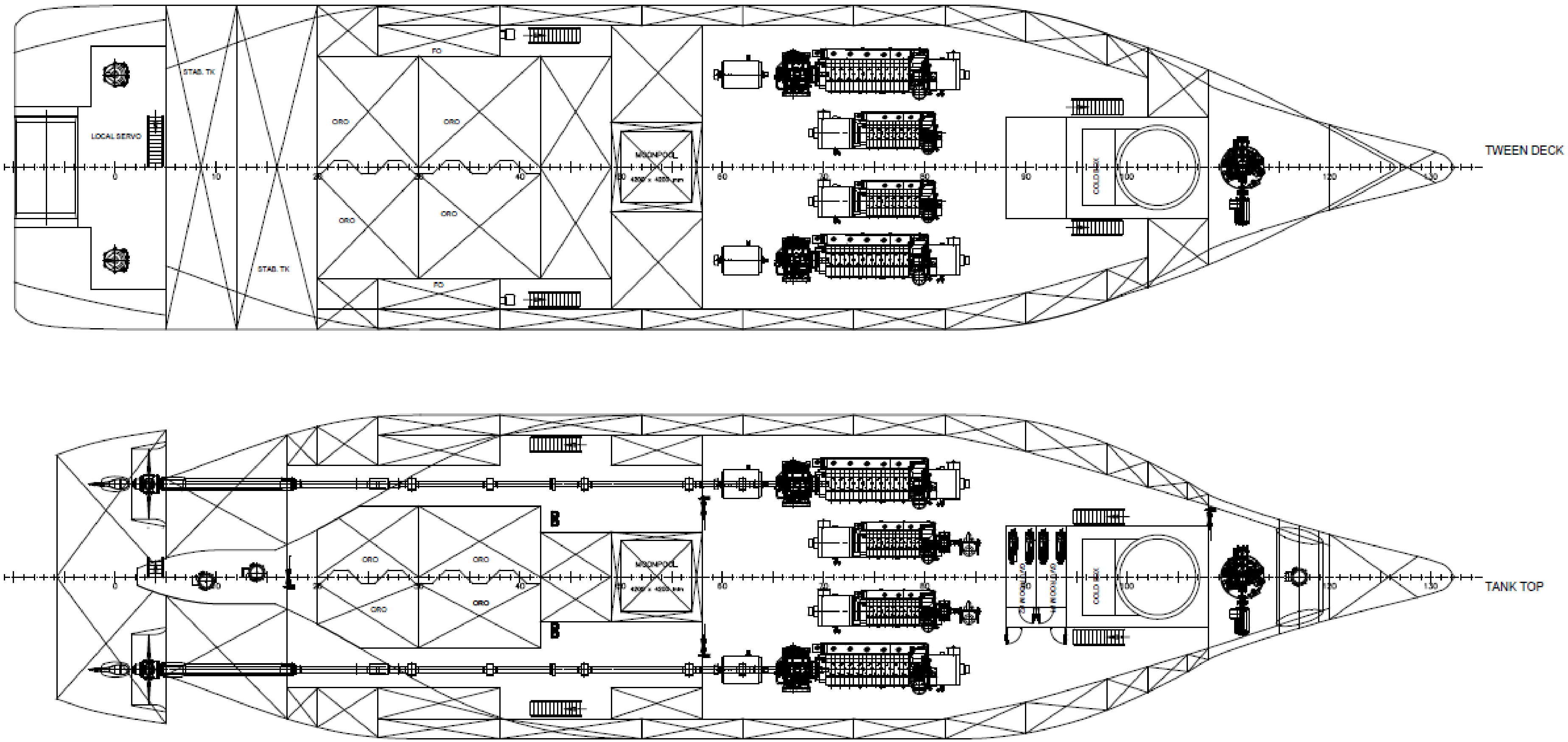


Figure 174 – Vertical tank arrangement – Tank top / Tween deck

5.3.10.2 Horizontal - Transversal aft

The arrangement of the LNG tank horizontal - transversal aft, have the following considerations:

- The arrangement of the LNG tank transversal implies that the tank shall be raised not to clash with the propulsion shafts.
- The vessel movements in that area are lower, but the transversal arrangement of the tank implies that the roll has higher impact in sloshing.
- The arrangement allows the route from the engine room to the aft spaces through the tank room
- Gas ramps are located further to the engines increasing the pipe length between the gas ramps and the engines. In case that the length exceeds the manufacturer requirement (10 m) the gas ramps shall be moved forward
- Aftward the tank room a moonpool can be arranged. The dimensions of the moonpool are 4.8x4.8 m, allowing the use of diving bells
- Aft the moonpool specific tanks for oil recovery are considered. In the present arrangement the maximum oil recovery capacity will be about 930 m^3 (complying with the minimum capacity required of 875 m^3)
- The Fuel Oil tanks are reduced significantly

In the following page it is shown the horizontal-transversal tank arrangement.

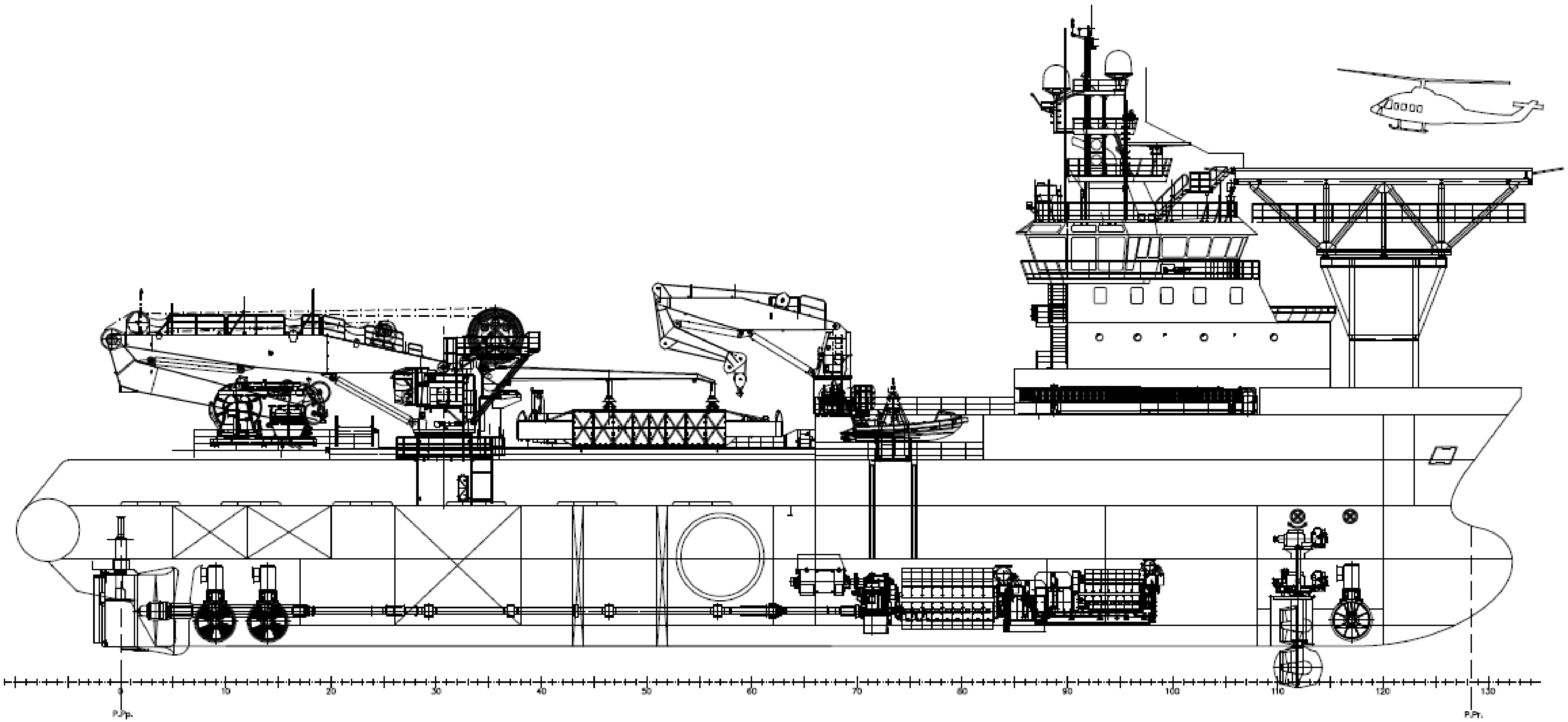


Figure 175 – LNG tank transversal aft - Profile

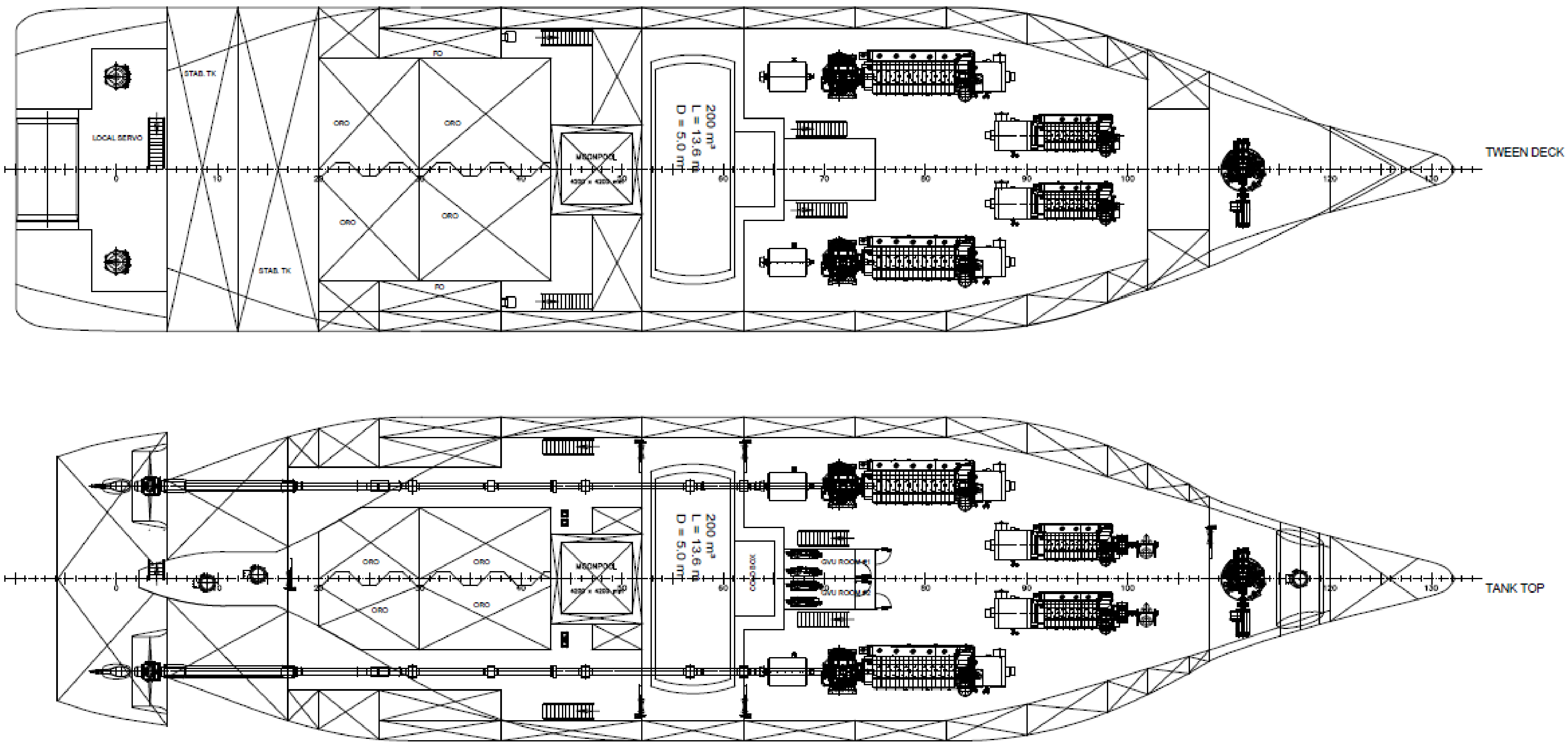


Figure 176 - LNG tank transversal aft – Tank top / Tween deck

5.3.10.3 Horizontal - Longitudinal centre

The arrangement of the LNG tank longitudinal centre, have the following considerations:

- The vessel movements in that area are lower with less impact in the fluid movements and therefore less sloshing.
- The arrangement allows the route from the engine room to the aft spaces without going through the tank room
- Gas ramps are located close to the tank and to the engines reducing the pipe length.
- Aft area can be used for the installation specific tanks for oil recovery is considered. In the present arrangement the maximum oil recovery capacity will be about 895 m^3 (complying with the minimum capacity required of 875 m^3)
- The main drawback of this option is that it does not allow the installation of a moonpool

In the following page it is shown the horizontal-longitudinal tank arrangement.

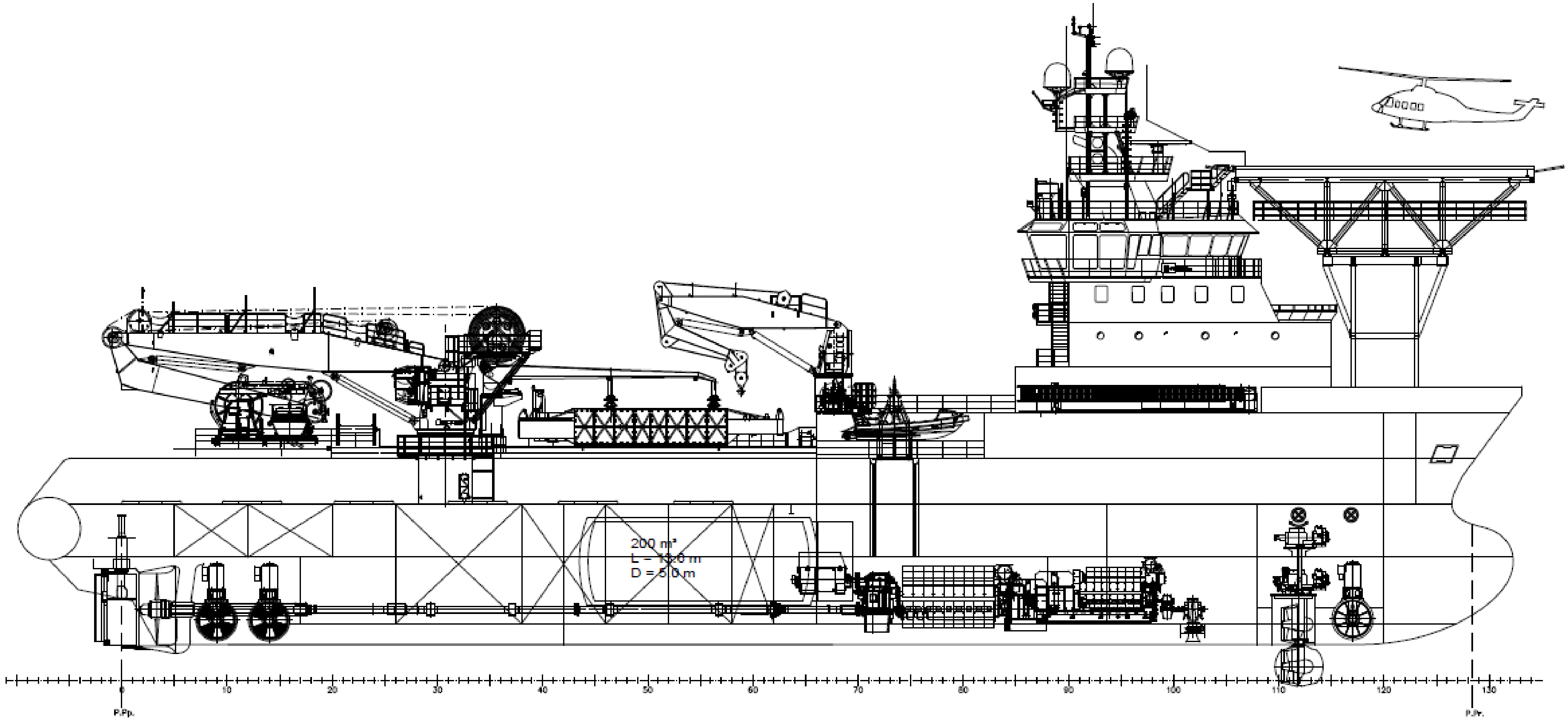


Figure 177 – LNG tank longitudinal center - Profile

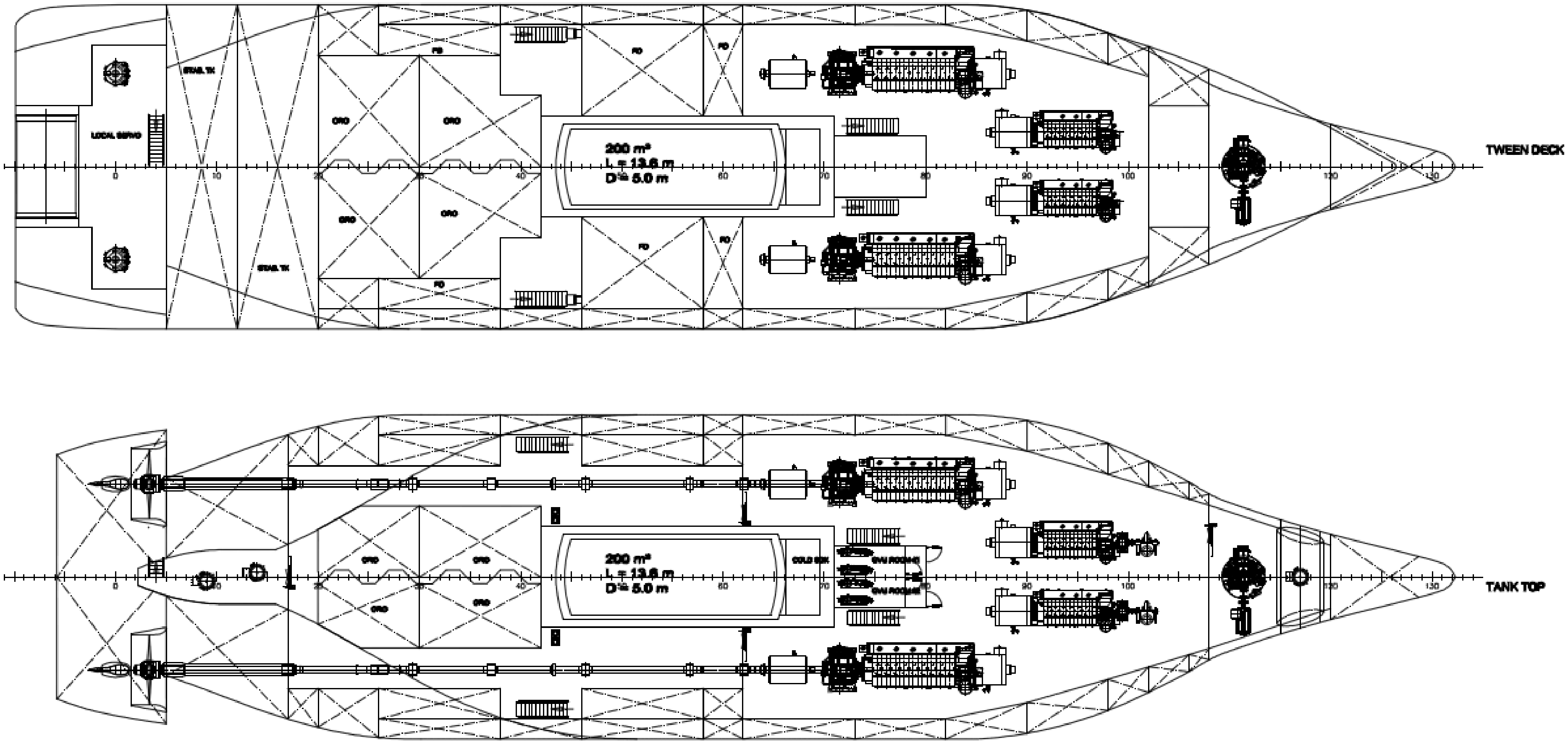


Figure 178 - LNG tank longitudinal center - Tank top / Tween deck

5.4. CONCLUSIONS

New Building gas fuelled ship definition is done as per SASEMAR compromise with environmentally sustainable operations. The preliminary development is based on the present operation of the vessels Clara Campoamor and Don Inda plus additional capabilities in order to provide SASEMAR with the latest technology available improving the present operability.

In previous sections have been analysed the potential retrofitting of the overall fleet. Preliminary conclusion was that even when in some cases the retrofitting was feasible, there are several limitations of the installation of new engines and LNG tanks.

The New Building allows to design on purpose the unit with the specifications and requirements overcoming limitations.

At present there is only one existing vessel (k/v Turva) with similar capabilities and operating in gas fuel mode. On the other hand sixteen platform support vessels (and growing number) with similar size are in operation in gas fuel mode.

The market review regarding technology development of main engines (dual fuel) and LNG tanks show that at present, the technology is mature enough to go ahead with the construction of a new unit using gas as fuel and provides sufficient flexibility to operate in different modes (Transit, Port, Diving, Oil recovery).

Preliminary design for a new building shows three different alternatives in the general arrangement based on the operational requirements. All of them are feasible but with some limitations. The implementation of the LNG tank means the reduction on the oil recovery storage capacity. Such limitation is not of paramount importance as the installation of separation equipment on deck reduces the need for available volume. The main drawback is the potential incompatibility of the LNG tank arrangement with the installation of a moonpool required for diving and ROV operations.

Further development will be needed in order to define the most suitable option to be developed and selected to move forward in the inclusion of a Gas fuelled vessel in SASEMAR fleet.