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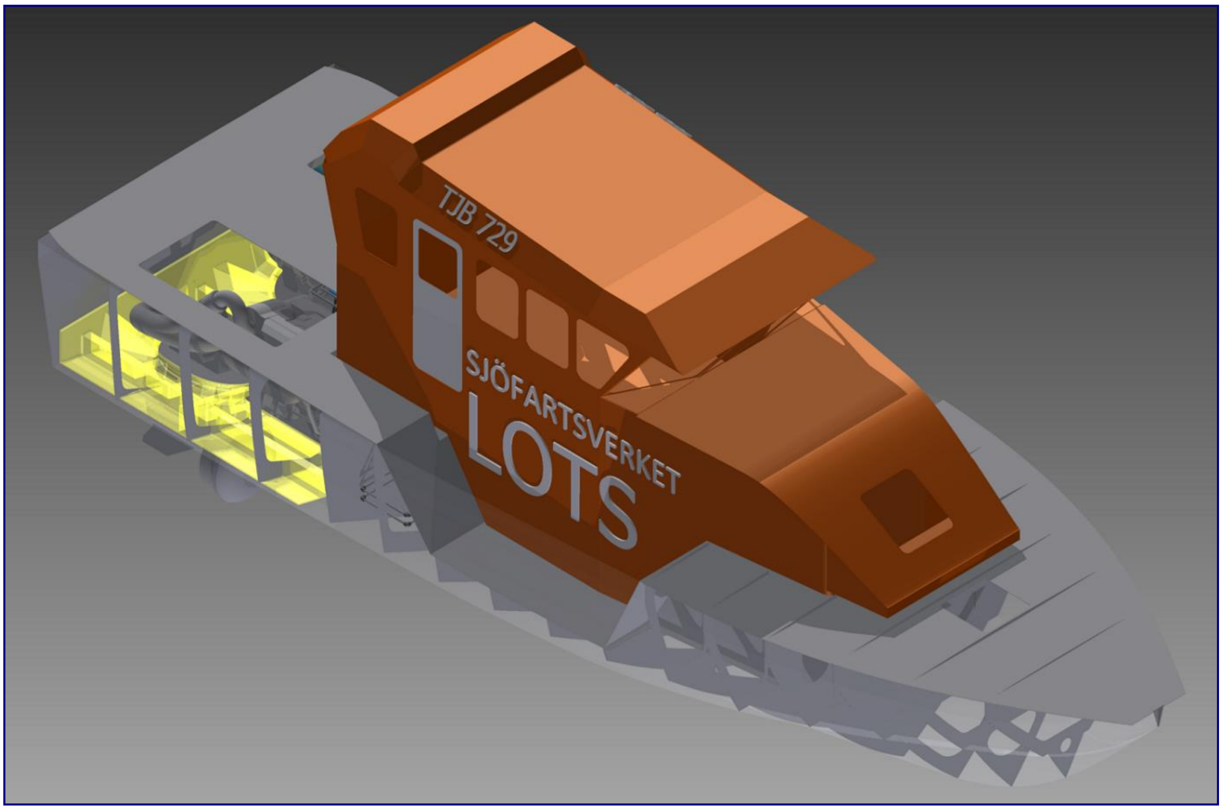

Conversion of a Pilot Boat to Operation on Methanol

Master's Thesis in the International Master's Programme Naval Architecture and Ocean Engineering

YOUMIN HUANG

Department of Shipping and Marine Technology
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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
3D model of pilot boat 729 created by Autodesk Inventor.

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ABSTRACT

There is currently a great need and interest in alternative fuels for shipping. Methanol is considered to be the most cost-effective alternative fuel for conversion of existing ships in order to reduce harmful emissions. There are now a number of project ongoing for conversion and new building of large vessels for methanol operation. Methanol can be produced from renewable raw materials, and will therefore be an attractive option for operators who want to/can/must prioritize this aspect. This includes for example operators of road ferries, boats for coast guard, pilot boats and boats public transport.

The aim for this project was convert a pilot boat to operate on methanol. This will support the development towards reduced greenhouse gas emissions and sustainability.

The report is mainly focused on the feasibility study of an identified pilot boat given by the Swedish Maritime Administration (Pilot boat 729). The report shows the methanol engine concepts, arrangement of the equipment, firefighting system and the model of the pilot boat with all the necessary conversion equipment.

Key words: alternative fuel, emission, engine, firefighting system, methanol, methanol engine, pilot boat

Contents

Preface

This thesis is a part of the requirements for the master's degree in Naval Architecture and Ocean Engineering at Chalmers University of Technology, Gothenburg, and has been carried out at ScandiNAOS AB, Gothenburg, between January and November of 2015.

I would like to express the deepest gratitude to my examiner and supervisor, Bengt Ramne, for his excellent guidance, support, patience and insight throughout the work of this thesis. His valuable advice and inspiring ideas have advanced my work and made possible the carrying out of this thesis. I highly appreciate his great efforts, amiable attention and understanding evinced in the guidance of my thesis work.

This project has been carried out in cooperation with ScandiNAOS AB in Gothenburg. I would like to sincerely thank all the colleagues of ScandiNAOS AB, for their excellent guidance and support throughout the work with this thesis. Without their continuous supervision and efforts for our understanding and earning it would have been impossible to accomplish this work.

Finally, I would like to thank my fiancée Grace Yang and for her love and patience. As well, I express my sincere gratitude to my parents Xin Huang and Minghua Fan for the continuous encouragement, motivation, care and their priceless support.

Göteborg, December 2015

Youmin Huang

Notations

CCAI	-	Calculated Carbon Aromaticity Index
CO_2	-	Carbon Dioxide
cSt	-	Centistokes
DWT	-	Dead Weight Ton(s)
IFO	-	Intermediate Fuel Oil
IMO	-	International Maritime Organization
MKL	-	Longitudinal Metacentre
KMT	-	Transverse Metacentre
LCB	-	Longitudinal Centre Of Buoyancy
LCF	-	Longitudinal Centre Of Floatation
LNG	-	Liquefied Natural Gas
MDO	-	Marine Diesel Oil
MGO	-	Marine Gas Oil
MTcm	-	Moment To Trim One Centimeter
NOX	-	Nitrogen Oxides
SOX	-	Sulphur Oxide
TPcm	-	Tonnes Per Cm Immersion
VCB	-	Vertical Centre Of Buoyancy

1 Introduction

The shipping industry is facing challenges to reduce emissions and greenhouse gases from their ships. Mainly the emissions need to be reduced are sulphur oxide, nitrogen oxide, particulate matter and carbon dioxide. International regulatory bodies such as International Maritime Organization and local governments of many countries have issued regulations and rules to control the emissions of trade ships.

There is currently a great need and interest in alternative fuels for shipping. Methanol is one of the alternative fuel candidates. It is clean and cost effective. The conversion of existing ships to operate on methanol could reduce harmful emissions and potentially save bunker cost. Since the emission regulations are becoming increasingly stringent, there are now a number of projects ongoing for conversion and new building of large vessels for methanol operation.

Methanol produced from fossil feedstock is today readily available anywhere. It can also be produced from renewable raw materials, and will therefore be an attractive option for operators who want to/can/must prioritize this aspect. This includes for example operators of road ferries, boats for coast guard, pilot boats and boats for public transport.

There are a number of alternative ways of utilizing methanol in internal combustion engines. The different alternatives vary in terms of resources required for the development to commercial products and potential in terms of engine efficiency. Methanol produced from fossil free feedstock is today available in limited quantities but the production can be easily increased to meet future demand. Piteå has today a demonstration plant that produces 3-4 tonnes of bio-methanol per day. Carbon Recycling International in Iceland produces annually 5 000 tons of methanol from recycled CO_2 (Carbon Capture and Recycling).

The Swedish Maritime Administration will provide a pilot boat for conversion. They are responsible for the Swedish pilotage operations and also a key player for promoting Swedish maritime research and development. This project shows the Swedish Maritime Administration is progressive in the development towards reduced greenhouse gas emissions and sustainability. Meanwhile, this is a good opportunity for the Swedish marine technology industry to establish itself as a world leader in the field of application of new energy technology.

This report mainly focusses on the detailed solution of the conversion of a pilot boat to operate on methanol. First it will identify and evaluate the various potential methanol engine concepts, and make a feasibility study on the conversion, such as the impact of the performance of the ship and the possible solution about ignition system. Then the report will show the code, rules and regulations which may affect the conversion. After that, the report will show the stability calculation with all possible plans with a 3D hull models by using Autoship. According to the stability results, choose the most efficient plan. Then make a detailed 3D model with Autodesk Inventor in order to show the detailed design such as firefighting system, inert gas system and fuel supply system.

An overall project objective is to find a detailed plan of using methanol as fuel and to make sure that the design for methanol is safe and reliable.

2 Background

One of the main challenges for shipping industry is to reduce emissions. Mainly, there are four kinds of emissions which are needed to be measured and controlled. These are nitrogen oxide(NOx), sulphur oxide(SOx), particulate matter(PM) and carbon dioxide (CO_2). NOx and SOx are the main formation of acid rain, Particulate matters direct impact our humans' health and CO_2 cause the greenhouse effect. According to the International Convention for the Prevention of Pollution from Ships (MARPOL), the maximum sulphur content of the fuel oil is limited to 0.1% m/m in the SOx Emission Control Area (SECA) after 1 January 2015. There are also work in progress to reduce the NOx emissions. For the engine types relevant for the pilot boat (RPM > 2000) the stricter rules are expected to limit the NOx emission to 2.3 g/kWh in the North Sea and Baltic Sea area. The particulate matter emissions are regulated by local government and the CO_2 emission is under evaluation by IMO. This chapter mainly shows the different parameters of different fuels that is used on marine engines. It also holds a deep analysis about the cost and performance of the alternative fuels.

2.1 Emission requirements

For this project, one of the main focus has been on low emissions, high efficiency and robust solution. The International Maritime Organization has officially designated the North Sea and Baltic Sea as emission control areas. In Figure 2.1, the areas in violet shows the ECA areas. That means all the Swedish coastline is included in the emission control area. These regulations will reduce air pollution from ships and benefits the air quality and public health.

Figure 2.1 IMO Emission Control Areas (ECA) areas in violet

The regulations on control of diesel engine NOx emissions are mandatory to follow. In addition, the fuel oil sulphur limits are becoming stricter. The changing of limitations of NOx and SOx are shown in Figure 2.2 and Figure 2.3.

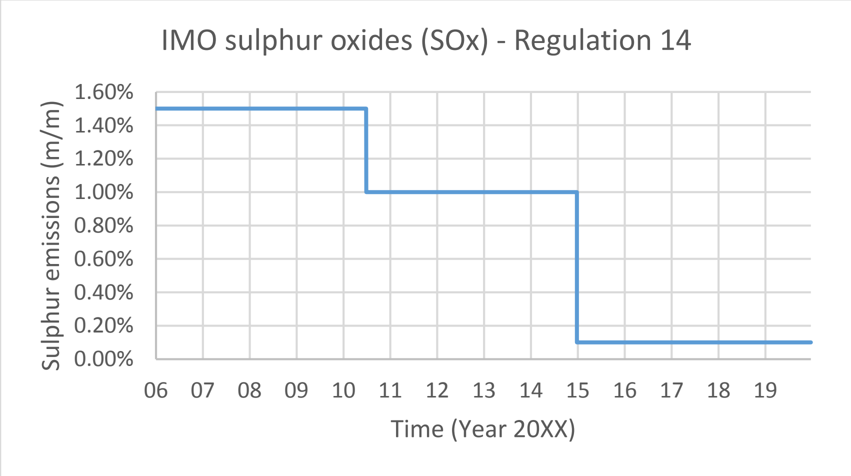

Figure 2.2 Sulphur oxides emission limitations

The engine speed of the pilot boat will be larger than 2000rpm, which means that the nitrogen oxides emission limitation will be a fixed number.

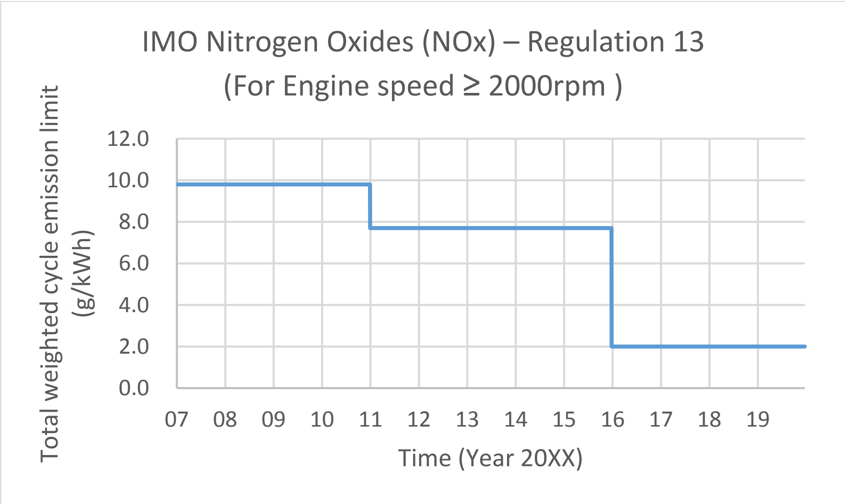

Figure 2.3 Nitrogen Oxides emission limitations

According to the International Convention for the Prevention of Pollution from Ships (MARPOL), the Regulations for the Prevention of Air Pollution from Ships (Annex VI, 2008) seek to minimize airborne emissions from ships. After 2016, the NOx emission must be lower than 2.0 g/kWh and the fuel oil sulphur must be limited below 0.1% (expressed in terms of % m/m – that is by weight) or an exhaust gas cleaning system need to be installed to reach a similar SOx emission level. In this case, the conversion is not considered as a “major conversion”, so the new rules is not necessary to apply. However, the project could be an exemplary project for new-built ships.

To meet these regulations, low and medium speed vessels can choose to install after treatment systems such as scrubbers in order to reduce the SOx. However, most common solution is using fuel with lower sulphur content such as MGO. For high speed engines scrubbers is not an option. Both of these solutions will increase the operation cost especially for large merchants. Meanwhile there is another solution, which is using alternative fuels such as methanol or natural gas.

The rest of this chapter will evaluate a number of marine fuels and alternative fuels to see which alternative is the most cost efficient, environmental friendly and technical maturity way of meeting the strict emission regulations.

2.2 Marine fuels

The International Standard Organization standard ISO 8217:2012 gives 15 different marine fuels which runs in the worldwide marine engines. Mainly, the marine fuels could be divided into two parts: residual marine fuels and distillate marine fuels. The most common fuel types used on board are shown in Table 2.1 Most common fuel types used on board:

Table 2.1 Most common fuel types used on board

Fuel type	ISO name	Industry name
Distillate	DMA DMX DMB DMC	MGO MDO
Residual	RMG380 RMH380 RME180 RMF180	IFO380 IFO180

Ships mainly run on intermediate fuel oil. The marine diesel oil and marine gas oil is usually used in auxiliary engines and when ships go inside the port. The shipping companies says that about 95% of the fuel used was intermediate fuel oil and 5% was MDO or MGO (Kalli, 2009).

2.2.1 Intermediate Fuel Oil (IFO)

Intermediate fuel oil (IFO) also known as heavy fuel oil (HFO) is a kind of residual oil. It is the main marine fuel used on low speed engines and large medium speed engines. It is very competitive in price but generates a large amount of harmful emissions such as SOx, NOx, PM, BC and CO_2. One of the most common grade of intermediate fuel oil is IFO380, its ISO name is called RMG380, and this means that at 50 ℃ the oil has a viscosity of 380 cSt. Normally the pumpable viscosity for feeder pump is 75 cSt and for booster pump is 20 cSt which means that the heavy fuel oil needs to be preheated in order to reduce its viscosity.

Table 2.2 The ISO standard of RMG380 and RME180 (Source: ISO8217:2012)

	Unit	**Limit**	**RMG380**	**RME180**
Kinematic viscosity at 50 ℃	mm^2/s	max.	380	180
Density at 15 ℃	kg/m^3	max.	991	991

CCAI		-	max.	870	860
Sulphur		mass %	max.	Statutory requirements	
Flash point		℃	min.	60	60
Hydrogen sulphide		mg/kg	max.	2	2
Acid number		mg KOH/g	max.	2.5	2.5
Total sediment aged		mass %	max.	0.1	0.1
Carbon residue: micro method		mass %	max.	15	18
Pour point (upper)	winter quality	℃	max.	30	30
	summer quality	℃	max.	30	30
Water		volume %	max.	0.5	0.5
Ash		mass %	max.	0.1	0.07
Vanadium		mg/kg	max.	350	150
Sodium		mg/kg	max.	100	50
Aluminium plus silicon		mg/kg	max.	60	50
Auto-ignition temperature		℃	appr.	260	260

Table 2.2 shows the residual marine fuels standard according to ISO8217:2012. The minimum flash point is limited to 60℃ by SOLAS. SOLAS specifies that all marine fuels must have a flashpoint not lower than 60℃ (IMO, 2002). The flash point of a volatile material is the lowest temperature at which it can vaporise to form an ignitable mixture in air.

As can be seen in Table 2.2, the RMG380 has a maximum of 18% of the residual carbon content and RMG180 has 15% residual carbon content, the carbon residue is measured when the fuel combustion residues produced. The high carbon residue may cause the contamination of the internal components of the engine and increase emissions.

The IFO need treatment process before used on board, the water and impurities need to be removed. So various fuel filters and separators are used on board. This fuel is mostly used by low speed and large medium speed engines.

2.2.2 MGO

Marine gas oil is a kind of marine distillate oil, in ISO standard the grade for MGO is called DMA. Table 2.3 shows its detailed standard.

Table 2.3 The ISO standard of DMA (Source: ISO8217:2012)

		Unit	Limit	DMA
Kinematic viscosity at 40 ℃		mm^2/s	max.	6000
Density at 15 ℃		kg/m^3	max.	890
Cetane Index		-	min.	40
Sulphur		mass %	max.	1.5
Flash point		℃	min.	60
Hydrogen sulphide		mg/kg	max.	2
Acid number		mg KOH/g	max.	0.5
Total sediment by hot filtration		mass %	max.	-
Carbon residue: micro method on the 10% volume distillation residue		mass %	max.	0.3
Oxidation stability		g/m^3	max.	25
Pour point (upper)	winter quality	℃	max.	-6
	summer quality	℃	max.	0
Water		volume %	max.	-
Ash		mass %	max.	0.01
Auto-ignition temperature		℃	-	257

The appearance of MGO should be clear and bright. It is the highest grades of marine fuel. It has very low sulphur content and carbon residue content. All types of diesel engines can run with MGO.

2.2.3 MDO

Marine diesel oil is a marine distillate oil including marine diesel and gas oil, while DMB is a typical grade of MDO.

Table 2.4 The ISO standard of DMB (Source: ISO8217:2012)

	Unit	Limit	DMB
Kinematic viscosity at 40 ℃	mm^2/s	max.	11000
Density at 15 ℃	kg/m^3	max.	900

<table>
<tr><td colspan="2">Cetane Index</td><td>-</td><td>min.</td><td>35</td></tr>
<tr><td colspan="2">Sulphur</td><td>mass %</td><td>max.</td><td>2.00</td></tr>
<tr><td colspan="2">Flash point</td><td>℃</td><td>min.</td><td>60</td></tr>
<tr><td colspan="2">Hydrogen sulphide</td><td>mg/kg</td><td>max.</td><td>2</td></tr>
<tr><td colspan="2">Acid number</td><td>mg KOH/g</td><td>max.</td><td>0.5</td></tr>
<tr><td colspan="2">Total sediment by hot filtration</td><td>mass %</td><td>max.</td><td>0.1</td></tr>
<tr><td colspan="2">Carbon residue: micro method</td><td>mass %</td><td>max.</td><td>0.3</td></tr>
<tr><td colspan="2">Oxidation stability</td><td>g/m^3</td><td>max.</td><td>25</td></tr>
<tr><td rowspan="2">Pour point (upper)</td><td>winter quality</td><td>℃</td><td>max.</td><td>0</td></tr>
<tr><td>summer quality</td><td>℃</td><td>max.</td><td>6</td></tr>
<tr><td colspan="2">Water</td><td>volume %</td><td>max.</td><td>0.3</td></tr>
<tr><td colspan="2">Ash</td><td>mass %</td><td>max.</td><td>0.01</td></tr>
<tr><td colspan="2">Auto-ignition temperature</td><td>℃</td><td></td><td>350</td></tr>
</table>

MDO is made of a mixture of MGO and some lower grade fuel. Table 2.4 shows that the standard of MDO is a bit lower than MGO, where the carbon residue content and sulphur content is higher than MGO. This means that the MDO is cheaper than MGO while the sulphur emissions might not meet the requirement of IMO regulations.

2.3 General on alternative fuels

For the reason of abundant, practical and cheap oil products are used as marine fuel for decades. While using alternative fuels was put on the agenda for a lot of shipping company since climate change and reduction of air emission. There are mainly three realistic alternatives to achieve the emission regulations: use MDO, install scrubbers and using cleaner alternative fuels. Liquefied natural gas and methanol are the two main alternative fuels which are developed today. This chapter explains how these alternative fuels might be used as marine fuels. Table 2.5 shows the characteristics of methanol and natural gas.

Table 2.5 Characteristics of Methanol and Natural Gas

Property	Methanol	Natural Gas
Density (kg/l)	0.79	0.44(as LNG)
Boiling point (℃)	65	-162
Flash point (℃)	11	-188
Auto ignition (℃)	464	540

Viscosity at 20 ℃ (cSt)	0.6	N/A
Octane RON/MON	109/89	120/120
Cetane No.	3	-
LHV (MJ/kg)	20	50
LHV (MJ/l)	16	22
Flammability Limits, Vol%	7-36	5-15
Flame Speed (cm/s)	52	37
Heat of Evaporation (kJ/kg)	1178	N/A
Stoichiometric Air-Fuel Ratio	6.4	17.2
Adiabatic flame temp. (℃)	1910	1950

2.3.1 LNG

Liquefied natural gas (LNG) is natural gas (predominantly methane, CH_4) that has been converted to liquid form for ease of storage or transport. LNG's volume is 600 times lower than its gas form. The natural gas is condensed into a liquid at close to atmospheric pressure by cooling it to approximately -162 ℃.

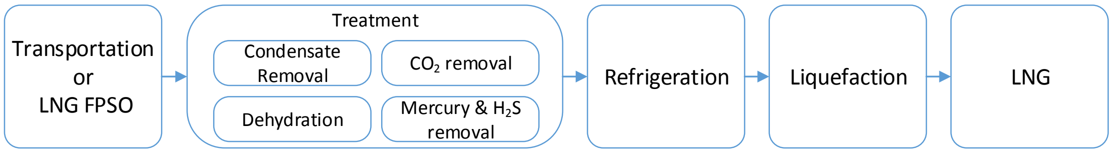

Figure 2.4 A typical LNG process

Figure 2.4 shows a typical LNG process. The gas is first extracted and transported to a processing plant or LNG FPSO where it is purified by removing any condensates such as water, oil, mud, as well as other gases such as CO_2 and H_2S. An LNG process train will also typically be designed to remove trace amounts of mercury from the gas stream to prevent mercury amalgamating with aluminium in the cryogenic heat exchangers. The gas is then cooled down in stages until it is liquefied. LNG is finally stored in storage tanks and can be loaded and shipped.

LNG has been promoted as a marine fuel and has some significant development. There are over 40 ships in the world running on LNG, and more are under construction. However, the installing of a LNG supply system is expensive, e.g. the whole fuel storage and distribution system need to be designed to maintain the LNG at -163 ℃ in order to keep it liquid. LNG can be handled efficiently in large volumes but for smaller volumes the cryogenic equipment becomes too costly.

Methane generates 25% less CO_2 when combusted compared to oil. However, it should be noticed that methane is a very potent greenhouse gas about 16-20 times more potent than CO_2. A 3% methane slip due to leakage and incomplete combustion will completely eliminate the benefits of the lower CO_2 emissions.

2.3.2 Methanol

Methanol, also known a s methyl alcohol and wood alcohol. The chemical formula of methanol is CH_3OH. Methanol is the simplest alcohol, and is a light, volatile, colourless, flammable liquid with a unique smell very similar to that of ethanol (drinking alcohol). However, unlike ethanol, methanol is highly toxic and not suitable for human consumption. It is liquid at room temperature. The combustion equation of methanol is:

$$2\mathrm{CH}_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$$

which means that it has lower carbon content on a mass basis and produce less CO_2.

Figure 2.5 shows the feedstock and products of alternative marine fuels, which includes LNG, methanol and DME. The figure shows that methanol can be produced from several different feedstock, includes coal energy and renewable energy. This means that methanol could be produced in many ways. Nowadays the feedstock of fossil methanol is typically methane (natural gas) and coal, the feedstock of bio-methanol is typically lignocellulose or wood biomass.

Bio-methanol has the potential of being a carbon neutral fuel. It can be used as feedstock for other alternative fuels production (DME) and as additive for conventional fuels. However, the cost of fossil free methanol is higher than the cost of oil based fuels, but this could be reduced with the upgrading of yield and process.

Emerging technology will enable production of large quantities of CO_2 neutral methanol from renewable primary energy sources such as geothermal, sun, wind, and hydro power. Iceland has already build a renewable methanol plant, called The George Olah Plant, it has a capacity of 5 million litres per year. This shows the future of bio-methanol.

Since methanol is a liquid at ambient conditions and being less volatile, it can be handled similar to other liquid fuels. The physical form of methanol an advantage for storage and transport. The cost for handling methanol will be lower than LNG.

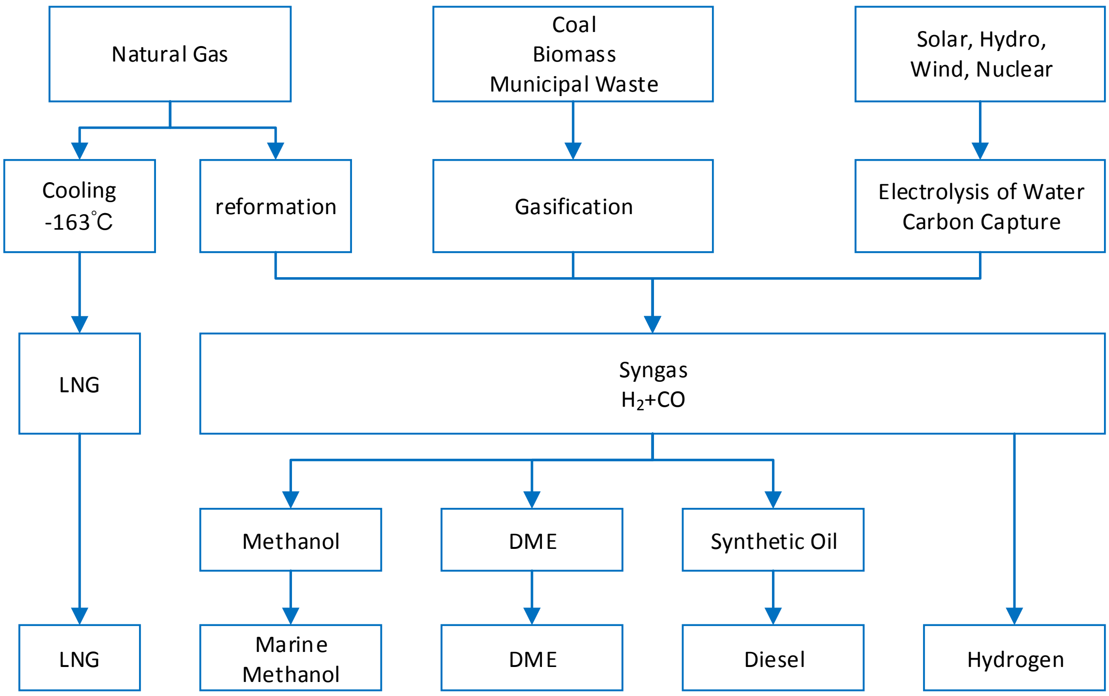

Figure 2.5 The feedstock and products of alternative marine fuels

2.3.3 Costs and performance comparison

Different types of fuels can be used in different type of machinery technology. The Table 2.6 below use a matrix to compare different types of fuel with different power solutions.

Table 2.6 The usage of different fuels on different engines

	HFO	MDO /MGO	LSHFO	LNG	Hydrogen	Methanol
2-stroke engine	√	√	√			√
4-stroke engine	√	√	√			√
Diesel electric	√	√	√			√
Dual fuel engine	√	√	√	√		√
Gas engine				√		
Fuel cells				√	√	√

From the table, it shows that the dual fuel engine could run on either HFO, diesel and LNG or HFO, diesel and methanol. This gives a flexible fuel choice for the ship. If a ship goes to a harbour which do not have LNG or methanol, then the ship could refuel pure diesel instead. Fuel flexibility can be considered an advantage for larger ships but for smaller ships and vehicles single fuel solution is normally preferred

After figure out the possible machinery technology, then the cost of the adoption of alternative fuel will be discussed. The table below shows the estimation of costs and performance parameters for each concept design. Where the UPC is the unit procurement cost, it is the cost of storage tanks, modification of engines, fuel cells, pipes, firefighting systems etc. TLC is through life cost for fuel cells. SFC is the specific fuel consumption and DWT_LOSS is deadweight tonnes loss. DWT_LOSS is the reduction in cargo carrying capacity due to the modification of machinery and fuel storage room.

Table 2.7 Costs and performance parameters for each concept design (Source: University College London)

Concept design description	Costs		Performance	
	UPC	TLC	SFC @75% MCR	DWT_LOSS
	million$/MW	million$/MW	g/kWh	t/MWh

H2+Fuel Cells+ Electric motor	5.3	0.17	57	0.26
LNG + 2/4 stroke engine	1.65	-	150	0.09
Methanol + 2/4 stroke engine	0.95	-	381	0.07

From Table 2.7, it is easy to find that using methanol is the cheapest in all three design concepts. Meanwhile, Stena claims that the cost of Stena Germanica project which is a methanol conversion project is about € 300/kW, and a LNG conversion at least 3 times as expensive.

Table 2.8 Cost for MDO and Methanol (Fuel price: June 2015)

	MDO	Methanol
Price (SEK/MT)	5233	2732
Price (SEK/MJ)	0.127	0.137

Table 2.8 shows the fuel price for marine diesel oil and methanol produced from natural gas, where methanol has 20% discount as a big buyer. From the table, it shows that when producing the same power, methanol will be more expensive than MDO with the current oil prices. However, the current oil price is considered to be exceptionally low and when the oil price returns to normal level it is expected that methanol will show a price advantage. In addition, methanol could be produced with both fossil energy sources and organic materials. So methanol is a renewable and clean energy, and with the wider range of applications of methanol, production cost of methanol will reduce.

2.4 Conclusion

In general, from the perspective of reducing emissions, using methanol as marine alternative fuel is the cheapest and easiest way to achieve this goals. The cost of the conversion to methanol operation is significantly lower than the cost of a LNG conversion, and methanol is easier to handle and store than LNG. Meanwhile, methanol is a renewable source of energy that can be produced in a big way everywhere. Although the oil price is low while writing this report, the methanol is a kind of economical fuel, and with the oil price rising, methanol will show strong competitiveness in marine fuel fields.

3 Project Concept

As mentioned in the introduction, the intended ship to be used for the conversion is a pilot boat for the Swedish Maritime Administration. The engine and propulsion system is provided by Volvo Penta. This chapter shows the detailed information of the boat and the engine used in conversion. Figure 3.1 shows the Pilot Boat 729 during cruise.

Figure 3.1 The photo of Pilot Boat 729

3.1 Specification of the pilot boat

The pilot boat was built in 1996, it was designed with two engines with water jet propulsion system, but for some reason it was built with one single engine. After a serious accident, the ship was sent to a shipyard to be repaired, then double engine replaced the single engine. So now this pilot boat has two Cummins engines with two Hamilton water jet propulsion systems. Due to the reason above, there are two different original drawings. In this project, the drawings with two engines will be used as reference.

Table 3.1 below shows the principal dimensions of Pilot Boat 729, and Figure 3.2 shows the general arrangement of the ship. The figure shows that the engine room is small, and not suitable for people to stay inside, which means that this engine room is unmanned engine room. This could be an advantage of using methanol, because if the methanol is leaked, it won't heart the crew, and the firefighting system could start to work immediately without evacuate the crew. In the middle of the ship, two diesel tanks already exist, their volume is 900 litres each.

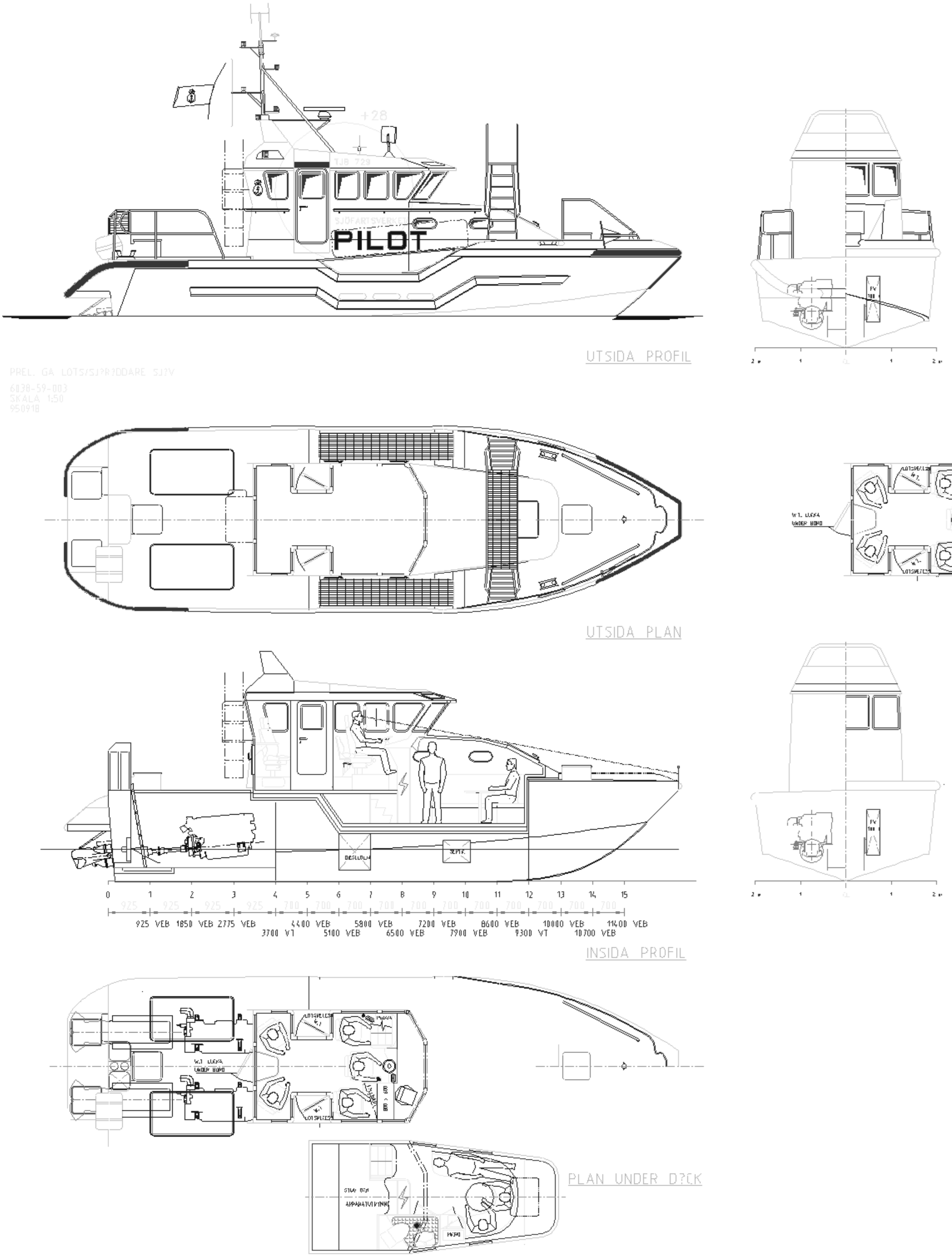

Figure 3.2 General arrangement of pilot boat 729

Table 3.1 principal dimensions of Pilot Boat 729

Length Over All	L_{OA}	12.6	m
Length Between Perpendiculars	L_{PP}	11.1	M
Breadth, Moulded	B_M	4.16	M
Depth, Moulded	D_M	1.05	M
Draught, DWL	T_{DWL}	0.7	M
Bilge Radius	R_B		
Light Ship Weight		11	ton
Gross Tonnage	GT	20	ton
Net Tonnage	NT	6	ton
Dead Weight	DWT	1.5 ton	ton
Max Engine Load		2200	rpm
Max Speed*	V_{max}	32	kn

*This speed is measured after the pilot boat has been repaired, at that time the pilot boat was replaced by two engines and two water jets.

3.2 Specification of the new engine

The intention is to replace the existing Cummins engines with two methanol converted Volvo Penta engines. It was proposed to change the propulsion system to a Volvo Penta Integrated Propulsion System IPS at the same time as the engines was replaced. The whole propulsion system including engines, propellers and gear box will all be replaced by the IPS system. Figure 3.3 shows the outward appearance of this system.

Figure 3.3 The outward appearance of IPS system

Table 3.2 The specification of IPS 1050

System designation	IPS1050	
Engine displacement	12.8 (780)	l (in3)
Configuration	in-line 6	
Crankshaft power	588 (800) @ 2300 rpm	kW (hp)
Prop shaft power	564 (768) @ 2300 rpm	kW (hp)
Aspiration	Dual stage turbo with twin charge air coolers	
Package weight	2300 (5060)	kg (lb)
Propeller series	Q1–Q7	
Voltage	24V	
Emission compliance	IMO NOx, EU RCD, US EPA Tier 3	
Application	Twin/multiple engine installation in planing hulls	
Speed range	26 to 40 knots	

Table 3.2 shows the specification of IPS 1050. The technical description shows that the system could meet the IMO emission requirements.

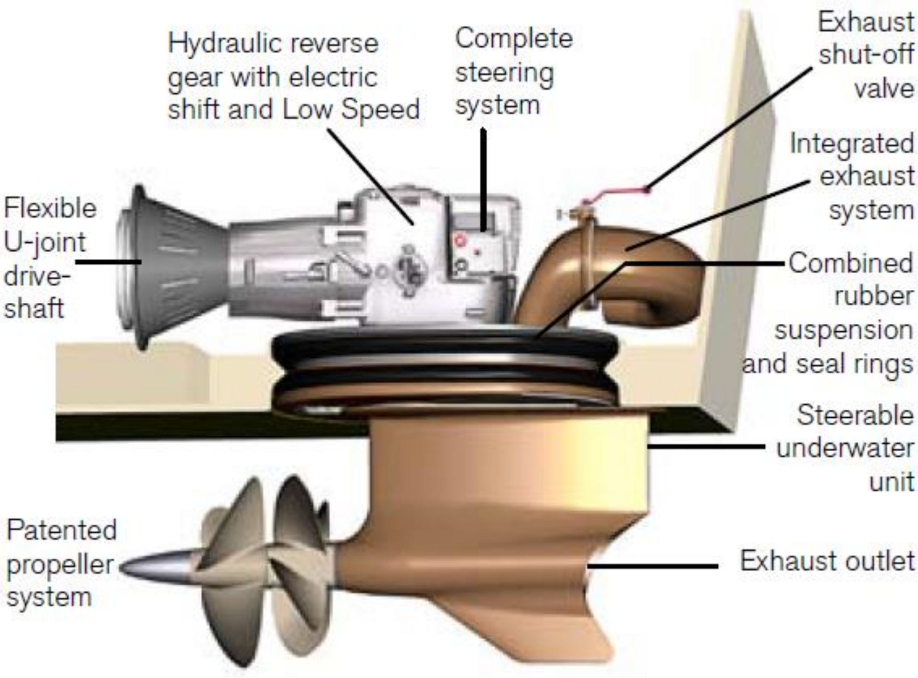

Figure 3.4 The propulsion unit

The Volvo Penta IPS includes engine unit and proplusion unit. Figure 3.4 shows the proplusion unit. One feature should be noticed is that the exhauust outlet is located behind the proplusion pod, which means that the exhausts are emitted into the prop wash and carried well behind the boat. This will impacet the design of the exhaust system, which will explain later.

4 Feasibility study

This chapter is mainly a feasibility study of the conversion the engine to operate on methanol as fuel and finding and evaluating the possible engine modification solution. There are several successful usages for methanol to operate on cars, trucks and large vessels. Stena Germanica is the first full scale methanol conversion project on ships so far. That project provides a lot of experience, but Stena Germanica is a large vessel and the engine is quite different from the pilot boat. The engines of the pilot boat are similar to truck engines, but the pilot boat need more safety measures than trucks. So the limitation of engine room area and the high safety requirement are the two main challenge of this project. The feasibility will concern the potential methanol engine concepts; ignition system solution; firefighting system; fuel tank arrangement and the impact on performance.

4.1 Potential methanol engine concepts

There are some advantages for engines to run on methanol. First, the boiling point of methanol is lower than diesel, so the mixture gas forms faster and more even, it is good for combustion. Moreover, the combustion speed is faster than diesel which could reduce the emission of particular matter.

However, methanol has its disadvantages. The cetane number of methanol is much lower than diesel, and its auto-ignition temperature is twice as diesel. Furthermore, methanol has poor lubrication, this might increase the abrasion of engine components, and methanol is corrosive, so there will be extra requirements of corrosion for parts in contact. Methanol is oxygenated hydrocarbons contains polar hydroxyl (OH), it is polar substances. While diesel is a mixture of various hydrocarbons, hydrocarbon compounds are non-polar. According to the similarity dissolves, diesel and methanol are not miscible each other without cosolvent.

Moreover, since the lower heating value (LHV) of methanol is much lower than diesel, to ensure the power output, the injected fuel amount should be increased. In summary, the diesel engine cannot run on methanol without some modifications.

Knowingly, there is only one ship that runs on methanol, this is Stena Germanica the third largest RoPax vessel in the world, this project might be the first one to use methanol on a small craft. There is almost no engine supplier who produce small methanol fuel engine, but the engines for small craft is close to heavy vehicle engines. The parameters of both engines are close. The conversion could refer to the heavy vehicle engines.

The researchers and engineers in State Key Laboratory of Engines, Tianjin University, China, has provide a solution of methanol engines called Diesel/methanol compound combustion system (DMCC).

Figure 4.1 shows the schematic of DMCC engine system. Using DMCC, methanol will be injected into the intake port of each cylinder to form a homogeneous mixture with air for combustion, while the original Diesel fuel injection system will be retained but slightly modified to limit the Diesel fuel injection. At engine start and low speed, the engine will operate on Diesel alone to ensure cold starting capability and to avoid aldehydes production under these conditions. At medium to high loads, the engine will operate on a homogeneous air/methanol mixture ignited by pilot Diesel to reduce particulate and NOx emissions. The system thus developed can be retrofitted on in use Diesel engines. (C. Yao, 2015)

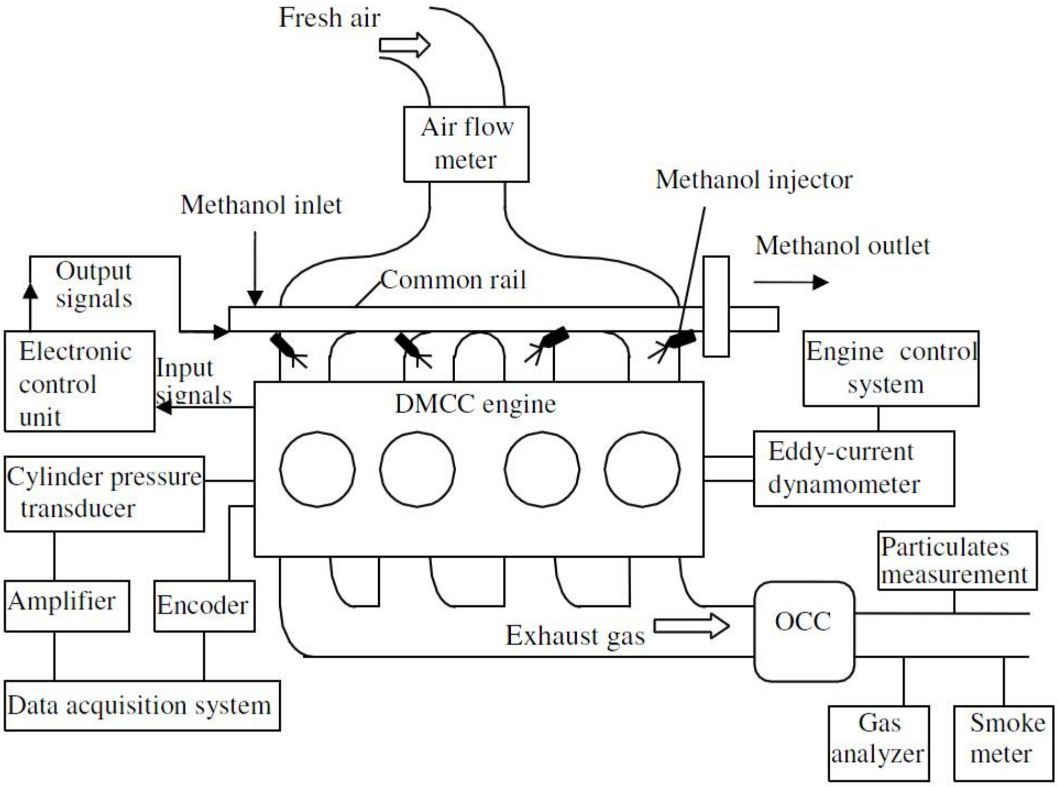

Figure 4.1 Schematic of DMCC engine system (C. Yao, 2015)

Figure 4.2 shows the strategy of the control of DMCC engine, where T_w is the cooling water temperature, T_{w0} is the lowest cooling water temperature when injecting methanol, T_e is the exhaust gas temperature, T_{e0} is the lowest exhaust gas temperature when injecting methanol, n is the engine speed, n_0 is the lowest engine speed when injecting methanol, T_A is the throttle angle, T_{A0} is the minimum throttle opening at a given speed when injecting methanol.

In DMCC engine system, diesel is used to ignite a methanol/air mixture while methanol is injected into the air intake of each cylinder to form a homogeneous mixture with the intake air. In the test of DMCC engine system shows that the modified engine has longer ignition delay and lower gas temperature due to the high latent heat of methanol. The lower gas temperature contributes to lower NOx emission.

The DMCC system makes full use of the advantages of both diesel and methanol, the former is easy to ignite by compression ignition, and the latter has higher latent heat and oxygen content. Even there is no adoption of the DMCC engine to use on board, it shows a great trend in marine area.

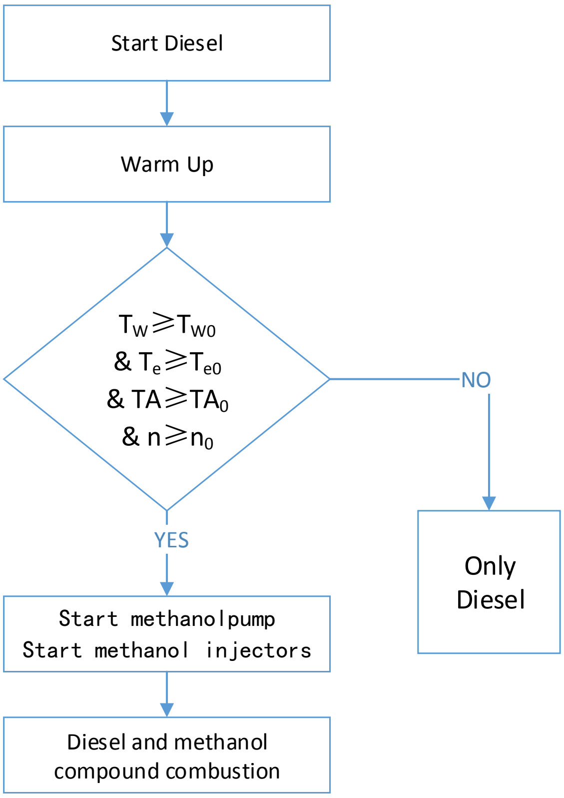

Figure 4.2 The strategy of control of DMCC engine

4.2 Firefighting system

Figure 4.3 shows the methanol flame in infrared camera, and observation by human eyes, which shows that methanol flame is more difficult to see with human eyes. That's because the carbon content of methanol is lower than other fuels. The combustion of methanol tends to generate flames that are less visible than the flames generated by the combustion of other substances.

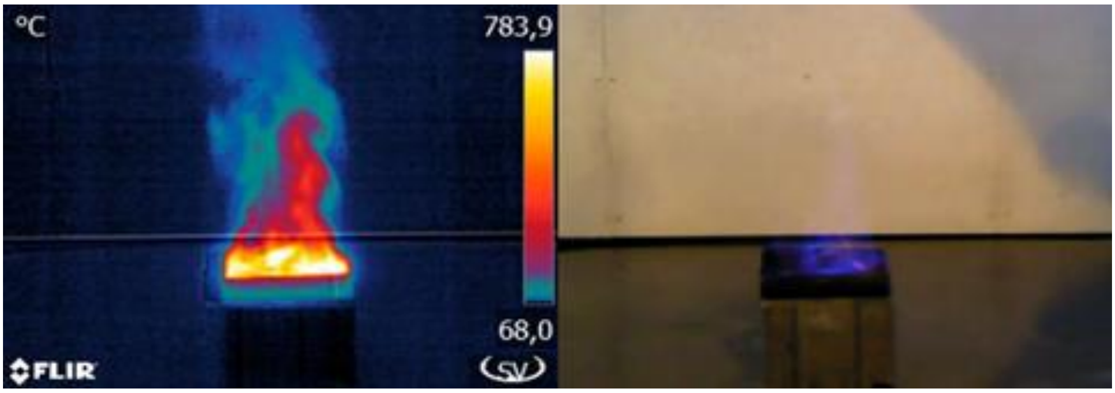

Figure 4.3 Methanol flame in infrared camera (left), observation of methanol flame by human eyes (right)

4.3 Fuel consumption

Table 4.1 shows the fuel consumption of two engines at the maximum power. The output power of Volvo engine is 10% more than Cummins engine, while, the specific fuel consumption is lower than Cummins engine. Which means that the Volvo engine will be more fuel-efficient. Moreover, when Volvo engine run at the same power as Cummins engine, the fuel consumption should be still lower than Cummins engine. However, this is only speculation, Volvo do not provide relevant data, this needs detailed information to proof.

Table 4.1 The comparison of the old and new engines

Brand	Type	Power	Fuel Consumption
Cummins	QSM11	526 kW@2500rpm	214 g/kWh
Volvo	IPS 1050	588 kW@2300rpm	195 g/kWh

4.4 The impact on performance

While with the replacement of the engines and the addition of extra methanol tank, the performance of the ship will change. This section mainly explains how the weight of the ship changes and the impact of these changes.

4.4.1 Weight of the ship

The table below shows the weight calculation of the original design. The ship now will be installed two Volvo Penta IPS 1050 engine and pod propulsion system which means that the weight of the whole machinery system will increased to 4600 kg (2300 kg for each IPS 1050 system). The light ship weight will increase. Since the deadweight is fixed, the design draft will increase.

Table 4.2 Original weight calculation of the ship

	Property	**Weight(kg)**	**LCG(m)**	**TCG(m)**	**VCG(m)**
6000	**MACHINERY**	3180			
6100	**Main Engines**				
6110	**Cummins QSM11*2**	2250	2.7	0	0.9
				0	
6120	**Reverse gear with gear**	340	1.9	0	0.6
6130	**Propeller Plant**				
6130	Hamilton Water Jet*2	590	0.98	0	505

4.4.2 Stability

The previous shows that the weight of the ship might increase 2000 kg, and there will be three different alternatives for methanol tank arrangement. All of them will impact the stability of the ship.

The ship must meet the requirement of the transport agency regulations and general advice on the safety of high-speed craft. All the alternatives must recalculate the intact stability in order to make sure that the modification of methanol tank must not break the regulation.

4.4.3 Resistance

The resistance will be recalculated for two reasons:

The first reason is that, the ship was designed and built in 1990s, some of the documents was lost. The original resistance data was lost too. While this time, Volvo Penta IPS system will replace the original engines and water jets, the speed of the ship needs re-measurement.

While the increase of the weight of the ship might increase the draught of the ship, that will also increase the resistance. That is the second reason.

In summary, in order to estimate the speed of the ship after modification, the resistance must be re-calculated.

5 Regulations

At the time of this thesis study, there were no specific rules governing the use of methanol as a marine fuel. The Code of Safety for Ships using Gases or other Low Flashpoint Fuels (IGF Code) was agreed in draft form by IMO Sub-Committee in 2014, but the main focus of the code is on liquefied natural gas (LNG). While the methanol is more similar to traditional liquid fuels in regular pressure and temperature.

5.1 Identify the Type of the Ship

According to *INTERNATIONAL CODE ON INTACT STABILITY, 2008,* Section 2(Definitions) of the Introduction. "High-speed craft" is defined with the formula shows below:

$$3.7\nabla^{0.1667}$$

Where:

$$\nabla = \text{volume of displacement corresponding to the design waterline}(\mathrm{m}^3)$$

If the maximum speed of the craft, in meters per second (m/s) is equal or larger than this value then the code could be applicable to this craft.

In this case the volume of displacement is about 12.5 m^3, the result of the formula 5.64, and the maximum speed is 11.32 m/s (22 kn) which mentioned in chapter 3. So the code can be applicable to this craft, and this pilot boat is a high-speed craft.

Then the 2008 IS CODE, Section 3.5(High-speed craft) of Chapter 3 Special criteria for certain types of ships defines that:

> *Any high-speed craft to which chapter X of the 1974 SOLAS Convention applies, irrespective of its date of construction, which has undergone repairs, alterations or modifications of a major character; and a high-speed craft constructed on or after 1 July 2002, shall comply with stability requirements of the 2000 HSC Code (resolution MSC.97(73)).*

This ship will be modified in 2016, which means the stability of the ship should obey International Code of Safety for High-Speed Craft, 2000.

5.2 Swedish Transport Agency (Sjöfartsverket) Regulations

According to *Swedish Transport Agency Regulations and General Advice on the Safety of High-Speed Craft* (Transportstyrelsens föreskrifter och allmänna råd om säkerheten på höghastighetsfartyg HSC-koden 2000), Swedish vessels and foreign vessels in Swedish territorial waters by the construction date of 1 July 2002 or later, and unless otherwise specified, to be entitled to the craft, certificate, meet the code for high-speed craft (International Code of Safety for High-Speed Craft, 2000), adopted by the International maritime organization (IMO) December.

The requirement of intact stability was identified below:

INTERNATIONAL CODE OF SAFETY FOR HIGH-SPEED CRAFT, 2000 (HSC CODE)

Annex 8

1.2 The area under the righting lever curve (GZ curve) shall not be less than 0.07 mrad up to θ = 15° when the maximum righting lever (GZ) occurs at θ = 15°, and 0.055 mrad up to θ = 30° when the maximum righting lever occurs at θ = 30° or above.

1.3 The area under the righting lever curve between θ = 30° and θ = 40° or between θ = 30° and the angle of flooding θF74 if this angle is less than 40°, shall not be less than 0.03 mrad.

1.4 The righting lever GZ shall be at least 0.2 m at an angle of heel equal to or greater than 30 °.

1.5 The maximum righting lever shall occur at an angle of heel not less than 15 °.

1.6 The initial metacentric height GMT shall not be less than 0.15 m.

These regulations show the intact stability demand for this ship, which should be fulfilled during the simulation later.

5.3 The Code of Safety for Ships using Gases or other Low Flashpoint Fuels

The latest comprehensive amendments of the IGF Code were adopted by resolution MSC.370(93), expected to enter into force on 1 July 2016. The basic philosophy of the IGF Code is to provide mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low flashpoint fuels, such as liquefied natural gas (LNG), to minimize the risk to the ship, its crew and the environment, having regard to the nature of the fuels involved. In this case, methanol is not included in IGF Code, while this project might contribute the IGF Code in the future.

6 Detailed Design and Calculation

This chapter shows all the related systems which are affected by the conversion. The system design will be emerged by CAD drawings. This chapter first show the intact stability calculation of three different fuel tank plans, and choose the best one. After that it describes the arrangement of fuel system, exhaust system and fire safety system and extra safe operating procedures. Then the whole will be show in 3D models so that every detail will show clearly. Finally, it will count all the controls, panels and wiring for the replacement of new engines.

6.1 Fuel Tank Arrangement and Related Calculation

One of the most important part of the project is the fuel tank arrangement. With the drawings provided by Swedish Maritime Administration, a 3D model was created by using Autoship. The fuel tanks will be arranged in the hull of the ship. This model is used to calculate the hydrostatics and intact stability of the pilot boat.

6.1.1 Ship Hull Development

The starting of calculate the stability is to create the hull model of the ship. Usually, the intended mission of the ship decides the size of the ship and its characteristics. The vessel size also might base on canal size or dry-docks. Generally, the hull-forms of ships are based on past designs which are proven good performance.

In this project, it’s an existing pilot boat, which means that the hull lines of the ship are fixed. The challenge of modelling the hull is to create the model as accurate as possible. This is related to the safety of navigation. Fortunately, the Swedish Maritime Administration has the original CAD drawings which was designed in 1996. So the points could be measured accurately.

Figure 6.1 shows the profile view of the pilot boat, which defined the location of each stations. There are some structures behind 0 station which is not the original design. These structures were added after an accident in 2002, when the broken engine was replaced by two new engines with water jet propulsion system. It is also shown in Figure 6.2.

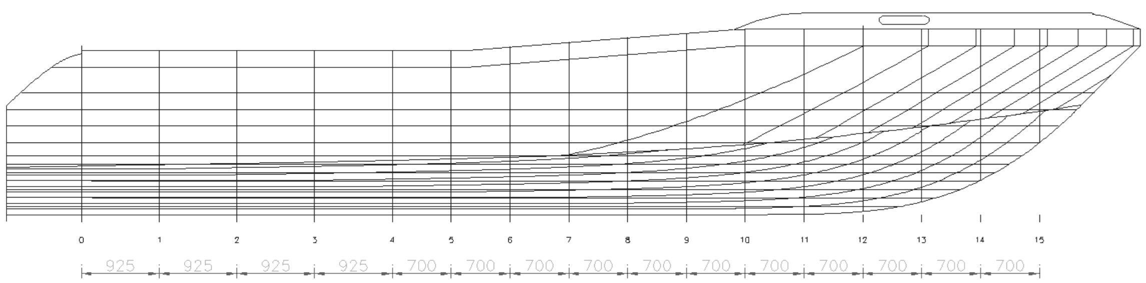

Figure 6.1 The profile view of pilot boat 729

Figure 6.2 shows the body plan for this project’s ship. Stations 8 to 13, corresponding to the forward half part of the ship are shown on the right side. Stations 1 to 7, corresponding to the after half part of the ship are shown on the left side. From the figure, it is clear to see that there is no mid-body. Meanwhile, a very fine bow to slice through seas are shown in the forward part of the ship. These two features are clearly shows that it is designed for high speed navigation.

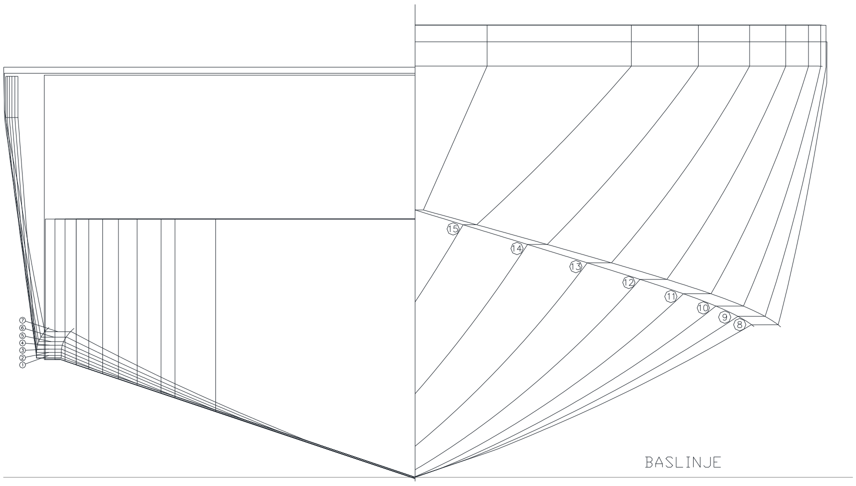

Figure 6.2 The body plan for pilot boat 729

With the existing drawing of the ship, a 3D model has been created with Autoship software. Figure 6.3 shows the side view, top view, front view and isometric view of the ship. The point of each section is picked from the original drawings of the body plan. Figure 6.4 shows an isometric view of the hull in Modelmaker. It should be noted that, the deckhouse is not shown in this view, while the weight of the deckhouse is taken into account in the stability calculation.

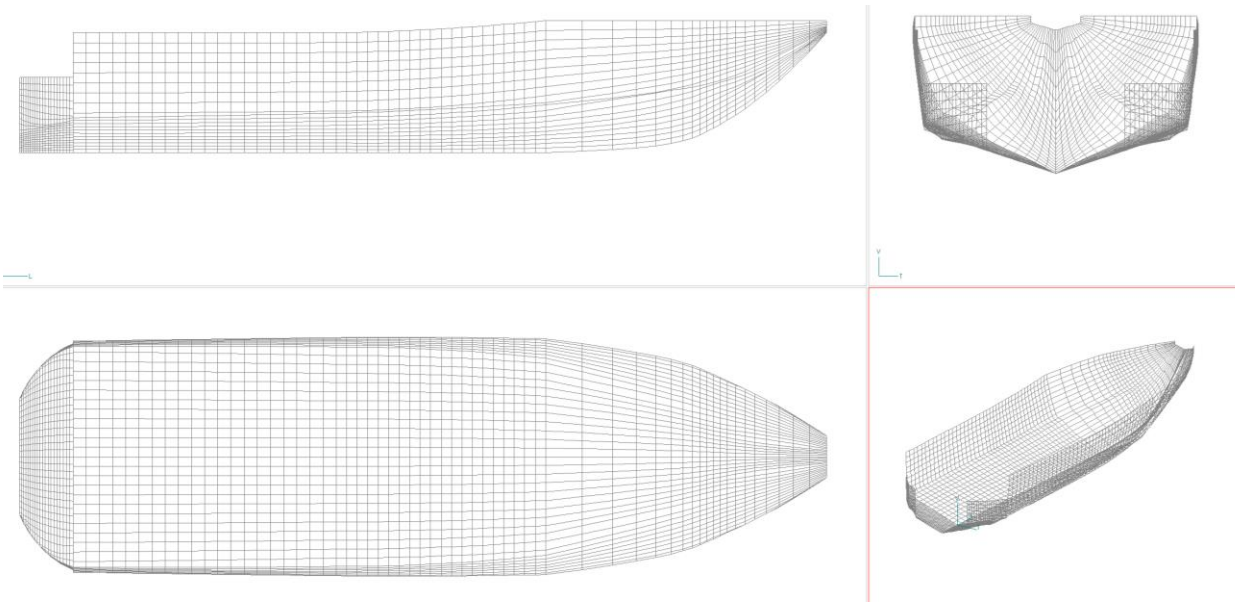

Figure 6.3 4 views of the models of the ship

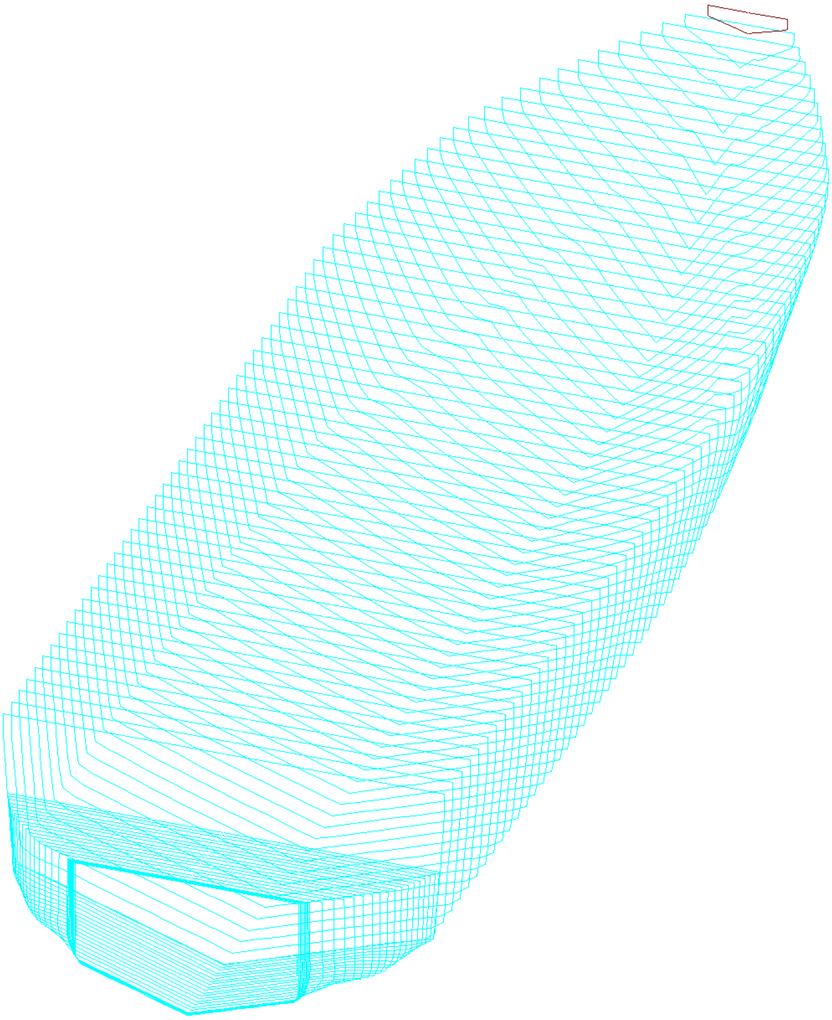

Figure 6.4 The isometric view of the hull of the pilot boat 729 created by Autoship

Figure 6.5 shows the sectional area curve of the ship. The sectional area curve is very useful in hydrostatic analysis of the vessel. The curve does not have any sharp corners or edges. This indicates that the hull curve is fair.

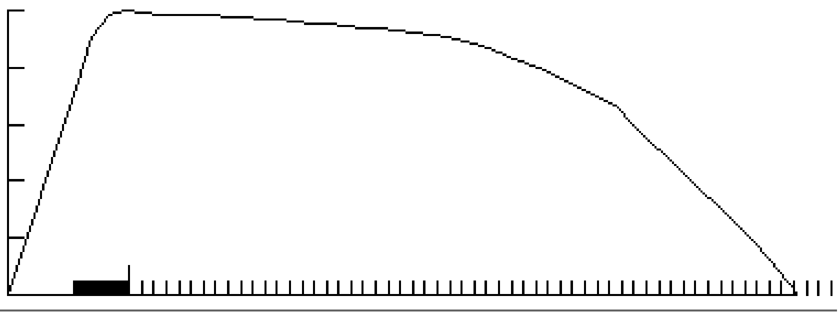

Figure 6.5 Sectional Area Curve

After created the hull model, next step is to compare with the original stability report to check whether the hydrostatics and stability parameters are similar.

First thing to check is the hydrostatic properties. Table 6.1 shows the hydrostatic properties of the ship model which created by author, While Table 6.2 shows the hydrostatic properties from the original documents. Please note that, both of these two tables are a part of the hydrostatic data, detailed hydrostatic properties is shown in appendix.

Table 6.1 Hydrostatic Properties of the ship model created by author

Draft at Origin	Displ	LCB	VCB	LCF	TPcm	MTcm	KML	KMT
(m)	(MT)	(m)	(m)	(m)	(MT/cm)	(MT-m /cm)	(m)	(m)
0.55	8.401	1.251a	0.366	1.169a	0.297	0.202	31.9	2.698
0.555	8.551	1.249a	0.369	1.167a	0.3	0.204	31.609	2.715
0.56	8.701	1.248a	0.372	1.166a	0.302	0.206	31.323	2.732
0.565	8.853	1.246a	0.376	1.164a	0.304	0.207	31.042	2.75
0.57	9.006	1.245a	0.379	1.162a	0.307	0.209	30.767	2.768
0.575	9.16	1.244a	0.382	1.160a	0.309	0.211	30.483	2.786
0.58	9.315	1.242a	0.385	1.158a	0.312	0.213	30.217	2.804
0.585	9.471	1.241a	0.389	1.156a	0.314	0.214	29.944	2.821
0.59	9.629	1.239a	0.392	1.153a	0.316	0.216	29.673	2.835
0.595	9.787	1.238a	0.395	1.150a	0.318	0.217	29.396	2.847
0.6	9.947	1.236a	0.398	1.146a	0.32	0.219	29.118	2.857
0.605	10.108	1.235a	0.402	1.141a	0.322	0.22	28.843	2.866
0.61	10.27	1.233a	0.405	1.137a	0.324	0.222	28.57	2.873
0.615	10.432	1.232a	0.408	1.132a	0.326	0.223	28.299	2.879

Table 6.2 Hydrostatic Properties from the original documents

Djupg. vid L/2	Displ	LCB	VCB	LCF	TPcm	MTcm	KML	KMT
(m)	(MT)	(m)	(m)	(m)	(MT/cm)	(MT-m /cm)	(m)	(m)
0.55	8.623	1.146a	0.362	1.131a	0.3	0.22	31.217	2.687
0.555	8.772	1.146a	0.365	1.128a	0.3	0.22	30.924	2.7
0.56	8.921	1.146a	0.368	1.126a	0.3	0.23	30.637	2.714
0.565	9.072	1.145a	0.371	1.123a	0.3	0.23	30.356	2.727
0.57	9.224	1.145a	0.375	1.120a	0.3	0.23	30.074	2.739
0.575	9.377	1.144a	0.378	1.127a	0.31	0.23	29.919	2.777
0.58	9.532	1.144a	0.381	1.122a	0.31	0.23	29.617	2.783
0.585	9.687	1.144a	0.384	1.117a	0.31	0.24	29.323	2.789
0.59	9.844	1.143a	0.388	1.130a	0.32	0.24	29.222	2.855
0.595	10.002	1.143a	0.391	1.124a	0.32	0.24	28.917	2.855
0.6	10.161	1.143a	0.394	1.125a	0.32	0.24	28.689	2.89
0.605	10.322	1.142a	0.397	1.126a	0.32	0.24	28.438	2.927
0.61	10.484	1.142a	0.401	1.118a	0.32	0.24	28.138	2.92
0.615	10.647	1.141a	0.404	1.109a	0.33	0.25	27.845	2.913

Figure 6.6 shows the deviation between the model and the original data. From the chart shows that most of the deviation of most parameters are less than 5%. Especially the displacement deviation between two sources of data are less than 2%. It can be considered that the model is effective.

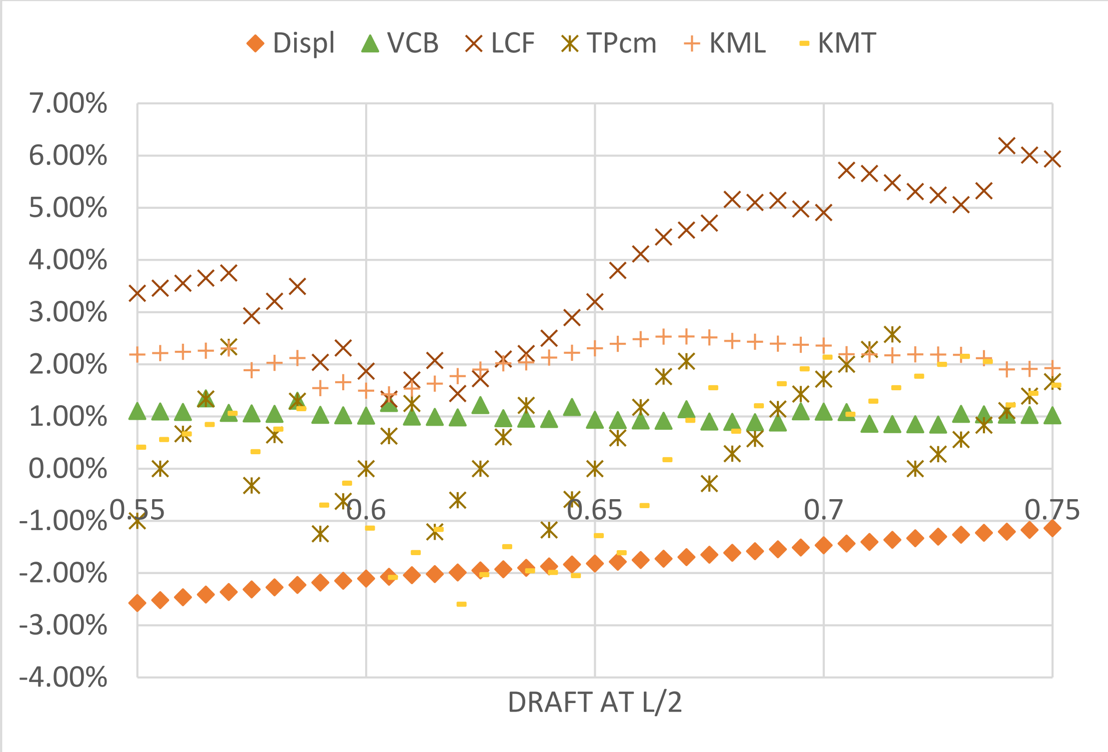

Figure 6.6 Deviation between the model and the original data

6.1.2 Tank Arrangement

This pilot boat has three different kinds of tanks: fresh water tank, diesel tank and sewage water tank. The fresh water tank is used to store fresh water for crew to use, when departure, the fresh water tank must be full. The volume of fresh water tank is 100liter, while the sewage water tank's volume is 70liter. There are two 600liter diesel tank installed inside port and starboard side separately.

The primary components of methanol conversion of the Pilot Boat 729 are the methanol fuel tank and its pipes. The arrangement of engines and diesel tanks are shown in Figure 6.7.

The new Volvo IPS 1050 engines are supplied with grade AAA methanol at ambient temperature and pressure. Since this is a small craft, there isn't any day tank for engines. The fuel tanks are directly connected with the engines. Because the engine conversion will apply pilot fuel injection system, the engine will need up to 95% of methanol and 5% of diesel as a pilot fuel.

The diesel tanks will be retained for two reasons. The first reason is that the engine still need some diesel as pilot fuel. The second reason is that if there is supply problems with methanol then the pilot boat could run on 100% of diesel oil.

There are four different plans for the arrangement of methanol tank, the plan will show later in this section. The tank has double walled bulkhead, and the tank top is filled with inert gas. The methanol is transferred to the engine room via the double walled fuel pipes which will be described later. The pipes will be routed in the middle of the ship.

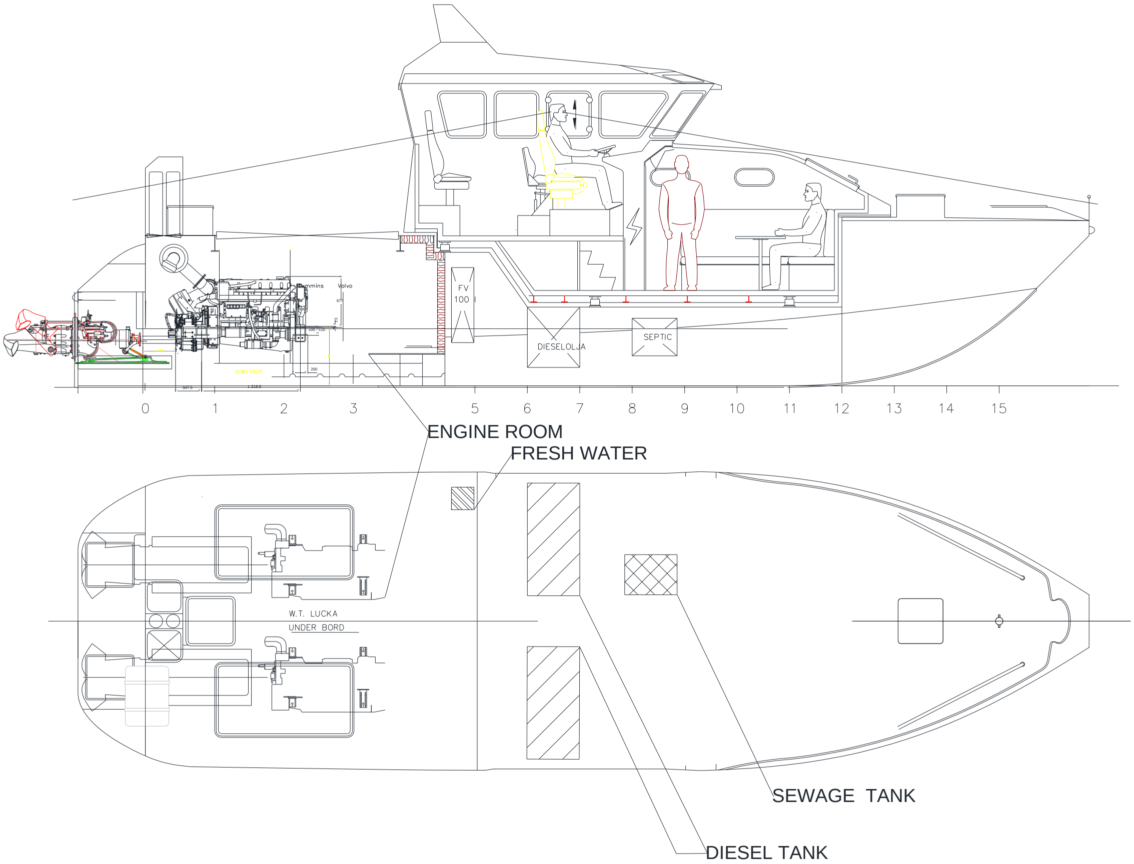

Figure 6.7 Original Tank Arrangement

Figure 6.8 shows the methanol tank arrangement plan 1, where there will be two methanol tanks located between section 7 and section 8, the same volume as the diesel tank which is 600liter each, and located on port and starboard sides separately.

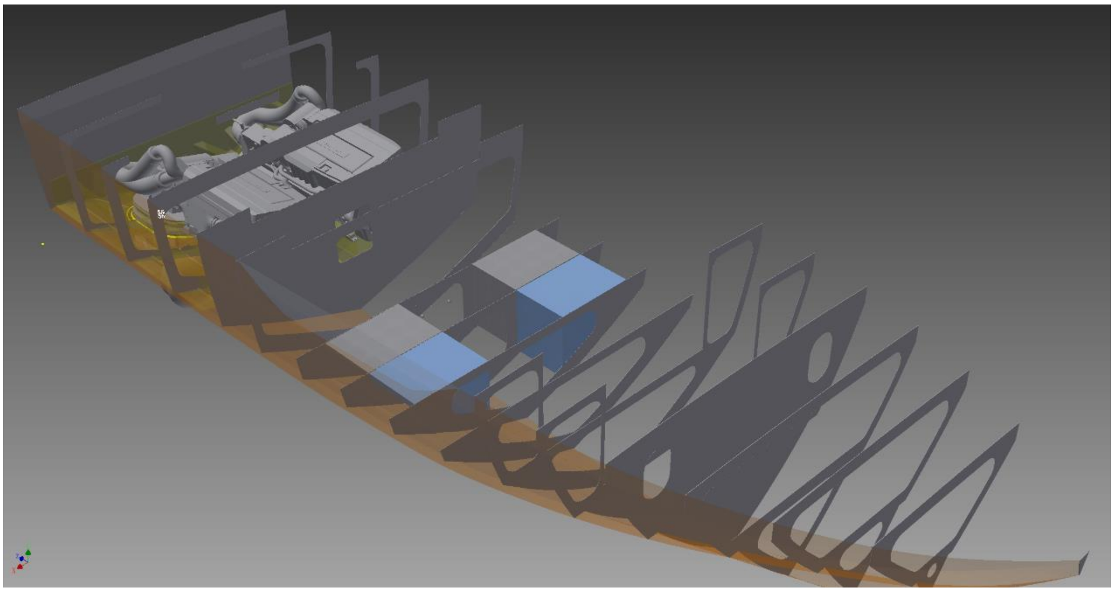

Figure 6.8 Methanol Tank Arrangement Plan 1 (methanol tank in blue)

Figure 6.9 shows the plan 2 of tank arrangement, which is similar to plan1, but located between section 7 and section 8.

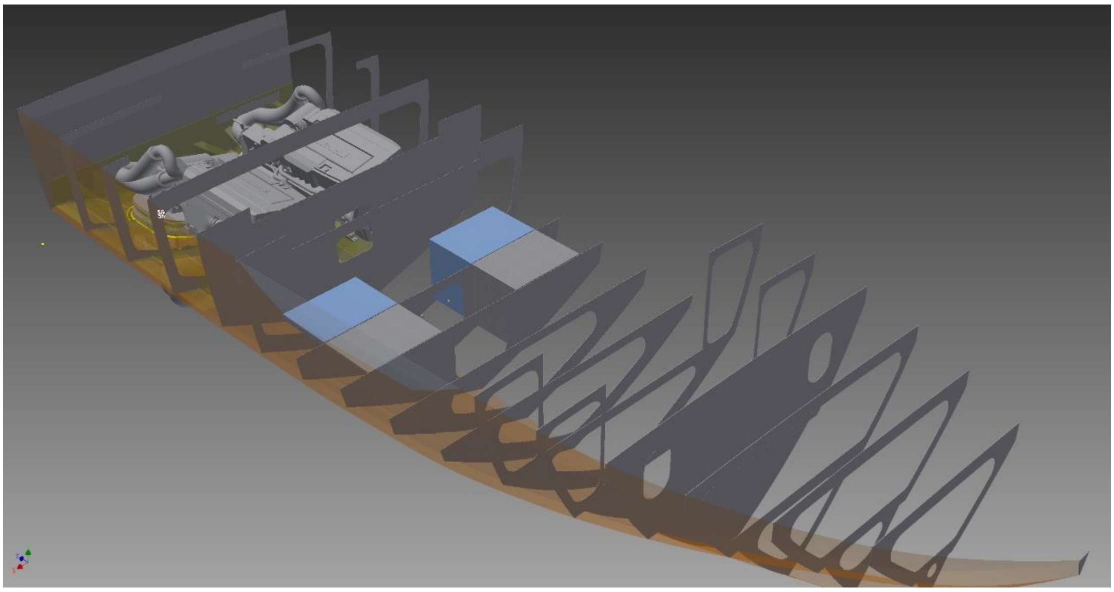

Figure 6.9 Methanol Tank Arrangement Plan 2 (methanol tank in blue)

Figure 6.10 shows the third plan of tank arrangement. There is one large tank located between section 5 and section 6, but the height of the tank is lower than the diesel tank, so that the pipes could be laid above the methanol tank.

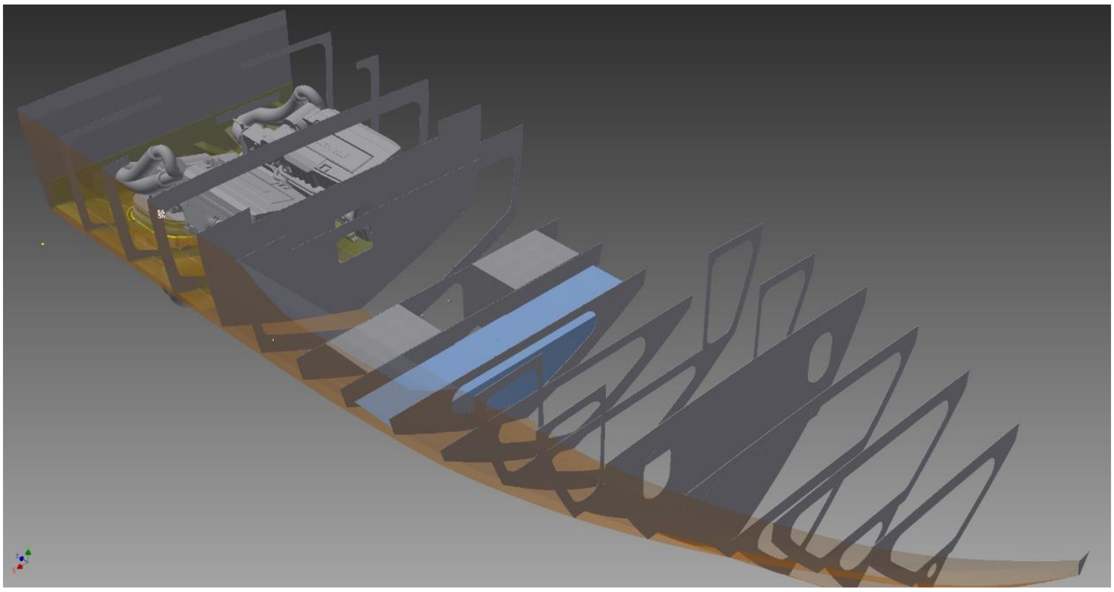

Figure 6.10 Methanol Tank Arrangement Plan 3 (methanol tank in blue)

Figure 6.11 shows the fourth plan of the tank arrangement. It's similar to plan 3, but located between section 7 to section 8 instead.

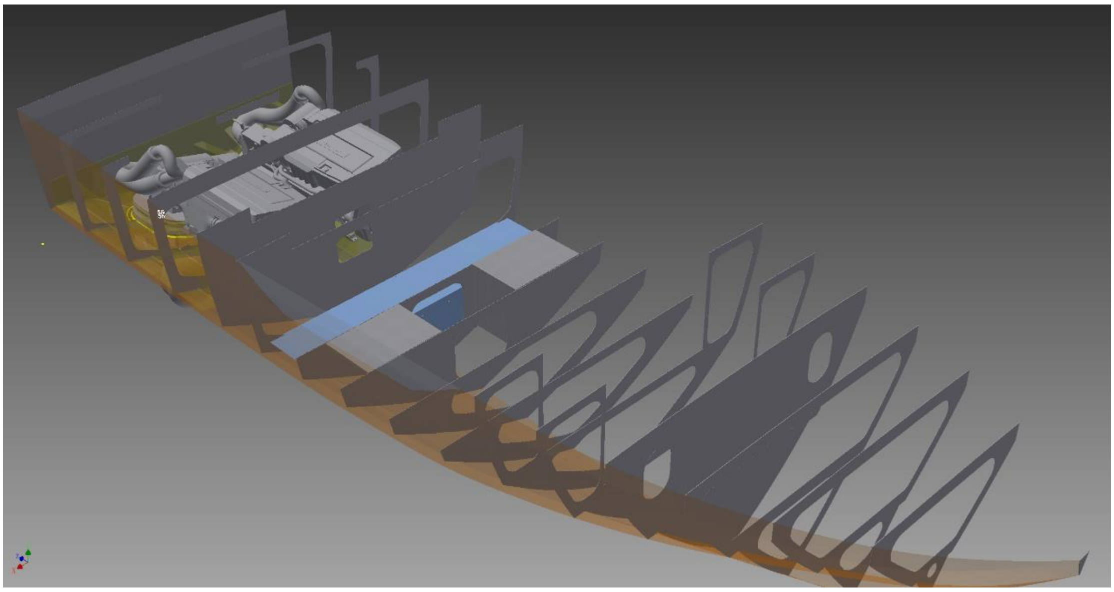

Figure 6.11 Methanol Tank Arrangement Plan 4 (methanol tank in blue)

Figure 6.12 shows the dimension of the methanol tank. The volume of plan 1 and plan 2 is about 600liter for each methanol tank. The volume of plan 3 and plan 4 is 1000liter. This could meet the fuel consumption of the navigation.

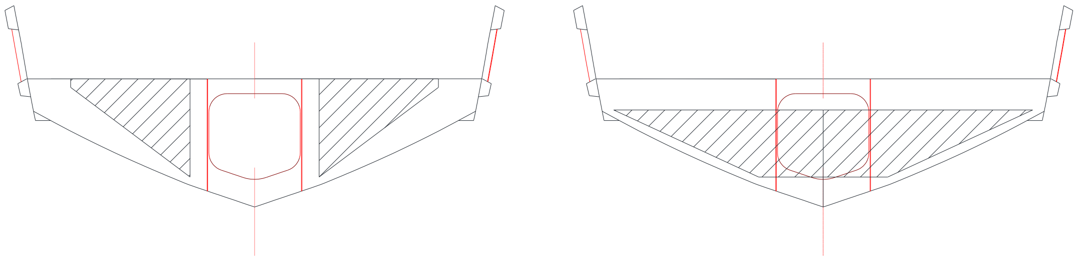

Figure 6.12 Dimension of the methanol tank (left: plan 1&2, right: plan 3&4)

6.1.3 Stability

There are four conditions in intact stability calculation: light ship condition, departure condition, arrival condition and arrival clogged with ice condition, the information about these four conditions are shown in Table 6.3.

Table 6.3 Four conditions in intact stability calculation

Condition 1	Light ship	The lightship means that the ship is ready for service in every respect, but the fuel and fresh water is empty.
Condition 2	Departure	The ship has all systems charged, all the fuel tanks and fresh water tank are filled with their normal operating fluids. Crews and storages are at normal values

Condition 3	Arrival	The fuel and water are at 10% full load, while the sewage tank are at 100% load.
Condition 4	Arrival clogged with ice	The same loading condition as condition 3, but the hull is clogged with ice, so there will be additional weight added on the ship.

Figure 6.13 and Figure 6.15 shows the dynamic stability curve of 4 design alternatives, where the x-axis is the heel angle of the ship and the y-axis is the righting arm, and the green lines is the HSC code requirements. The two figures show that all the maximum righting arm of all 4 conditions occurs over 15 degrees and the maximum righting arm is larger than 0.2 meter, which means that all the four plans could pass the HSC Code at condition 2 and condition 4, but the original design is failed in the test because the maximum righting arm is less than 0.2 meters. Meanwhile the righting arm of four plans are all better than the original design, and they are really close. It could be considered that the location of methanol tank doesn't affect the righting arm in this project.

Figure 6.14 and Figure 6.16 also shows the dynamic stability curve of 4 plans, where the x-axis is the heel angle of the ship and the y-axis is the area under the righting lever curve. The green points are the limitation of the minimum area at specific heel angle. In departure condition, all the plans could meet the regulation, but in condition 4, the original design failed to meet the requirement of the minimum area. While the new plans could all pass the test. It could also consider that the location of methanol tank doesn't affect the righting arm in this project.

Green lines in all these four figures are the minimum requirement for HSC Code.

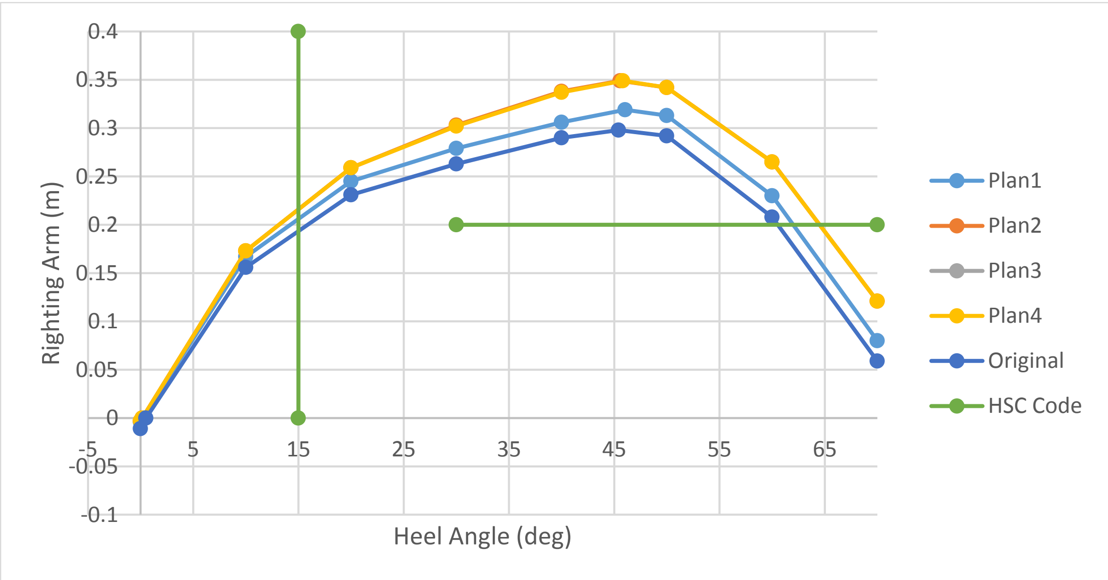

Figure 6.13 Righting arm vs Heel angel at departure condition

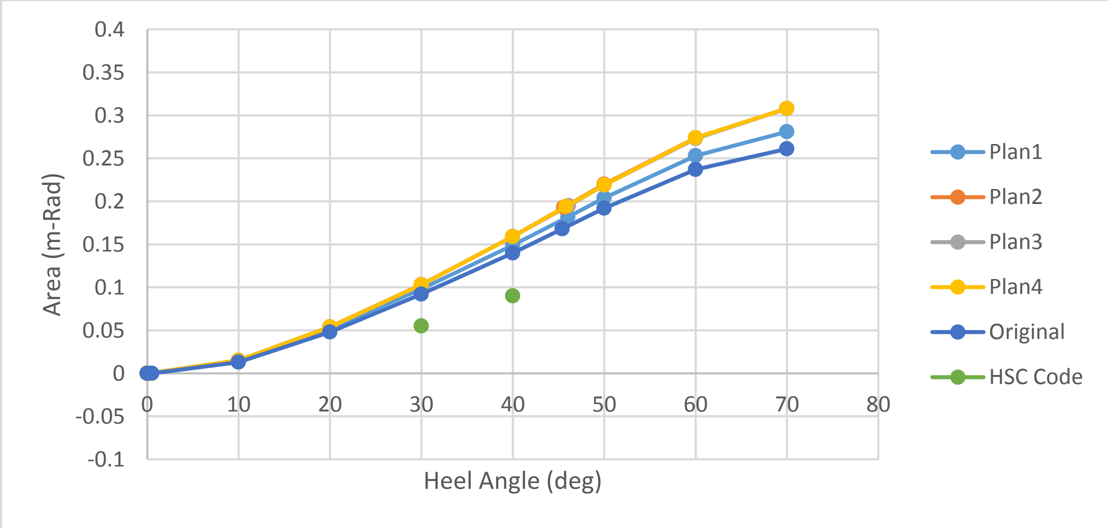

Figure 6.14 Area vs heel angle at departure condition

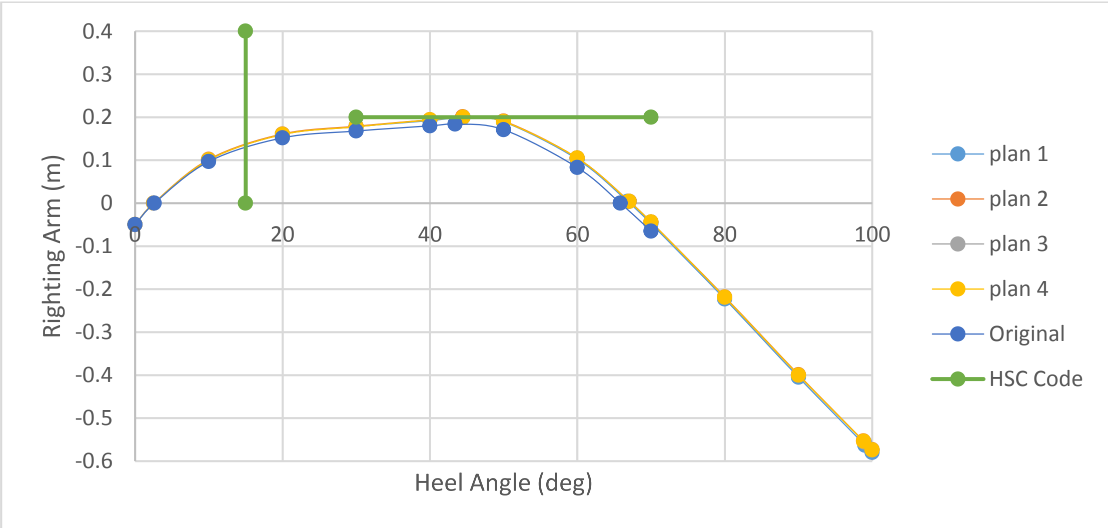

Figure 6.15 Righting arm vs Heel angle at arrival clogged with ice condition

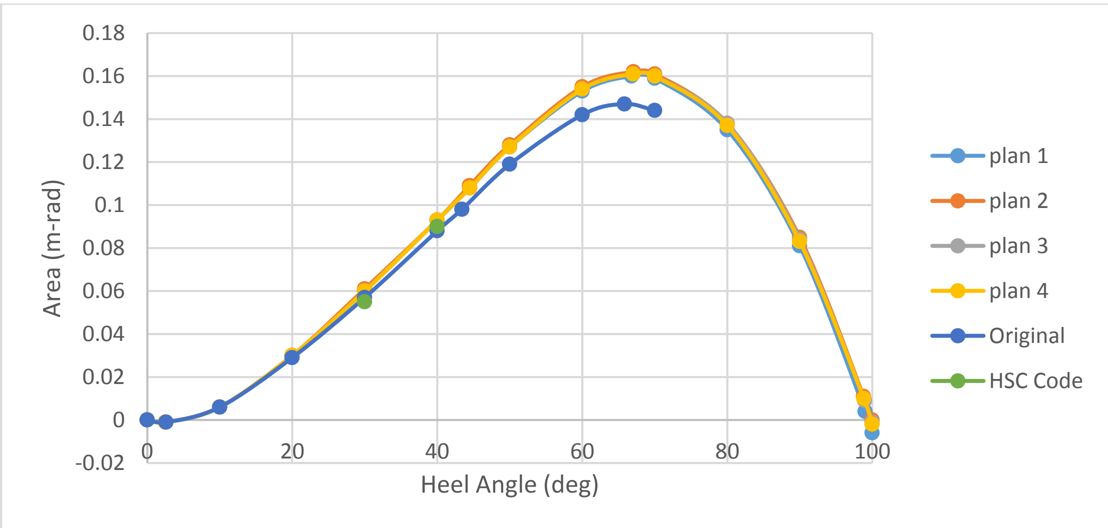

Figure 6.16 Area vs heel angle at arrival clogged with ice condition

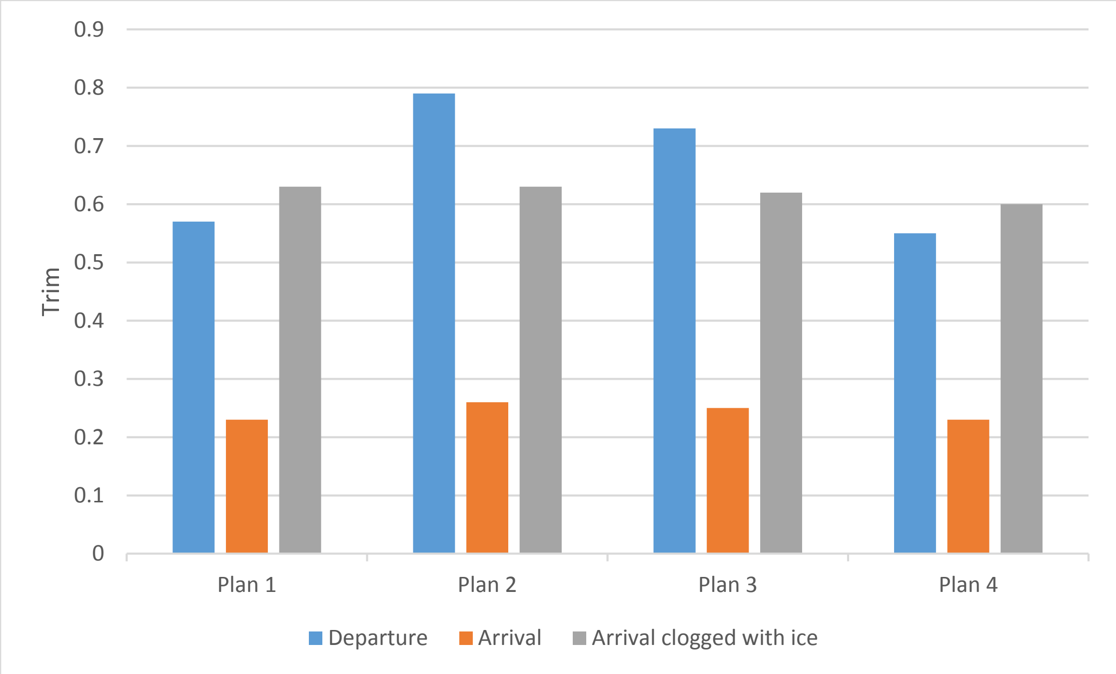

Figure 6.17 Trim at 3 different loading conditions of 4 plans

Figure 6.17 shows the trim at three different loading conditions of all four plans. From the figure, Plan 1 and plan 4 are better than the others, since the minimum trim are smaller than the other.

While creating the 3D models, in plan 3 and plan 4, the free space for pipes are limited due to the location of the methanol tank. Meanwhile, in plan 1 and plan 2, two individual methanol tanks are located at port side and starboard, that design leaves a lot of space in the middle of the ship above the bottom of the ship.

6.1.4 Result

In summary, plan 1 is the best solution for methanol tank location. Figure 6.18 shows the methanol tank location, and the inside profile of the whole ship. Table 6.4 shows the change of ship's stability data. The stability book shows that, even there is 1.2 tons heavier, the ship could still meet the regulations. The detailed stability reports of plan 1 is shown in Appendix I.

Table 6.4 The change of stability data in light ship condition

	Original	Methanol Conversion
Draft FP	0.674 m	0.705 m
Draft MS	0.678 m	0.715 m
Draft AP	0.682 m	0.726 m
Trim	0.08 deg.	0.09 deg.

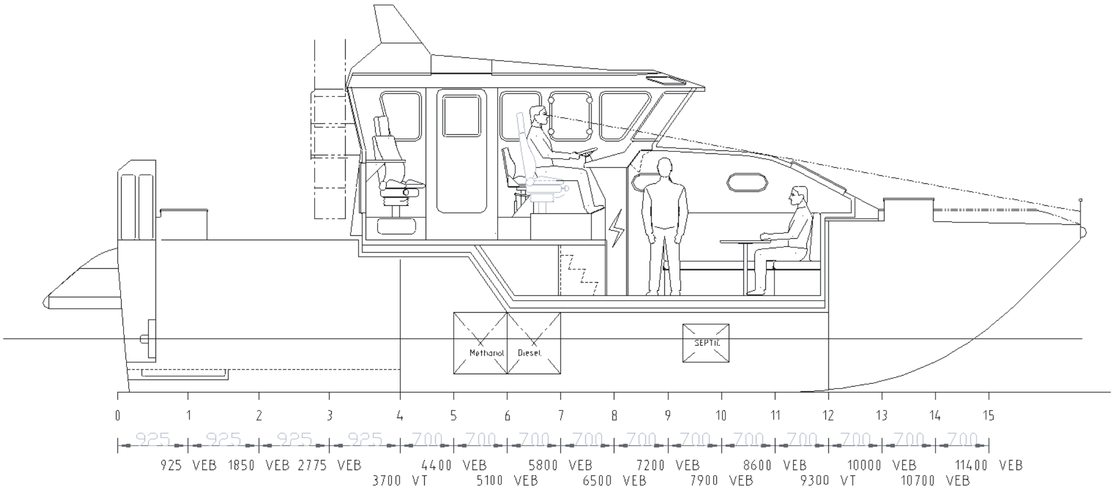

Figure 6.18 Final tank arrangement and inside profile

6.2 Descriptions of Systems

Equipment for methanol tank arrangement, inlet and outlet of different kinds of pipes and fire safety measures are briefly described as follows.

6.2.1 Fuel System

Methanol fuel piping system was designed to provide methanol from methanol tank between section 7 and 8 to the engines. In order to provide mechanical protection and to avoid any possible methanol leakage, all the methanol supply and return pipes are double walled fuel pipes as shown in the right corner of Figure 6.19.

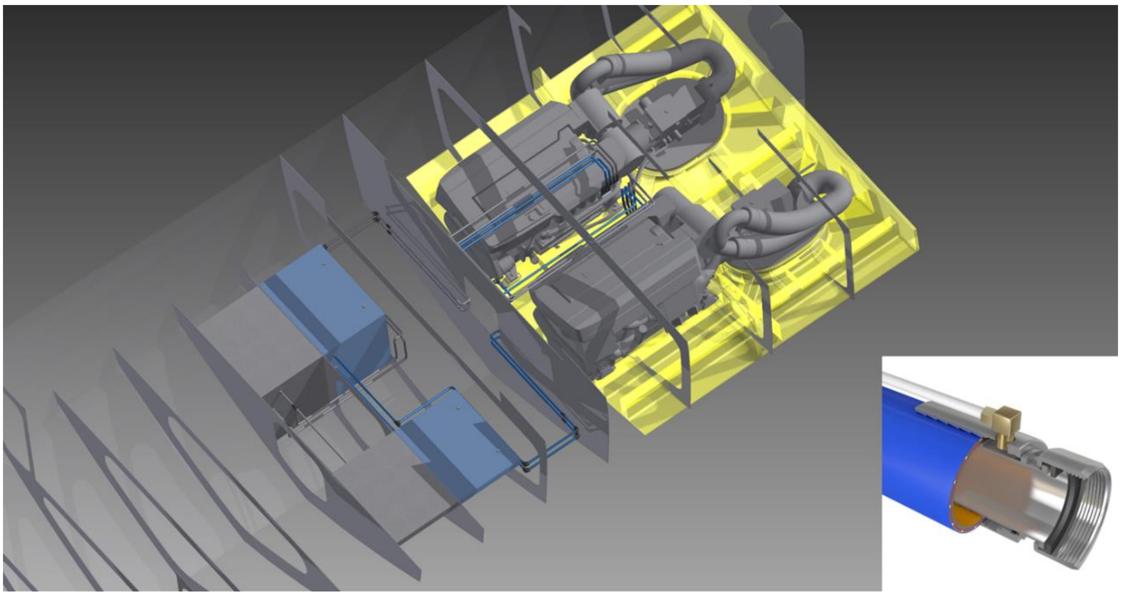

Figure 6.19 Tank arrangement and fuel system

The engine use pilot injection system, which means that the engine needs minimum 5% diesel during the whole combustion cycle. So both methanol and diesel pipes will be connected to the engines. The blue lines in Figure 6.19 are the methanol pipes and the grey lines are diesel pipes.

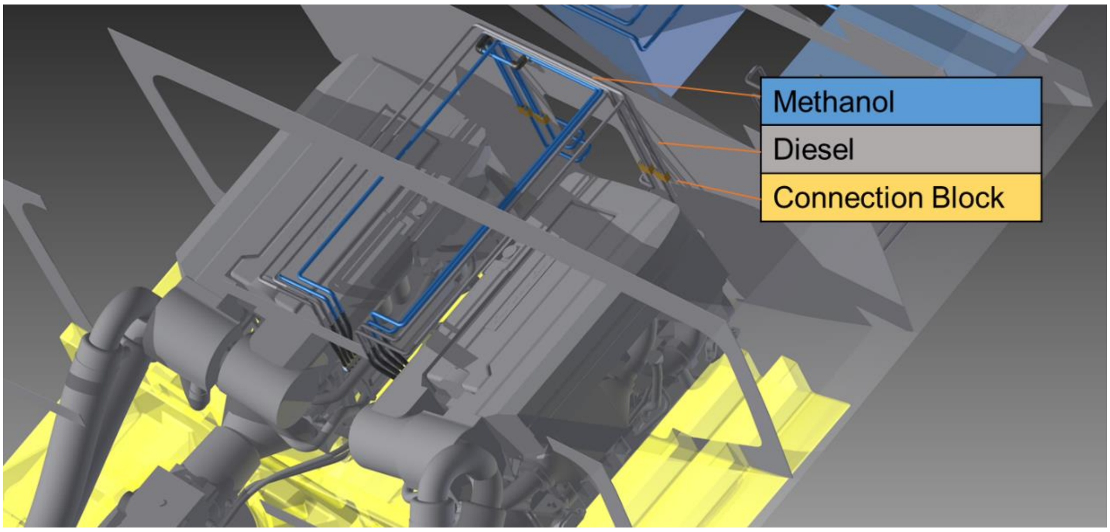

Figure 6.20 Engine room arrangement

Figure 6.20 shows the engine room arrangement, there is several connection blocks (brown in the figure) used in the engine room. These connection blocks let one fuel pipe in and divided into two smaller pipes out, two smaller pipes are connected to two engines.

There is a small boiler on board, this will also be converted to run on methanol, so the methanol pipe will be connected with the boiler.

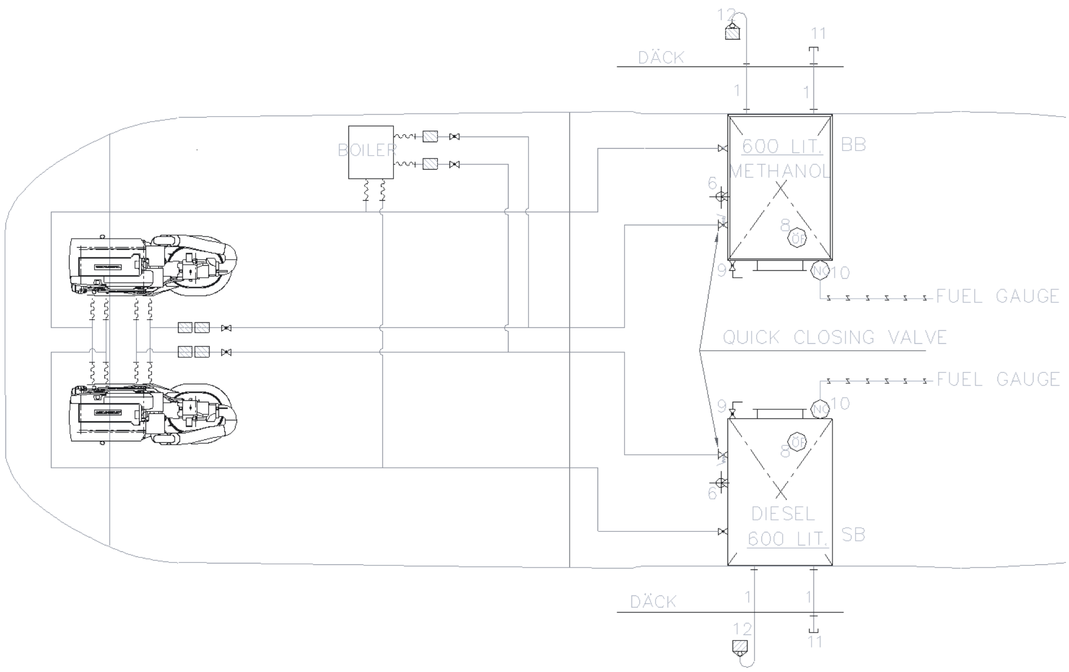

Figure 6.21 Fuel System

6.2.2 Inert Gas System

An inert gas is a gas which does not undergo chemical reactions under a set of condition, the inert gas system which installed in this ship is used to maintain the head space of methanol tank keep on non-explosive environment by filling the space with nitrogen. When refuelling the methanol, there won't be any methanol vapour release outside of the ship because of the head space of methanol tank is filled with nitrogen. Two 20liter nitrogen bottles are installed on the deck on the ship, the location is shown in Figure 6.22). Monitoring probe will be installed on top of the fuel tank to detect the methanol vapour concentration in the tank. The arrangement of inert gas pipes are shown in Figure 6.23, the pipe in red is the inert gas pipes. The nitrogen gas bottles are designed to be easy to change, because the gas bottles are consumables, once one bottle is empty, it should be replaced as soon as possible, while the other bottle could keep on working during cruise.

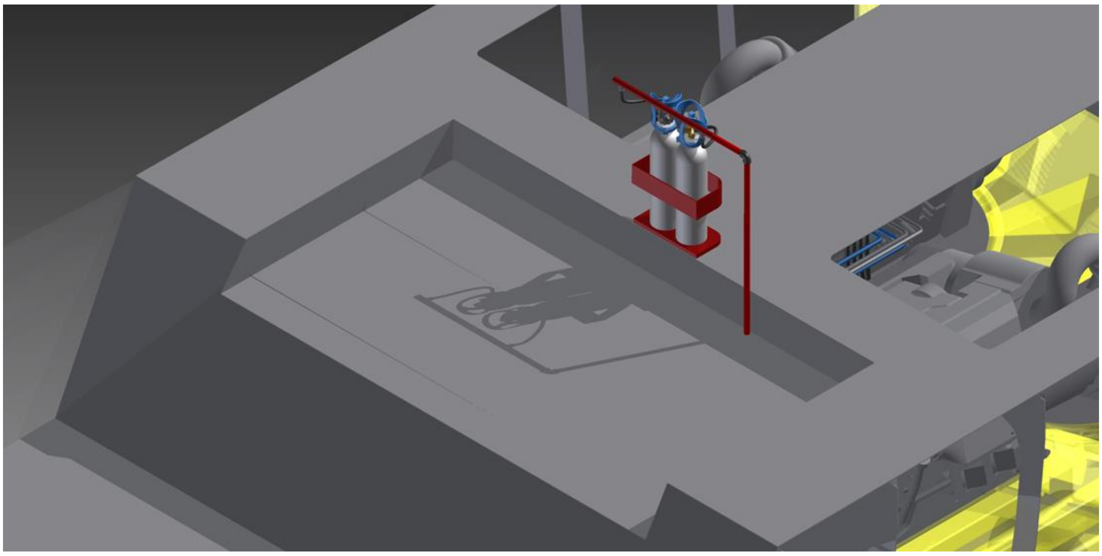

Figure 6.22 The location of nitrogen bottles

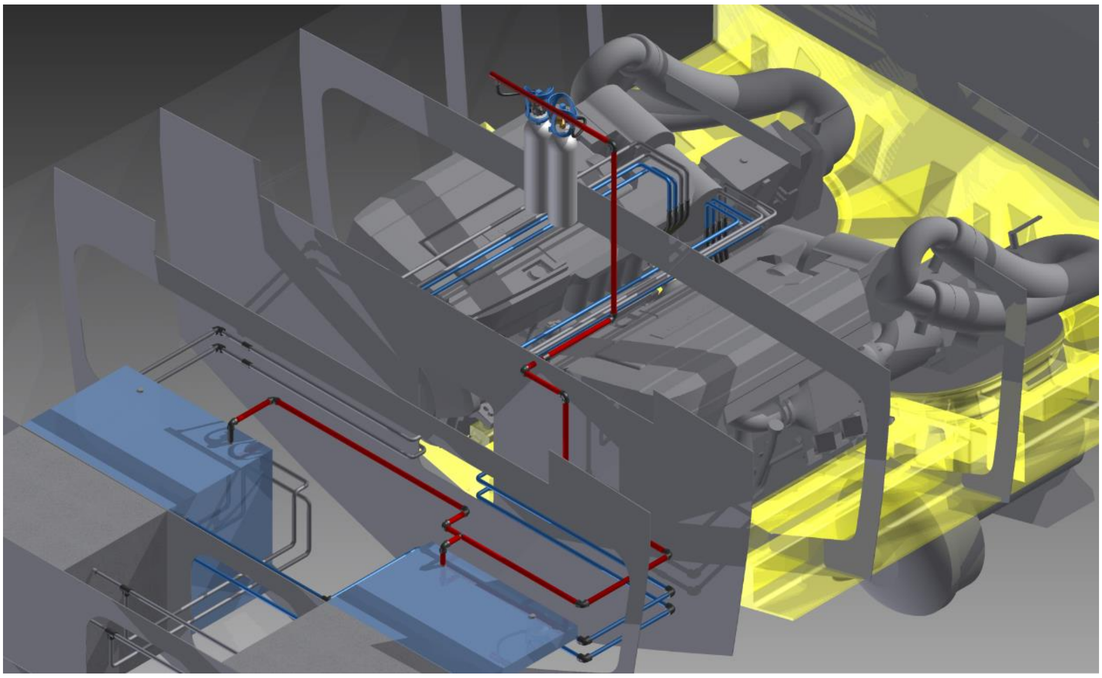

Figure 6.23 The arrangement of nitrogen pipes

In order to keep a stable inert gas environment on tank top, and to remove flammable methanol vapour, the operation process of inert gas system is shown below:

1. Methanol vapour concentration activates detection system.
2. Signal is sent to the control panel which in turn activates the suppression system.
3. During normal operation the nitrogen maintains continuously gauge pressure of 0.15 bar.
4. Inert gas is discharged into the fuel tank top through nozzles and remove the flammable and explosive methanol vapour.
5. The methanol vapour will exhaust through the pressure and vacuum relief valves (PV Valve) and discharge outside of the ship

6.2.3 Methanol Leaking Solution

Methanol is flammable and toxic, so safety measures to handle leakage should be considered during design. A double-walled fuel tank is used on board as Figure 6.24 shows. The green area is the methanol, and the red dots on the bottom are the leaking sensors.

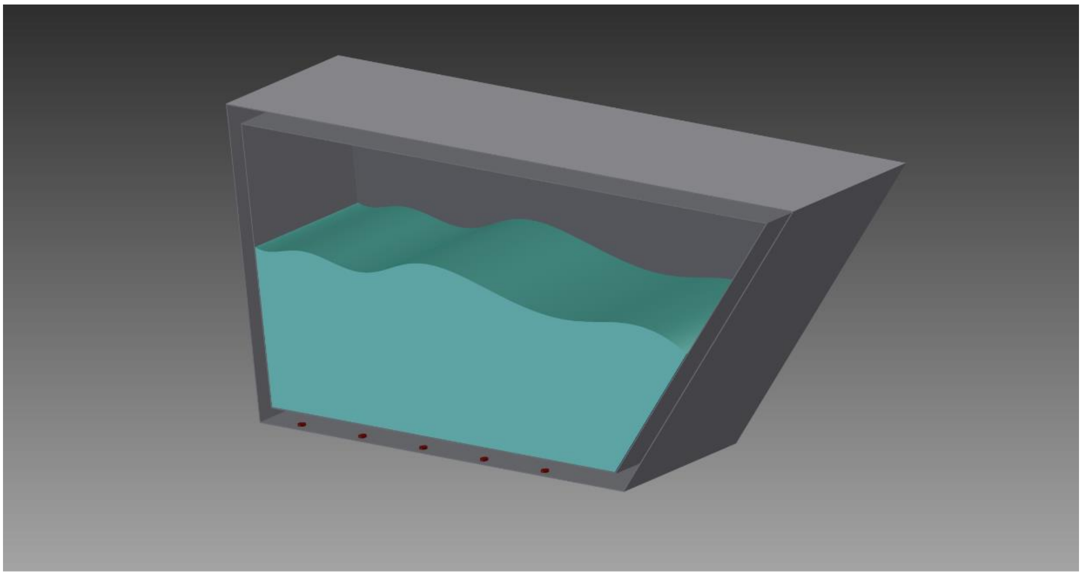

Figure 6.24 Double-walled methanol tank (Red dots are the leaking detection sensors)

If methanol is leaking, it will be detected by the sensor in the double wall space. Then a warning signal will be send to the bridge. The engine will switch to run on diesel. After that, it is suggested to stop working, return immediately and get repaired.

This solution is designed to maximize the navigation, increase the redundancy, keep the mariners away from the toxic methanol and protect the environment.

6.2.4 Firefighting System

A fire and gas detection system is installed in the engine room and outside of the methanol tank. The fire detection system is based on optical smoke detectors and infrared flame detectors. The gas detection system is based on infrared gas detectors. Both fire detection system and gas detection system are not only installed in engine room but outside of the methanol tank as well, and the whole system will be integrated to the ship's fire detection system.

A firefighting system called INERGEN System might be used on board. INERGEN System lowers the oxygen level to under the limit for when oil fires can burn, but still above the level where humans survive. To extinguish a methanol fire, the oxygen level will need to be lowered more and if that is done with higher concentration of INERGEN gas, it will also probable be lethal for humans. There is no application case for INERGEN system with methanol fire situation, so INERGEN system need to be further discussed.

Besides INERGEN system, CO_2 firefighting system is another candidate. It is an effective fire suppression agent applicable to a wide range of fire hazards. Carbon dioxide works quickly, with no residual clean-up associated with a system discharge. It is widely used on engine rooms. However, it is harmful for humans, so while CO_2 system works, the engine room need to be evacuated, while this ship is unmanned engine room, then CO_2 firefighting system could be used on board.

6.2.5 Safe Handling of Methanol

Figure 6.25 is the photo of the Stena Germanica firefighting training course, the mark 1 in the picture is the flame of diesel, while the mark 2 is the flame of methanol, and both of them are burning during that time. This figure clearly shows that if there is a serious fire in this methanol-driven pilot boat, it will be really hard to see the flame of methanol. Thus the special safety equipment and procedures for firefighting is needed.

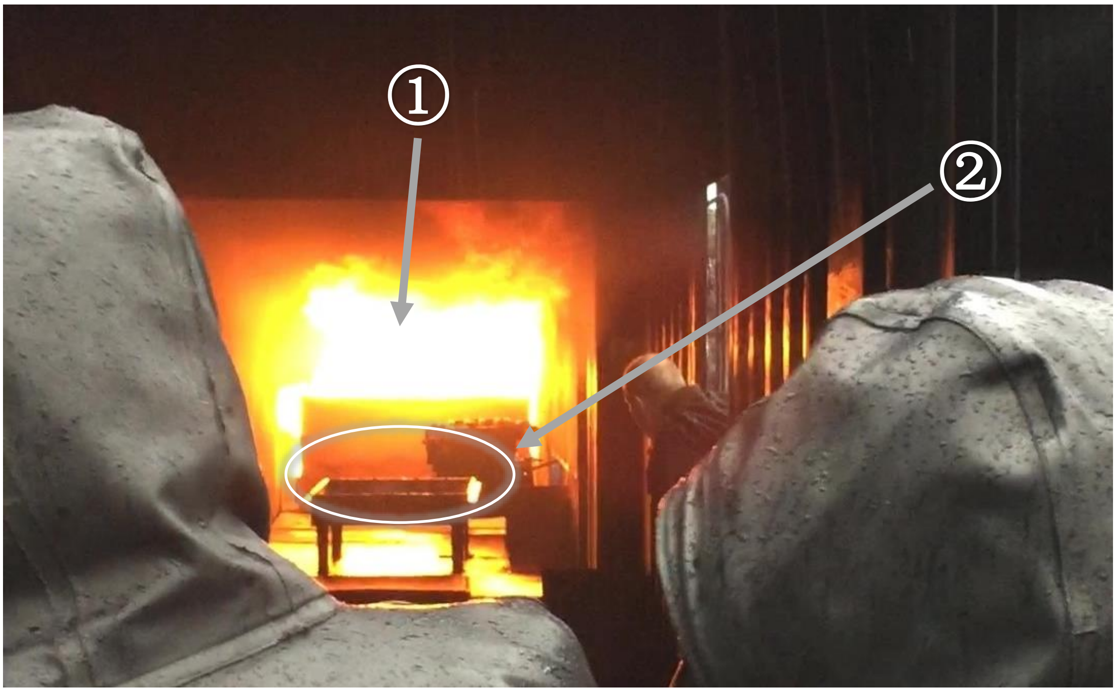

Figure 6.25 Firefighting training

Since methanol is a kind of new fuel for ships, safety training courses to explain system operations and methanol firefighting procedures should be taken for all crews. This course should include the properties of methanol and methanol fires, the fire systems on board, safety equipment and firefighting procedures and practical exercises of fire extinguishing. Moreover, operational manuals should be developed.

6.2.6 Intake and Exhaust System

The exhaust gas system of Volvo IPS system is different from the conventional exhaust gas system. Figure 6.26 shows the exhaust system of Volvo IPS system. It shows that the exhaust gases go out in the hub of the propeller and carried out behind the boat. This kind of exhaust system could reduce the fumes. Therefore, the original exhaust pipes of the engines will be removed, just keep the air intake pipes. The air intake pipes are used to support the combustion of the engines.

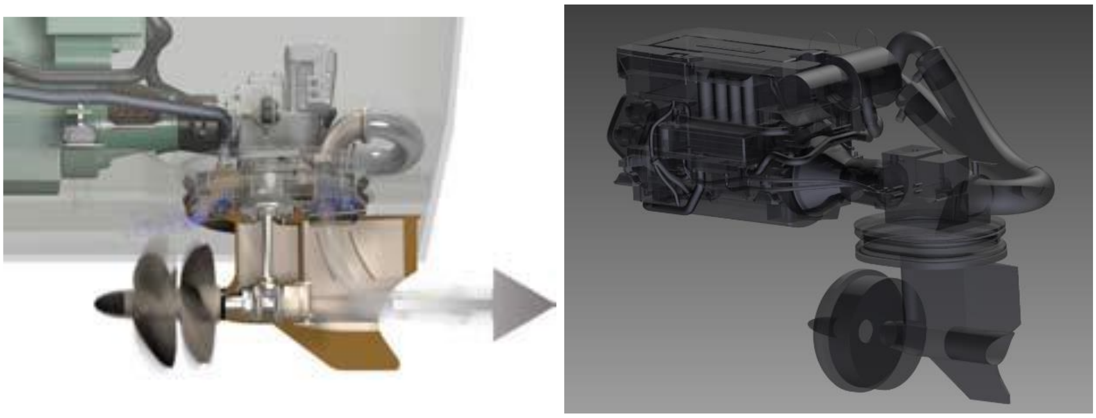

Figure 6.26 exhausts outlet of the Volvo IPS system

There is a new methanol ventilation pipe connected to the exhaust pipe. When the methanol volatile, the methanol vapour will exhaust through the exhaust pipes and carried out behind the boat. In Figure 6.27, the pipes in green are the methanol ventilation pipes with a PV valve outside of the ship.

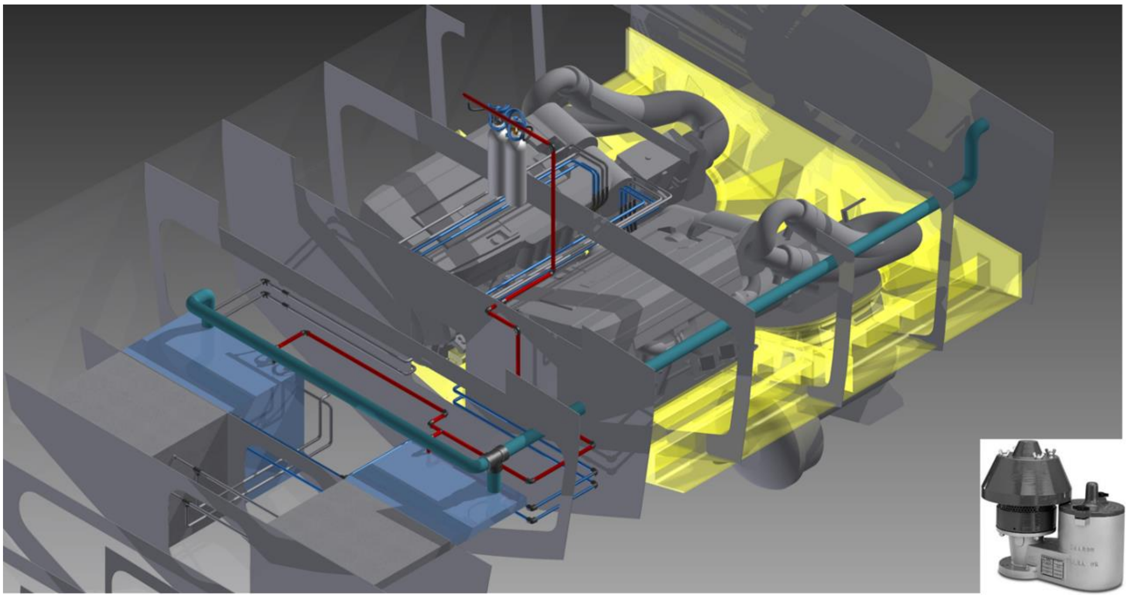

Figure 6.27 Exhaust and ventilation system and PV valve (right corner)

7 Conclusions

The stability calculation shows that the conversion work won't impact the ship's performance, and with the changing of the engines and propulsion system, the performance of the ship will become even better. There will be a lot of new equipment and pipes installed on board. The 3D models show that there is enough space for all pipes and equipment being installed on board. With 3D models, it is much easier to know about the location and arrangement of all equipment and pipes than 2D AutoCAD drawings.

There is little influence to the ship's structure, only new pipes and two pre-made methanol tanks will be installed on board.

The tank is ambient temperature and pressure, very easy to handle. The ship could be refuelled with methanol just like refuelling diesel oil, without special harbours.

The risk and safety solutions has been fully developed. There is almost no leakage risk during operation. Since there is unmanned engine room, the possibility of affecting the health of the crew will be minimized.

Apart from the cost of new engines, if the ship just converts to methanol without changing the engines, the cost of the whole conversion will be very low.

Considering the pilot boat is operating in one area, it is particularly suitable for operation on methanol, because the ship only refuels in a particular harbour. If this harbour could provide refuelling methanol, this harbour could supply methanol to all nearby pilot boats. The ship owner does not need to worry about the methanol supply in the port of arrival.

Using presently available technology, methanol engines can provide more than 90% reduction in SOx, about 20% reduction in CO_2 relative to high pollution diesel engines. It will be very easy to meet the emission regulations. The emission of particulate matter will also reduce.

Meanwhile, methanol can be produced as a biofuel and is sustainable because it can be made from cellulose and does not compete with food sources.

In conclusion, this project fully shows the advantage of converting to methanol. The author believes that methanol has a certain potential to become a competitive marine fuel.

8 Outlook and future work

This report focused on converting a pilot boat to operate on methanol. It is the first small boat that is considered for operating on methanol, which could be a role model to all small boats such as fishing boats, yachts and so on.

The stability calculation shows the draft between original and after conversion is different. That means that the resistance might change, meanwhile there will be new engines on boards. Therefore, the resistance of the modified ship need to be recalculated, in order to get the new maximum speed. Simultaneously the engine bed will be replaced, this might influence the structural strength, which should be considered in the future. Moreover, the replacement of propulsion system from waterjet to Volvo IPS system is needed to evaluate the benefits of the replacement.

For use of methanol as a marine fuel rules are currently being developed. For larger ships class rules has been issued by LR (provisional) and DNV (tentative). The International Maritime Organization’s draft IGF code (International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels) is mainly for LNG, work to include methanol in the code is ongoing but still in the early stages. Lacking of reference regulation could be an unfavourable factor of spreading methanol adoption. So developing comprehensive rules for methanol as a marine fuel is very necessary.

In spite of methanol shows excellent result in sulphur oxides emissions, the methanol and formaldehyde emissions from the engines need to be measured. Research has shown that the methanol and formaldehyde emissions from the engines are very low in 4-stroke car engines, but still lack of the measuring of the emissions from marine methanol engines.

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Appendix I – Stability Reports

CONDITION 1 LIGHT SHIP

Floating Status

Draft FP	0.679 m	Heel	zero	GM(Solid)	1.300 m
Draft MS	0.683 m	Equil	Yes	F/S Corr.	0.000 m
Draft AP	0.687 m	Wind	0.0 kn	GM(Fluid)	1.300 m
Trim	0.04 deg.	Wave	No	KMT	2.944 m
LCG	2.372a m	VCG	1.644 m	TPcm	0.35

Loading Summary

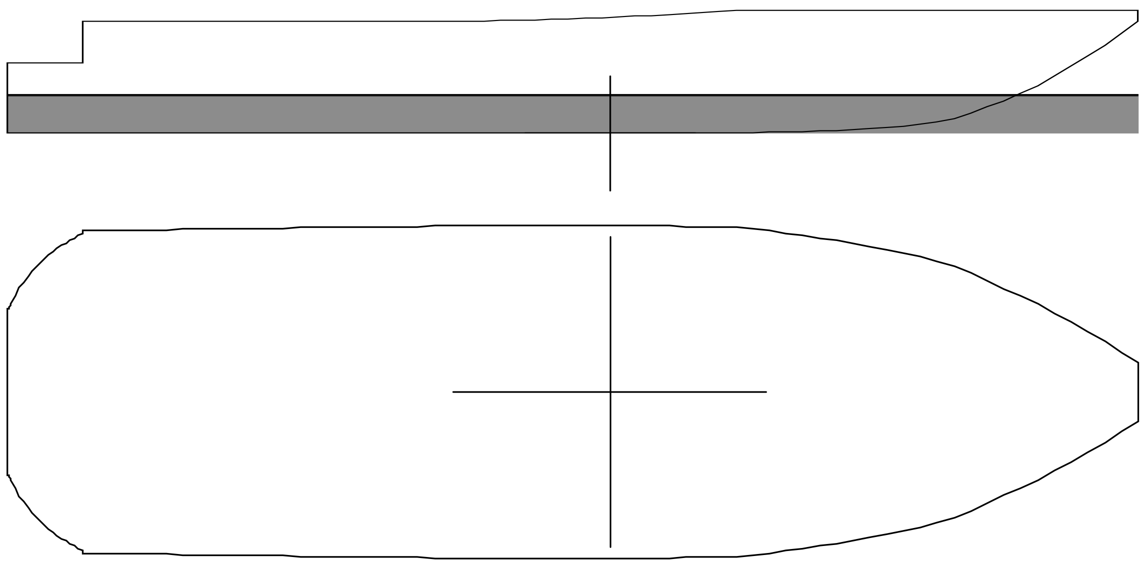
Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	12.48	2.400a	0.000	1.616
Deadweight	0.30	1.200a	0.000	2.800
Displacement	12.78	2.372a	0.000	1.644

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	12.48	2.400a	0.000	1.616u
CREW	0.30	1.200a	0.000	2.800u
Total Weight:	**12.78**	**2.372a**	**0.000**	**1.644u**

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	12.78	2.373a	0.000	0.453	1.000
SubTotals:			**12.78**	**2.373a**	**0.000**	**0.453**	



Righting Arms vs Heel Angle

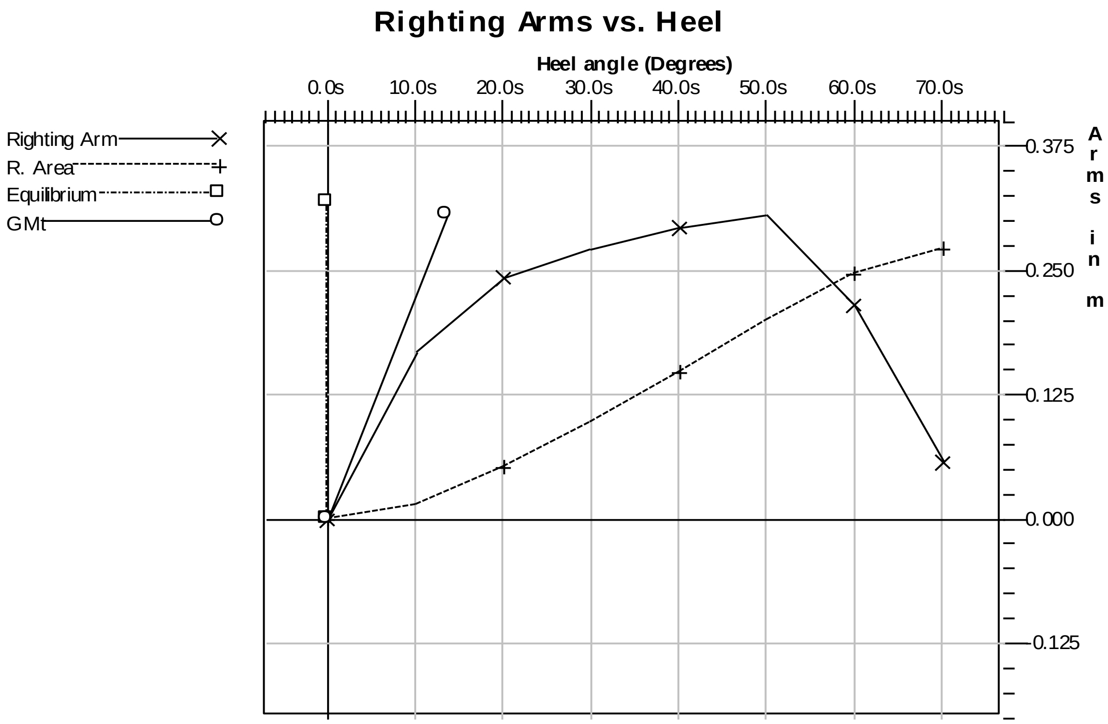
Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.04a	0.683	0.000	0.000	1.814 (1)	Equil
10.00s	0.08a	0.644	0.170	0.015	1.716 (1)	
20.00s	0.03a	0.544	0.244	0.052	1.615 (1)	
30.00s	0.04f	0.392	0.272	0.098	1.501 (1)	
40.00s	0.06f	0.195	0.293	0.147	1.372 (1)	
50.00s	0.11a	-0.041	0.307	0.200	1.218 (1)	
60.00s	0.67a	-0.308	0.215	0.247	1.023 (1)	
70.00s	1.37a	-0.584	0.057	0.272	0.802 (1)	

Unprotected Flood Point

Name	L,T,V (m)	Height (m)
(1) Engine Room	5.000a, 0.550s, 2.500	1.814

INTERNATIONAL CODE OF SAFETY FOR HIGH-SPEED CRAFT, 2000

Limit	Min/Max	Actual	Margin	Pass
(1) Area from 0.00 deg to 30.00	>0.0550 m-R	0.098	0.043	Yes
(2) Area from 0.00 deg to 40.00 or Flood	>0.0900 m-R	0.147	0.057	Yes
(3) Area from 30.00 deg to 40.00 or Flood	>0.0300 m-R	0.049	0.019	Yes
(4) Righting Arm at 30.00 deg or MaxRA	>0.200 m	0.307	0.107	Yes
(5) Angle from 0.00 deg to MaxRA	>15.00 deg	50.00	35.00	Yes
(6) GM at Equilibrium	>0.150 m	1.300	1.150	Yes



CONDITION 2 DEPARTURE

Floating Status

Draft FP	0.816 m	Heel	port 0.16 deg.	GM(Solid)	1.271 m
Draft MS	0.769 m	Equil	Yes	F/S Corr.	0.041 m
Draft AP	0.721 m	Wind	0.0 kn	GM(Fluid)	1.230 m
Trim	fwd 0.40 deg.	Wave	No	KMT	2.815 m
LCG	2.175a m	VCG	1.545 m	TPcm	0.37

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	12.48	2.400a	0.000	1.616
Deadweight	2.94	1.221a	0.019p	1.241
Displacement	15.42	2.175a	0.004p	1.545

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	12.48	2.400a	0.000	1.616u
CREW	0.30	1.200a	0.000	2.800u
STOCK	0.50	1.200a	0.000	2.500u
Total Fixed:	13.28	2.328a	0.000	1.676u

Tank Status

DIESEL OIL (SpGr 0.870)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
DIESEL_TK.P	98.00%	0.53	0.852a	0.979p	0.715	0.975
DIESEL_TK.S	98.00%	0.53	0.852a	0.977s	0.715	0.975
Subtotals:	98.00%	1.06	0.852a	0.001p	0.715	

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
FW_TK.P	100.00%	0.09	2.159a	0.600p	1.075	0.975
Subtotals:	100.00%	0.09	2.159a	0.600p	1.075	

METHANOL (SpGr 0.790)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
METHANOL_TK.P	98.00%	0.50	1.551a	0.992p	0.711	0.975
METHANOL_TK.S	98.00%	0.50	1.551a	0.990s	0.711	0.975
Subtotals:	98.00%	0.99	1.551a	0.000	0.711	

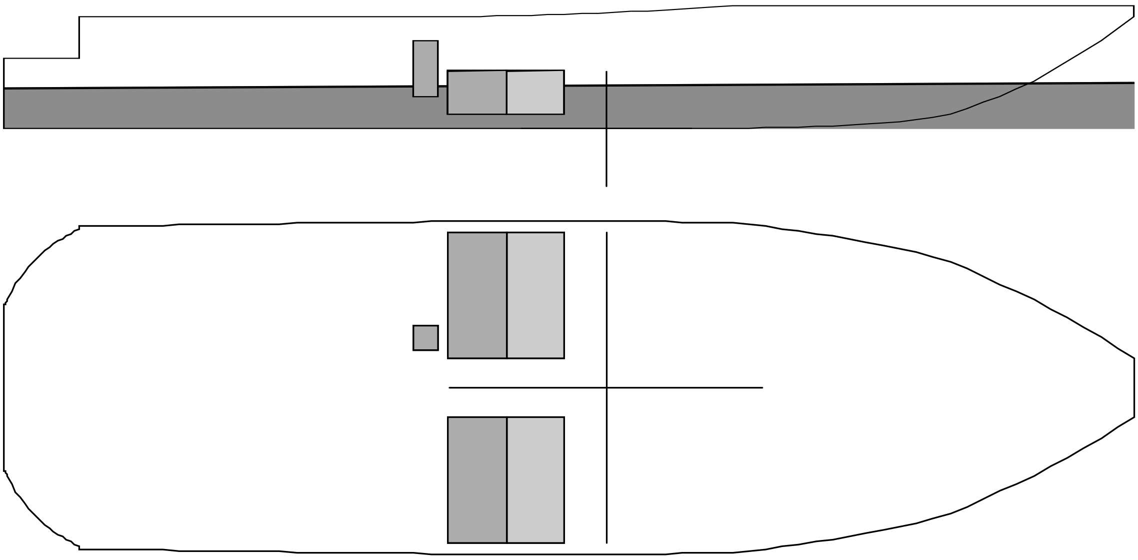
All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
Totals:		2.14	1.229a	0.025p	0.728	

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	15.42	2.168a	0.007p	0.499	1.000

SubTotals:			15.42	2.168a	0.007p	0.499	



Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		1.06	98.00%
FRESH WATER		.09	100.00%
METHANOL		.99	98.00%

Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.40f	0.772	-0.003	0.000	1.763 (1)	
0.16p	0.40f	0.772	0.000	0.000	1.765 (1)	Equil
10.00p	0.32f	0.737	0.173	0.015	1.849 (1)	
20.00p	0.32f	0.639	0.259	0.054	1.926 (1)	
30.00p	0.33f	0.488	0.303	0.103	1.981 (1)	
40.00p	0.30f	0.287	0.338	0.159	2.008 (1)	
45.57p	0.23f	0.160	0.349	0.193	2.002 (1)	MaxRa
50.00p	0.10f	0.057	0.342	0.220	1.980 (1)	
60.00p	0.40a	-0.189	0.265	0.274	1.881 (1)	
70.00p	1.06a	-0.448	0.121	0.308	1.727 (1)	

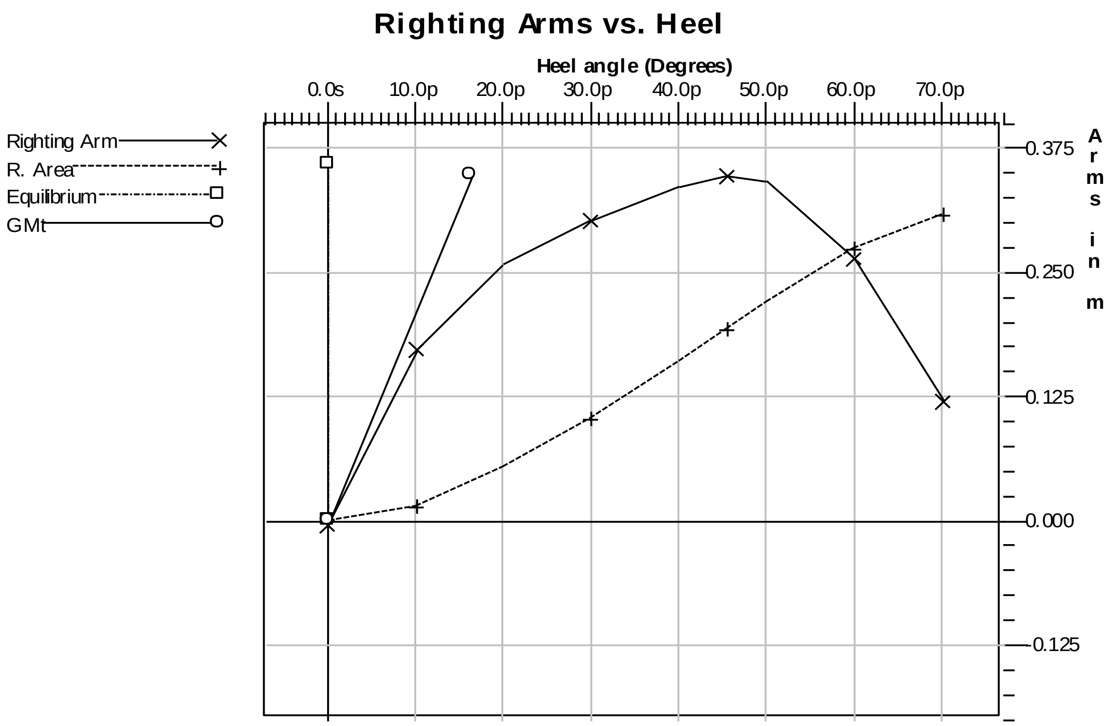
Unprotected Flood Point

Name	L,T,V (m)	Height (m)
(1) Engine Room	5.000a, 0.550s, 2.500	1.763

INTERNATIONAL CODE OF SAFETY FOR HIGH-SPEED CRAFT, 2000

Limit	Min/Max	Actual	Margin	Pass
(1) Area from 0.00 deg to 30.00	>0.0550 m-R	0.103	0.048	Yes
(2) Area from 0.00 deg to 40.00 or Flood	>0.0900 m-R	0.159	0.069	Yes
(3) Area from 30.00 deg to 40.00 or Flood	>0.0300 m-R	0.056	0.026	Yes

(4) Righting Arm at 30.00 deg or MaxRA	**>0.200 m**	**0.349**	**0.149**	**Yes**
(5) Angle from 0.00 deg to MaxRA	**>15.00 deg**	**45.57**	**30.57**	**Yes**
(6) GM at Equilibrium	**>0.150 m**	**1.229**	**1.079**	**Yes**



CONDITION 3 ARRIVAL

Floating Status

Draft FP	0.704 m	Heel	port 0.16 deg.	GM(Solid)	1.313 m
Draft MS	0.697 m	Equil	Yes	F/S Corr.	0.006 m
Draft AP	0.690 m	Wind	0.0 kn	GM(Fluid)	1.306 m
Trim	fwd 0.06 deg.	Wave	No	KMT	2.936 m
LCG	2.329a m	VCG	1.623 m	TPcm	0.36

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	12.48	2.400a	0.000	1.616
Deadweight	0.69	1.049a	0.071p	1.757
Displacement	13.17	2.329a	0.004p	1.623

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	12.48	2.400a	0.000	1.616u
CREW	0.30	1.200a	0.000	2.800u
STOCK	0.10	1.200a	0.000	2.500u
Total Fixed:	12.88	2.363a	0.000	1.650u

Tank Status

DIESEL OIL (SpGr 0.870)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
DIESEL_TK.P	10.02%	0.05	0.853a	0.640p	0.342	0.975
DIESEL_TK.S	10.02%	0.05	0.853a	0.638s	0.342	0.975
Subtotals:	10.02%	0.11	0.853a	0.001p	0.342	

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
FW_TK.P	10.00%	0.01	2.159a	0.600p	0.625	0.975
Subtotals:	10.00%	0.01	2.159a	0.600p	0.625	

SEWAGE (SpGr 0.985)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
SEWAGE.P	100.00%	0.07	0.325f	0.600p	0.650	0.985
Subtotals:	100.00%	0.07	0.325f	0.600p	0.650	

METHANOL (SpGr 0.790)

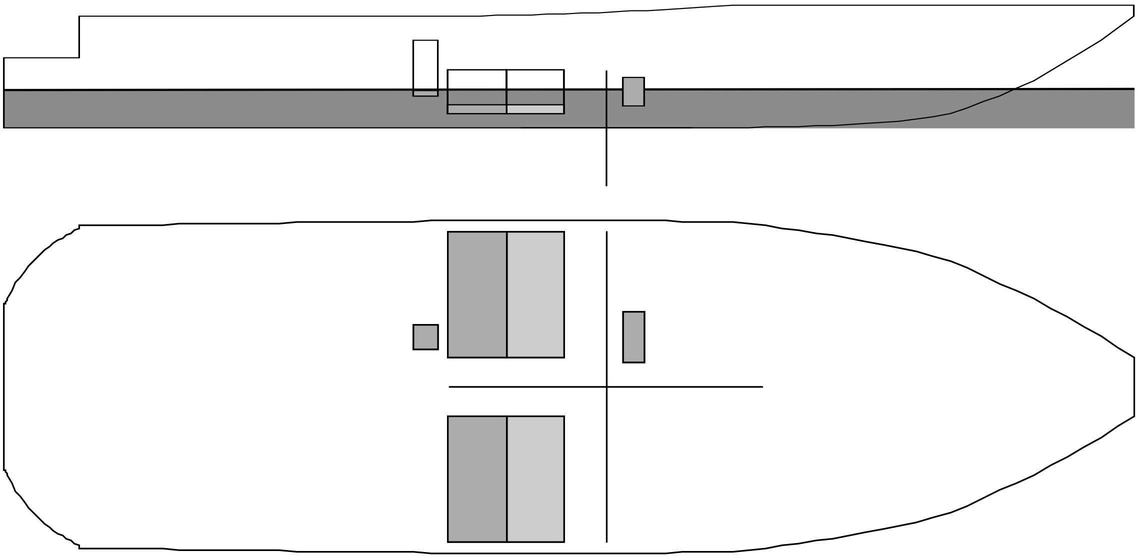
Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
METHANOL_TK.P	10.02%	0.05	1.551a	0.653p	0.341	0.975
METHANOL_TK.S	10.02%	0.05	1.551a	0.651s	0.341	0.975
Subtotals:	10.02%	0.10	1.551a	0.001p	0.341	

All Tanks

	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
Totals:		0.29	0.841a	0.169p	0.427	

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	13.17	2.328a	0.007p	0.460	1.000
SubTotals:			13.17	2.328a	0.007p	0.460	



Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		.11	10.02%
FRESH WATER		.01	10.00%
SEWAGE		.07	100.00%
METHANOL		.10	10.02%

Righting Arms vs Heel Angle

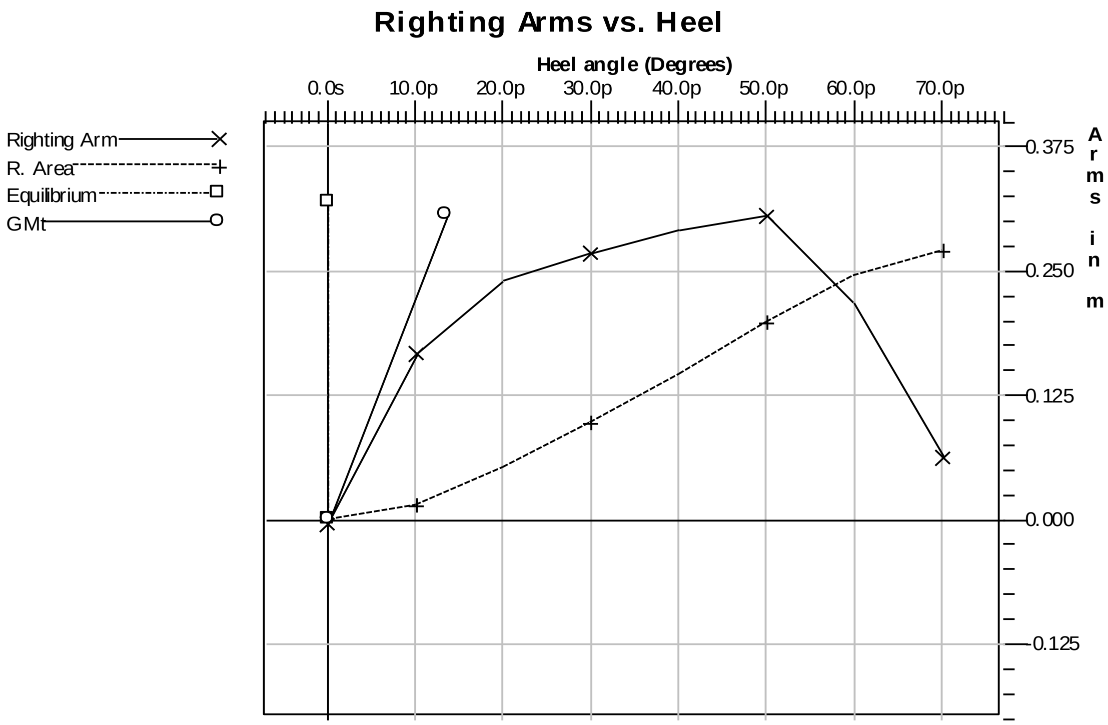
Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.06f	0.697	-0.004	0.000	1.808 (1)	
0.16p	0.06f	0.697	0.000	0.000	1.809 (1)	Equil
10.00p	0.01f	0.659	0.168	0.014	1.900 (1)	
20.00p	0.05f	0.559	0.241	0.051	1.983 (1)	
30.00p	0.11f	0.408	0.269	0.097	2.042 (1)	
40.00p	0.13f	0.210	0.291	0.145	2.070 (1)	
50.00p	0.04a	-0.025	0.306	0.198	2.050 (1)	
60.00p	0.58a	-0.288	0.218	0.245	1.964 (1)	
70.00p	1.28a	-0.561	0.064	0.270	1.822 (1)	

Unprotected Flood Point

Name	L,T,V (m)	Height (m)
(1) Engine Room	5.000a, 0.550s, 2.500	1.808

INTERNATIONAL CODE OF SAFETY FOR HIGH-SPEED CRAFT, 2000

Limit	Min/Max	Actual	Margin	Pass
(1) Area from 0.00 deg to 30.00	>0.0550 m-R	0.097	0.042	Yes
(2) Area from 0.00 deg to 40.00 or Flood	>0.0900 m-R	0.145	0.055	Yes
(3) Area from 30.00 deg to 40.00 or Flood	>0.0300 m-R	0.049	0.019	Yes
(4) Righting Arm at 30.00 deg or MaxRA	>0.200 m	0.306	0.106	Yes
(5) Angle from 0.00 deg to MaxRA	>15.00 deg	50.00	35.00	Yes
(6) GM at Equilibrium	>0.150 m	1.306	1.156	Yes



CONDITION 4 ARRIVAL CLOGGED WITH ICE

Floating Status

Draft FP	0.809 m	Heel	stbd 2.53 deg.	GM(Solid)	1.058 m
Draft MS	0.754 m	Equil	Yes	F/S Corr.	0.006 m
Draft AP	0.700 m	Wind	0.0 kn	GM(Fluid)	1.053 m
Trim	fwd 0.46 deg.	Wave	No	KMT	2.764 m
LCG	2.154a m	VCG	1.707 m	TPcm	0.37

Loading Summary

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	12.48	2.400a	0.000	1.616
Deadweight	2.39	0.872a	0.310s	2.180
Displacement	14.87	2.154a	0.050s	1.707

Fixed Weight Status

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
LIGHT SHIP	12.48	2.400a	0.000	1.616u
CREW	0.30	1.200a	0.000	2.800u
ICE ON HORIZONTAL PLANE	0.44	0.600a	1.790s	1.640u
ICE ON LATERAL AREA	1.26	0.870a	0.000	2.600u
STOCK	0.10	1.200a	0.000	2.500u
Total Fixed:	14.58	2.181a	0.054s	1.732u

Tank Status

DIESEL OIL (SpGr 0.870)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
DIESEL_TK.P	10.02%	0.05	0.851a	0.623p	0.342	0.975
DIESEL_TK.S	10.01%	0.05	0.851a	0.658s	0.342	0.975
Subtotals:	10.02%	0.11	0.851a	0.017s	0.342	

FRESH WATER (SpGr 1.000)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
FW_TK.P	10.00%	0.01	2.158a	0.597p	0.625	0.975
Subtotals:	10.00%	0.01	2.158a	0.597p	0.625	

SEWAGE (SpGr 0.985)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
SEWAGE.P	100.00%	0.07	0.325f	0.600p	0.650	0.985
Subtotals:	100.00%	0.07	0.325f	0.600p	0.650	

METHANOL (SpGr 0.790)

Tank Name	Load (%)	Weight (MT)	LCG (m)	TCG (m)	VCG (m)	Perm
METHANOL_TK.P	10.02%	0.05	1.549a	0.634p	0.341	0.975
METHANOL_TK.S	10.01%	0.05	1.549a	0.672s	0.341	0.975
Subtotals:	10.02%	0.10	1.549a	0.019s	0.341	

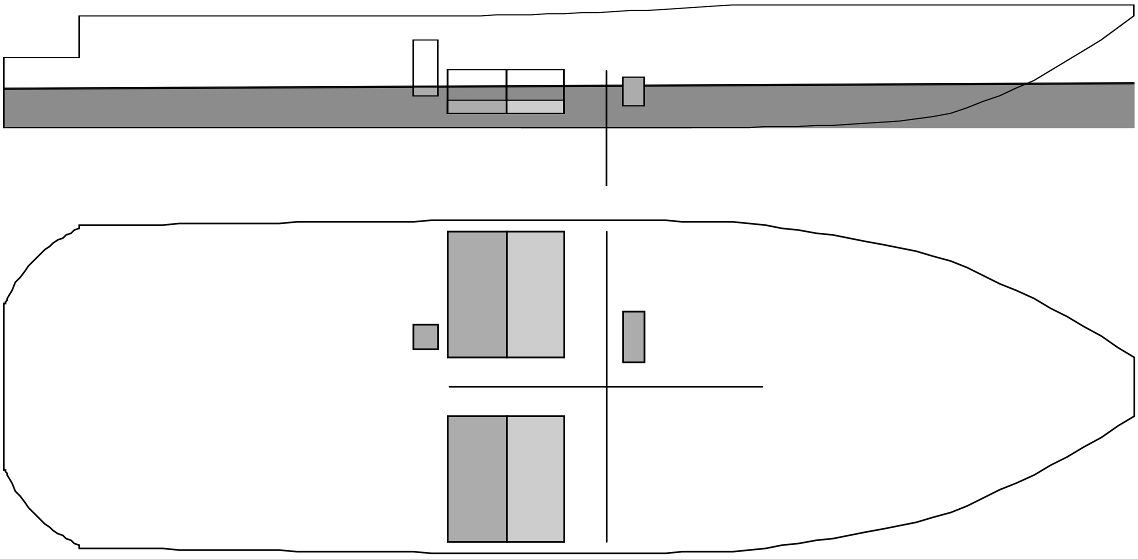
All Tanks

	Load	Weight	LCG	TCG	VCG	Perm

	(%)	(MT)	(m)	(m)	(m)	
Totals:		0.29	0.839a	0.155p	0.427	

Displacer Status

Item	Status	Spgr	Displ (MT)	LCB (m)	TCB (m)	VCB (m)	Eff /Perm
HULL	Intact	1.025	14.87	2.144a	0.103s	0.492	1.000
SubTotals:			14.87	2.144a	0.103s	0.492	



Fluid Legend

Fluid Name	Legend	Weight (MT)	Load%
DIESEL OIL		.11	10.02%
FRESH WATER		.01	10.00%
SEWAGE		.07	100.00%
METHANOL		.10	10.02%

Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (m)	Righting Arm (m)	Area (m-Rad)	Flood Pt Height (m)	Notes
0.00	0.47f	0.760	-0.050	0.000	1.782 (1)	
2.53s	0.46f	0.757	0.000	-0.001	1.756 (1)	Equil
10.00s	0.41f	0.723	0.102	0.006	1.679 (1)	
20.00s	0.42f	0.626	0.161	0.030	1.572 (1)	
30.00s	0.45f	0.517	0.179	0.061	1.456 (1)	
40.00s	0.44f	0.274	0.194	0.093	1.326 (1)	
44.46s	0.39f	0.172	0.201	0.109	1.261 (1)	MaxRa
50.00s	0.25f	0.042	0.191	0.128	1.166 (1)	
60.00s	0.22a	-0.207	0.105	0.155	0.962 (1)	
67.06s	0.65a	-0.391	0.004	0.162	0.802 (1)	
70.00s	0.85a	-0.468	-0.044	0.161	0.732 (1)	RaZero
80.00s	1.53a	-0.726	-0.218	0.138	0.485 (1)	

90.00s	2.20a	-0.969	-0.399	0.085	0.228 (1)	
98.81s	2.74a	-1.164	-0.553	0.011	0.000 (1)	FldPt
100.00s	2.81a	-1.189	-0.573	0.000	-0.031 (1)	

Unprotected Flood Point

Name	L,T,V (m)	Height (m)
(1) Engine Room	5.000a, 0.550s, 2.500	1.782

INTERNATIONAL CODE OF SAFETY FOR HIGH-SPEED CRAFT, 2000

Limit	Min/Max	Actual	Margin	Pass
(1) Area from 0.00 deg to 30.00	>0.0550 m-R	0.061	0.006	Yes
(2) Area from 0.00 deg to 40.00 or Flood	>0.0900 m-R	0.093	0.003	Yes
(3) Area from 30.00 deg to 40.00 or Flood	>0.0300 m-R	0.033	0.003	Yes
(4) Righting Arm at 30.00 deg or MaxRA	>0.200 m	0.201	0.001	Yes
(5) Angle from 0.00 deg to MaxRA	>15.00 deg	44.46	29.46	Yes
(6) GM at Equilibrium	>0.150 m	1.052	0.902	Yes